TMPRSS6 iRNA COMPOSITIONS AND METHODS OF USE THEREOF

Related Applications

This application claims the benefit of priority to U.S. Provisional Patent Application No. 61/826,178, filed on May 22, 2013 and U.S. Provisional Patent Application No. 61/912,988, filed on December 6, 2013. This application is related to U.S. Provisional Application No. 61/561,710, filed on November 18, 2011, and PCT/US2012/065601, filed on November 16, 2012. The entire contents of each of the foregoing applications are hereby incorporated herein by reference.

Sequence Listing

The instant application contains a Sequence Listing which has been submitted electronically in ASCII format and is hereby incorporated by reference in its entirety. Said ASCII copy, created on May 21, 2014, is named 121301-00720_SL.txt and is 449,620 bytes in size.

Background of the Invention

TMPRSS6 (Transmembrane Protease, Serine 6) gene encodes TMPRSS6, also known as matriptase-2, a type II serine protease. It is primarily expressed in the liver, although high levels of TMPRSS6 mRNA are also found in the kidney, with lower levels in the uterus and much smaller amounts detected in many other tissues (Ramsay et al., *Haematologica* (2009), 94(6), 840-849). TMPRSS6 plays a role in iron homeostatis by binding and proteolytically degrading the hepcidin activator and BMP co-receptor HJV (hemojuvelin), which causes down-regulation of hepcidin levels.

TMPRSS6 consists of a short N-terminal intracytoplasmic tail, a type II transmembrane domain, a stem region composed of two extracellular CUB (complement factor Cls/Clr, urchin embryonic growth factor and BMP (bone morphogenetic protein)) domains, three LDLR (low-density-lipoprotein receptor class A) domains, and a C-terminal trypsin- like serine protease domain. There are also consensus sites for N-glycosylation in the extracellular domain, and a potential phosphorylation site in the intracytoplasmic tail region.

Numberous disorders can be associated with iron overload, a condition characterized by increased levels of iron. Iron overload can result in excess iron deposition in various tissues and can lead to tissue and organ damage. Accordingly, methods for effective treatment of disorders associated with iron overload are currently needed.

Summary of the Invention

The present invention provides compositions comprising RNAi agents, *e.g.*, double-stranded iRNA agents, targeting TMPRSS6. The present invention also provides methods

using the compositions of the invention for inhibiting TMPRSS6 expression and for treating TMPRSS6 associated disorders, *e.g.*, iron overload associated disorders, such as thalassemia, *e.g.*, β-thalassemia, or hemochromatosis.

Accordingly, in one aspect, the present invention provides RNAi agents, *e.g.*, double-stranded RNAi agents, capable of inhibiting the expression of TMPRSS6 (matriptase-2) in a cell, wherein the double stranded RNAi agent comprises a sense strand and an antisense strand forming a double-stranded region, wherein the sense strand comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the nucleotide sequences of SEQ ID NO:1, SEQ ID NO:2, or SEQ ID NO:3, SEQ ID NO:4, or SEQ ID NO:5, and the antisense strand comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the nucleotide sequences of SEQ ID NO:6, SEQ ID NO:7, or SEQ ID NO:8, SEQ ID NO:9, or SEQ ID NO:10,

wherein substantially all of the nucleotides of the sense strand and substantially all of the nucleotides of the antisense strand are modified nucleotides, and

wherein the sense strand is conjugated to a ligand attached at the 3'-terminus.

In one embodiment, all of the nucleotides of said sense strand and all of the nucleotides of said antisense strand are modified nucleotides.

In one embodiment, the sense strand and the antisense strand comprise a region of complementarity which comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the antisense sequences listed in any one of Tables 1, 2, 4, 5, 8, 10, and 12.

In one embodiment, at least one of the modified nucleotides is selected from the group consisting of a 3'-terminal deoxy-thymine (dT) nucleotide, a 2'-O-methyl modified nucleotide, a 2'-fluoro modified nucleotide, a 2'-deoxy-modified nucleotide, a locked nucleotide, an abasic nucleotide, a 2'-amino-modified nucleotide, a 2'-alkyl-modified nucleotide, a morpholino nucleotide, a phosphoramidate, a non-natural base comprising nucleotide, a nucleotide comprising a 5'-phosphorothioate group, a nucleotide comprising a 5' phosphate or 5' phosphate mimic (see, *e.g.,* PCT Publication No. WO 2011/005860), and a terminal nucleotide linked to a cholesteryl derivative or a dodecanoic acid bisdecylamide group.

In one embodiment, at least one strand comprises a 3' overhang of at least 1 nucleotide. In another embodiment, at least one strand comprises a 3' overhang of at least 2 nucleotides. In another aspect, the present invention provides RNAi agents, *e.g.*, double-stranded RNAi agents, capable of inhibiting the expression of TMPRSS6 (matriptase-2) in a cell, wherein the double stranded RNAi agent comprises a sense strand complementary to an antisense strand, wherein the antisense strand comprises a region complementary to part of an mRNA encoding TMPRSS6, wherein each strand is about 14 to about 30 nucleotides in length, wherein the double stranded RNAi agent is represented by formula (III):

sense: 5' n_p -N_a -(X X X) $_i$-N_b -Y Y Y -N_b -(Z Z Z)$_j$ -N_a - n_q 3'

antisense: 3' n_p'-N_a'-(X'X'X')$_k$-N_b'-Y'Y'Y'-N_b'-(Z'Z'Z')$_l$-N_a'- n_q' 5' (III)

wherein:

i, j, k, and l are each independently 0 or 1;

p, p', q, and q' are each independently 0-6;

each N_a and N_a' independently represents an oligonucleotide sequence comprising 0-25 nucleotides which are either modified or unmodified or combinations thereof, each sequence comprising at least two differently modified nucleotides;

each N_b and N_b' independently represents an oligonucleotide sequence comprising 0-10 nucleotides which are either modified or unmodified or combinations thereof;

each n_p, n_p', n_q, and n_q', each of which may or may not be present, independently represents an overhang nucleotide;

XXX, YYY, ZZZ, X'X'X', Y'Y'Y', and Z'Z'Z' each independently represent one motif of three identical modifications on three consecutive nucleotides;

modifications on N_b differ from the modification on Y and modifications on N_b' differ from the modification on Y'; and

wherein the sense strand is conjugated to at least one ligand.

In one embodiment, i is 0; j is 0; i is 1; j is 1; both i and j are 0; or both i and j are 1. In another embodiment, k is 0; l is 0; k is 1; l is 1; both k and l are 0; or both k and l are 1.

In one embodiment, XXX is complementary to X'X'X', YYY is complementary to Y'Y'Y', and ZZZ is complementary to Z'Z'Z'.

In one embodiment, YYY motif occurs at or near the cleavage site of the sense strand.

In one embodiment, Y'Y'Y' motif occurs at the 11, 12 and 13 positions of the antisense strand from the 5'-end.

In one embodiment, Y' is 2'-O-methyl.

In one embodiment, formula (III) is represented by formula (IIIa):

sense: 5' n_p -N_a -Y Y Y -N_a - n_q 3'

antisense: 3' $n_{p'}$-$N_{a'}$- Y'Y'Y'- $N_{a'}$- $n_{q'}$ 5' (IIIa).

In another embodiment, formula (III) is represented by formula (IIIb):

sense: 5' n_p -N_a -Y Y Y -N_b -Z Z Z -N_a - n_q 3'

antisense: 3' $n_{p'}$-$N_{a'}$- Y'Y'Y'-$N_{b'}$-Z'Z'Z'- $N_{a'}$- $n_{q'}$ 5' (IIIb)

wherein each N_b and N_b' independently represents an oligonucleotide sequence comprising 1-5 modified nucleotides.

In yet another embodiment, formula (III) is represented by formula (IIIc):

sense: 5' n_p -N_a –X X X -N_b -Y Y Y -N_a - n_q 3'

antisense: 3' $n_{p'}$-$N_{a'}$- X'X'X'-$N_{b'}$- Y'Y'Y'- $N_{a'}$- $n_{q'}$ 5' (IIIc)

wherein each N_b and N_b' independently represents an oligonucleotide sequence comprising 1-5 modified nucleotides.

In one embodiment, formula (III) is represented by formula (IIId):

sense: 5' n_p -N_a –X X X- N_b -Y Y Y -N_b -Z Z Z -N_a - n_q 3'

antisense: 3' $n_{p'}$-$N_{a'}$- X′X′X′- $N_{b'}$-Y′Y′Y′-$N_{b'}$-Z′Z′Z′- $N_{a'}$- $n_{q'}$ 5'

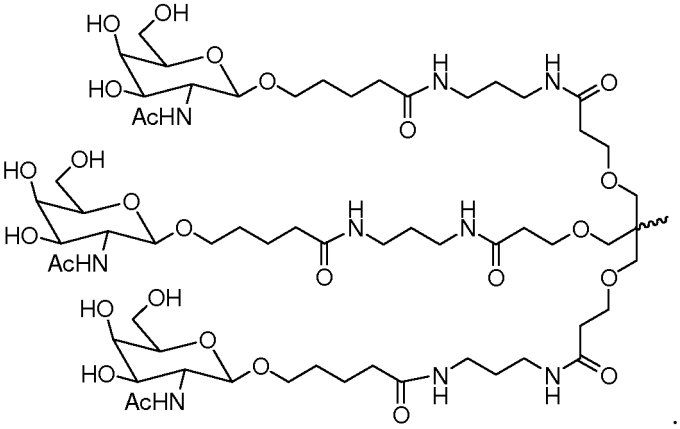
(IIId)

wherein each N_b and N_b' independently represents an oligonucleotide sequence comprising 1-5 modified nucleotides and each N_a and N_a' independently represents an oligonucleotide sequence comprising 2-10 modified nucleotides.

In one embodiment, the double-stranded region is 15-30 nucleotide pairs in length. In another embodiment, the double-stranded region is 17-23 nucleotide pairs in length. In yet another embodiment, the double-stranded region is 17-25 nucleotide pairs in length. In one embodiment, the double-stranded region is 23-27 nucleotide pairs in length. In another embodiment, the double-stranded region is 19-21 nucleotide pairs in length. In another embodiment, the double-stranded region is 21-23 nucleotide pairs in length. In one embodiment, each strand has 15-30 nucleotides. In another embodiment, each strand has 19-30 nucleotides.

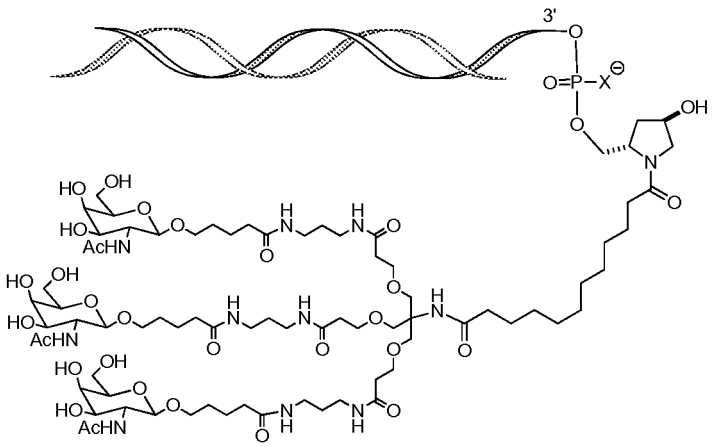
In one embodiment, the modifications on the nucleotides are selected from the group consisting of LNA, HNA, CeNA, 2′-methoxyethyl, 2′-O-alkyl, 2′-O-allyl, 2′-C- allyl, 2′-fluoro, 2′-deoxy, 2'-hydroxyl, and combinations thereof. In another embodiment, the modifications on the nucleotides are 2′-O-methyl or 2′-fluoro modifications.

In one embodiment, the ligand is one or more GalNAc derivatives attached through a bivalent or trivalent branched linker. In another embodiment, the ligand is



In one embodiment, the ligand is attached to the 3′ end of the sense strand.

In one embodiment, the RNAi agent is conjugated to the ligand as shown in the following schematic



wherein X is O or S. In a specific embodiment, X is O.

In one embodiment, the agent further comprises at least one phosphorothioate or methylphosphonate internucleotide linkage.

In one embodiment, the phosphorothioate or methylphosphonate internucleotide linkage is at the 3'-terminus of one strand. In one embodiment, the strand is the antisense strand. In another embodiment, the strand is the sense strand.

In one embodiment, the phosphorothioate or methylphosphonate internucleotide linkage is at the 5'-terminus of one strand. In one embodiment, the strand is the antisense strand. In another embodiment, the strand is the sense strand.

In one embodiment, the phosphorothioate or methylphosphonate internucleotide linkage is at the both the 5'- and 3'-terminus of one strand. In one embodiment, the strand is the antisense strand.

In one embodiment, the RNAi agent comprises 6-8 phosphorothioate internucleotide linkages.

In one embodiment, the antisense strand comprises two phosphorothioate internucleotide linkages at the 5'-terminus and two phosphorothioate internucleotide linkages at the 3'-terminus, and the sense strand comprises at least two phosphorothioate internucleotide linkages at either the 5'-terminus or the 3'-terminus.

In one embodiment, the base pair at the 1 position of the 5′-end of the antisense strand of the duplex is an AU base pair.

In one embodiment, the Y nucleotides contain a 2′-fluoro modification.

In one embodiment, the Y′ nucleotides contain a 2′-O-methyl modification.

In one embodiment, p′>0. In another embodiment, p′=2.

In one embodiment, q'=0, p=0, q=0, and p' overhang nucleotides are complementary to the target mRNA. In another embodiment, q'=0, p=0, q=0, and p' overhang nucleotides are non-complementary to the target mRNA.

In one embodiment, the sense strand has a total of 21 nucleotides and the antisense strand has a total of 23 nucleotides.

In one embodiment, at least one n_p' is linked to a neighboring nucleotide via a phosphorothioate linkage.

In one embodiment, all n_p' are linked to neighboring nucleotides via phosphorothioate linkages.

In one embodiment, the RNAi agent is selected from the group of RNAi agents listed in any one of Tables 1, 2, 4, 5, 8, 10, and 12.

In one embodiment, the RNAi agent is AD-59743. In another embodiment, the RNAi agent is AD-60940.

In one aspect, the present invention provides double stranded RNAi agents for inhibiting expression of TMPRSS6 in a cell,

wherein the double stranded RNAi agent comprises a sense strand and an antisense strand forming a double stranded region,

wherein the sense strand comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the nucleotide sequences of SEQ ID NO:1, SEQ ID NO:2, or SEQ ID NO:3, SEQ ID NO:4, or SEQ ID NO:5, and the antisense strand comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the nucleotide sequences of SEQ ID NO:6, SEQ ID NO:7, or SEQ ID NO:8, SEQ ID NO:9, or SEQ ID NO:10,

wherein substantially all of the nucleotides of the sense strand comprise a modification selected from the group consisting of a 2'-O-methyl modification and a 2'-fluoro modification,

wherein the sense strand comprises two phosphorothioate internucleotide linkages at the 5'-terminus,

wherein substantially all of the nucleotides of the antisense strand comprise a modification selected from the group consisting of a 2'-O-methyl modification and a 2'-fluoro modification,

wherein the antisense strand comprises two phosphorothioate internucleotide linkages at the 5'-terminus and two phosphorothioate internucleotide linkages at the 3'-terminus, and

wherein the sense strand is conjugated to one or more GalNAc derivatives attached through a branched bivalent or trivalent linker at the 3'-terminus.

In one embodiment, all of the nucleotides of the sense strand and all of the nucleotides of the antisense strand comprise a modification.

In another aspect, the present invention provides RNAi agents, *e.g.*, double stranded RNAi agents, capable of inhibiting the expression of TMPRSS6 (matriptase-2) in a cell, wherein the double stranded RNAi agent comprises a sense strand complementary to an antisense strand, wherein the antisense strand comprises a region complementary to part of an mRNA encoding TMPRSS6, wherein each strand is about 14 to about 30 nucleotides in length, wherein the double stranded RNAi agent is represented by formula (III):

sense: 5' n_p -N_a -(X X X) $_i$-N_b -Y Y Y -N_b -(Z Z Z)$_j$ -N_a - n_q 3'

antisense: 3' n_p'-N_a'-(X'X'X')$_k$-N_b'-Y'Y'Y'-N_b'-(Z'Z'Z')$_l$-N_a'- n_q' 5' (III)

wherein:

i, j, k, and l are each independently 0 or 1;

p, p', q, and q' are each independently 0-6;

each N_a and N_a' independently represents an oligonucleotide sequence comprising 0-25 nucleotides which are either modified or unmodified or combinations thereof, each sequence comprising at least two differently modified nucleotides;

each N_b and N_b' independently represents an oligonucleotide sequence comprising 0-10 nucleotides which are either modified or unmodified or combinations thereof;

each n_p, n_p', n_q, and n_q', each of which may or may not be present independently represents an overhang nucleotide;

XXX, YYY, ZZZ, X'X'X', Y'Y'Y', and Z'Z'Z' each independently represent one motif of three identical modifications on three consecutive nucleotides, and wherein the modifications are 2'-O-methyl or 2'-fluoro modifications;

modifications on N_b differ from the modification on Y and modifications on N_b' differ from the modification on Y'; and

wherein the sense strand is conjugated to at least one ligand.

In yet another aspect, the present invention provides RNAi agents, *e.g.*, double stranded RNAi agents, capable of inhibiting the expression of TMPRSS6 (matriptase-2) in a cell, wherein the double stranded RNAi agent comprises a sense strand complementary to an antisense strand, wherein the antisense strand comprises a region complementary to part of an mRNA encoding TMPRSS6, wherein each strand is about 14 to about 30 nucleotides in length, wherein the double stranded RNAi agent is represented by formula (III):

sense: 5' n_p -N_a -(X X X) $_i$-N_b -Y Y Y -N_b -(Z Z Z)$_j$ -N_a - n_q 3'

antisense: 3' n_p'-N_a'-(X'X'X')$_k$-N_b'-Y'Y'Y'-N_b'-(Z'Z'Z')$_l$-N_a'- n_q' 5' (III)

wherein:

i, j, k, and l are each independently 0 or 1;

each n_p, n_q, and n_q', each of which may or may not be present, independently represents an overhang nucleotide;

p, q, and q' are each independently 0-6;

n_p' >0 and at least one n_p' is linked to a neighboring nucleotide via a phosphorothioate linkage;

each N_a and N_a' independently represents an oligonucleotide sequence comprising 0-25 nucleotides which are either modified or unmodified or combinations thereof, each sequence comprising at least two differently modified nucleotides;

each N_b and N_b' independently represents an oligonucleotide sequence comprising 0-10 nucleotides which are either modified or unmodified or combinations thereof;

XXX, YYY, ZZZ, X′X′X′, Y′Y′Y′, and Z′Z′Z′ each independently represent one motif of three identical modifications on three consecutive nucleotides, and wherein the modifications are 2′-O-methyl or 2′-fluoro modifications;

modifications on N_b differ from the modification on Y and modifications on N_b' differ from the modification on Y′; and

wherein the sense strand is conjugated to at least one ligand.

In a further aspect, the present invention provides RNAi agents, *e.g.*, double stranded RNAi agents, capable of inhibiting the expression of TMPRSS6 (matriptase-2) in a cell, wherein the double stranded RNAi agent comprises a sense strand complementary to an antisense strand, wherein the antisense strand comprises a region complementary to part of an mRNA encoding TMPRSS6, wherein each strand is about 14 to about 30 nucleotides in length, wherein the double stranded RNAi agent is represented by formula (III):

sense: $5'\ n_p\text{-}N_a\text{-}(X\ X\ X)_i\text{-}N_b\text{-}Y\ Y\ Y\text{-}N_b\text{-}(Z\ Z\ Z)_j\text{-}N_a\text{-}n_q\ 3'$

antisense: $3'\ n_p'\text{-}N_a'\text{-}(X'X'X')_k\text{-}N_b'\text{-}Y'Y'Y'\text{-}N_b'\text{-}(Z'Z'Z')_l\text{-}N_a'\text{-}n_q'\ 5'$ (III)

wherein:

i, j, k, and l are each independently 0 or 1;

each n_p, n_q, and n_q', each of which may or may not be present, independently represents an overhang nucleotide;

p, q, and q′ are each independently 0-6;

$n_p' > 0$ and at least one n_p' is linked to a neighboring nucleotide via a phosphorothioate linkage;

each N_a and N_a' independently represents an oligonucleotide sequence comprising 0-25 nucleotides which are either modified or unmodified or combinations thereof, each sequence comprising at least two differently modified nucleotides;

each N_b and N_b' independently represents an oligonucleotide sequence comprising 0-10 nucleotides which are either modified or unmodified or combinations thereof;

XXX, YYY, ZZZ, X′X′X′, Y′Y′Y′, and Z′Z′Z′ each independently represent one motif of three identical modifications on three consecutive nucleotides, and wherein the modifications are 2′-O-methyl or 2′-fluoro modifications;

modifications on N_b differ from the modification on Y and modifications on N_b' differ from the modification on Y′; and

wherein the sense strand is conjugated to at least one ligand, wherein the ligand is one or more GalNAc derivatives attached through a bivalent or trivalent branched linker.

In another aspect, the present invention provides RNAi agents, *e.g.*, double stranded RNAi agents capable of inhibiting the expression of TMPRSS6 (matriptase-2) in a cell, wherein the double stranded RNAi agent comprises a sense strand complementary to an antisense strand, wherein the antisense strand comprises a region complementary to part of an mRNA encoding TMPRSS6, wherein each strand is about 14 to about 30 nucleotides in

length, wherein the double stranded RNAi agent is represented by formula (III):

sense: 5' n_p -N_a -(X X X) $_i$-N_b -Y Y Y -N_b -(Z Z Z)$_j$ -N_a - n_q 3'

antisense: 3' n_p'-N_a'-(X'X'X')$_k$-N_b'-Y'Y'Y'-N_b'-(Z'Z'Z')$_l$-N_a'- n_q' 5' (III)

wherein:

i, j, k, and l are each independently 0 or 1;

each n_p, n_q, and n_q', each of which may or may not be present, independently represents an overhang nucleotide;

p, q, and q' are each independently 0-6;

n_p' >0 and at least one n_p' is linked to a neighboring nucleotide via a phosphorothioate linkage;

each N_a and N_a' independently represents an oligonucleotide sequence comprising 0-25 nucleotides which are either modified or unmodified or combinations thereof, each sequence comprising at least two differently modified nucleotides;

each N_b and N_b' independently represents an oligonucleotide sequence comprising 0-10 nucleotides which are either modified or unmodified or combinations thereof;

XXX, YYY, ZZZ, X'X'X', Y'Y'Y', and Z'Z'Z' each independently represent one motif of three identical modifications on three consecutive nucleotides, and wherein the modifications are 2'-O-methyl or 2'-fluoro modifications;

modifications on N_b differ from the modification on Y and modifications on N_b' differ from the modification on Y';

wherein the sense strand comprises at least one phosphorothioate linkage; and

wherein the sense strand is conjugated to at least one ligand, wherein the ligand is one or more GalNAc derivatives attached through a bivalent or trivalent branched linker.

In yet another aspect, the present invention provides RNAi agents, *e.g.*, double stranded RNAi agents, capable of inhibiting the expression of TMPRSS6 (matriptase-2) in a cell, wherein the double stranded RNAi agent comprises a sense strand complementary to an antisense strand, wherein the antisense strand comprises a region complementary to part of an mRNA encoding TMPRSS6, wherein each strand is about 14 to about 30 nucleotides in length, wherein the double stranded RNAi agent is represented by formula (III):

sense: 5' n_p -N_a -Y Y Y - N_a - n_q 3'

antisense: 3' n_p'-N_a'- Y'Y'Y'- N_a'- n_q' 5' (IIIa)

wherein:

each n_p, n_q, and n_q', each of which may or may not be present, independently represents an overhang nucleotide;

p, q, and q' are each independently 0-6;

n_p' >0 and at least one n_p' is linked to a neighboring nucleotide via a phosphorothioate linkage;

each N_a and N_a' independently represents an oligonucleotide sequence comprising 0-

25 nucleotides which are either modified or unmodified or combinations thereof, each sequence comprising at least two differently modified nucleotides;

YYY and Y′Y′Y′ each independently represent one motif of three identical modifications on three consecutive nucleotides, and wherein the modifications are 2′-O-methyl or 2′-fluoro modifications;

wherein the sense strand comprises at least one phosphorothioate linkage; and

wherein the sense strand is conjugated to at least one ligand, wherein the ligand is one or more GalNAc derivatives attached through a bivalent or trivalent branched linker.

In one embodiment, the present invention provides RNAi agent selected from the group of RNAi agents listed in any one of Tables 1, 2, 4, 5, 8, 19, and 12.

In one aspect, the present invention provides compositions comprising a modified antisense polynucleotide agent, wherein the agent is capable of inhibiting the expression of TMPRSS6 in a cell, and comprises a sequence complementary to a sense sequence selected from the group of the sequences listed in any one of Tables 1, 2, 4, 5, 8, 10, and 12, wherein the polynucleotide is about 14 to about 30 nucleotides in length.

The present invention also provides cells, vectors, host cells, and pharmaceutical compositions comprising, *e.g.,* the double stranded RNAi agents of the invention.

In some embodiments, the RNAi agent is administered using a pharmaceutical composition.

In preferred embodiments, the RNAi agent is administered in a solution. In some such embodiments, the siRNA is administered in an unbuffered solution. In one embodiment, the siRNA is administered in water. In other embodiments, the siRNA is administered with a buffer solution, such as an acetate buffer, a citrate buffer, a prolamine buffer, a carbonate buffer, or a phosphate buffer or any combination thereof. In some embodiments, the buffer solution is phosphate buffered saline (PBS).

In one embodiment, the pharmaceutical compositions further comprise a lipid formulation. In one embodiment, the lipid formulation comprises a LNP, or XTC. In another embodiment, the lipid formulation comprises a MC3.

In one aspect, the present invention provides methods of inhibiting TMPRSS6 expression in a cell. The methods include contacting the cell with an RNAi agent, *e.g.*, a double stranded RNAi agent, or a modified antisense polynucleotide agent of the invention, or vector of the invention, or a pharmaceutical composition of the invention; and maintaining the cell produced in step (a) for a time sufficient to obtain degradation of the mRNA transcript of a TMPRSS6 gene, thereby inhibiting expression of the TMPRSS6 gene in the cell.

In one embodiment, the cell is within a subject.

In one embodiment, the subject is a human.

In one embodiment, the TMPRSS6 expression is inhibited by at least about 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 98%, or 100%.

In another embodiment, hepcidin gene expression is increased by at least about 1.5-fold, about 2-fold, about 3-fold, about 4-fold, or about 5-fold.

In yet another embodiment, serum hepcidin concentration is increased by at least about 10%, about 25%, about 50%, about 100%, about 150%, about 200%, about 250%, or about 300%.

In one embodiment, serum iron concentration is decreased by at least about 20%, about 30%, about 40%, about 50%, about 60%, about 70%, about 80%, about 90%, about 95%, about 98% or about 100%.

In another embodiment,a percent transferrin saturation is decreased by at least about 20%, about 30%, about 40%, about 50%, about 60%, about 70%, about 80%, about 90%, about 95%, about 98% or about 100%.

In another aspect, the present invention provides methods of treating a subject having a disorder mediated by, or associated with, TMPRSS6 expression. The methods include administering to the subject a therapeutically effective amount of an RNAi agent, *e.g.*, a double stranded RNAi agent, of the invention, or a modified antisense polynucleotide agent of the invention, or a vector of the invention, or a pharmaceutical composition of the invention, thereby treating the subject.

In one aspect, the present invention provides methods of treating a subject having a TMPRSS6-associated disorder. The methods include subcutaneously administering to the subject a therapeutically effective amount of a double stranded RNAi agent,

wherein the double stranded RNAi agent comprises a sense strand and an antisense strand forming a double stranded region,

wherein the sense strand comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the nucleotide sequences of SEQ ID NO:1, SEQ ID NO:2, or SEQ ID NO:3, SEQ ID NO:4, or SEQ ID NO:5, and the antisense strand comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the nucleotide sequences of SEQ ID NO:6, SEQ ID NO:7, or SEQ ID NO:8, SEQ ID NO:9, or SEQ ID NO:10,

wherein substantially all of the nucleotides of the antisense strand comprise a modification selected from the group consisting of a 2'-O-methyl modification and a 2'-fluoro modification,

wherein the antisense strand comprises two phosphorothioate internucleotide linkages at the 5'-terminus and two phosphorothioate internucleotide linkages at the 3'-terminus,

wherein substantially all of the nucleotides of the sense strand comprise a modification selected from the group consisting of a 2'-O-methyl modification and a 2'-fluoro modification,

wherein the sense strand comprises two phosphorothioate internucleotide linkages at the 5'-terminus and,

wherein the sense strand is conjugated to one or more GalNAc derivatives attached through a branched bivalent or trivalent linker at the 3'-terminus, thereby treating the subject.

In one embodiment, all of the nucleotides of the sense strand and all of the nucleotides of the antisense strand comprise a modification.

In one embodiment, the subject is a human.

In one embodiment, the subject has a disorder associated with iron overload, *e.g.*, hereditary hemochromatosis, β-thalassemia (*e.g.,* β-thalassemia major and β-thalassemia intermiedia) erythropoietic porphyria, Parkinson's Disease, Alzheimer's Disease or Friedreich's Ataxia.

In one embodiment, the RNAi agent, *e.g.*, double stranded RNAi agent, is administered at a dose of about 0.01 mg/kg to about 10 mg/kg, about 1 mg/kg to about 10 mg/kg, about 2 mg/kg to about 10 mg/kg, about 3 mg/kg to about 10 mg/kg, about 4 mg/kg to about 10 mg/kg, about 5 mg/kg to about 15 mg/kg, about 6 mg/kg to about 15 mg/kg, about 7 mg/kg to about 15 mg/kg, about 8 mg/kg to about 15 mg/kg, about 9 mg/kg to about 15 mg/kg, about 10 mg/kg to about 20 mg/kg, about 12 mg/kg to about 20 mg/kg, about 13 mg/kg to about 20 mg/kg, about 14 mg/kg to about 20 mg/kg, about 15 mg/kg to about 20 mg/kg, about 16 mg/kg to about 20 mg/kg or about 18 mg/kg to about 20 mg/kg. In particular embodiments, the double stranded RNAi agent is administered at a dose of about 0.1 mg/kg, about 1.0 mg/kg, or about 3.0 mg/kg.

In one embodiment, the RNAi agent, *e.g.*, double stranded RNAi agent, is administered subcutaneously or intravenously.

In one embodiment, the RNAi agent is administered in two or more doses. In a specific embodiment, the RNAi agent is administered at intervals selected from the group consisting of once every about 12 hours, once every about 24 hours, once every about 48 hours, once every about 72 hours, once every about 96 hours, once about every 7 days, or once about every 14 days. In particular embodiments, the RNAi agent is administered once a week for up to 2 weeks, up to 3 weeks, up to 4 weeks, up to 5 weeks, or longer.

In yet another aspect, the present invention provides methods of treating an iron overload associated disorder in a subject. The methods include administering to the subject a therapeutically effective amount of an RNAi agent, *e.g.*, a double stranded RNAi agent, or the vector of the invention, thereby treating the subject.

In one embodiment, the iron overload associated disorder is hemochromatosis. In another embodiment, the iron overload associated disorder is a thalassemia, *e.g.*, β-thalassemia (*e.g.,* β-thalassemia major and β-thalassemia intermiedia), or erythropoietic porphyria. In yet another embodiment, the iron overload associated disorder is a neurological disease, *e.g.*, Parkinson's Diasease, Alzheimer's Disease or Friedreich's Ataxia.

In one embodiment, the subject is a primate or rodent. In another embodiment, the subject is a human.

In one embodiment, the RNAi agent, *e.g.*, double stranded RNAi agent, is administered at a dose of about 0.01 mg/kg to about 10 mg/kg, about 0.5 mg/kg to about 50 mg/kg, about 10 mg/kg to about 30 mg/kg, about 10 mg/kg to about 20 mg/kg, about 15 mg/kg to about 20 mg/kg, about 15 mg/kg to about 25 mg/kg, about 15 mg/kg to about 30 mg/kg, or about 20 mg/kg to about 30 mg/kg.

In one embodiment, the RNAi agent, *e.g.*, double stranded RNAi agent, is administered subcutaneously or intravenously.

In one embodiment, the RNAi agent is administered in two or more doses. In a specific embodiment, the RNAi agent is administered at intervals selected from the group consisting of once every about 12 hours, once every about 24 hours, once every about 48 hours, once every about 72 hours, once every about 96 hours, once about every 7 days, or once about every 14 days.

In one embodiment, administering results in a decrease in iron levels, ferritin level and/or transferrin saturation level in the subject.

In one embodiment, the methods further comprise determining the iron level in the subject.

In one embodiment, the methods of the invention which include administering an iRNA agent of the invention (or pharmaceutical composition of the invention) to a subject are practiced in combination with administration of additional pharmaceuticals and/or other therapeutic methods. In one embodiment, the methods of the invention further comprise administering an iron chelator, *e.g.,* deferiprone, deferoxamine, and deferasirox, to a subject.

The present invention is further illustrated by the following detailed description and drawings.

Brief Description of the Drawings

Figure 1 is a graph showing relative levels of TMPRSS6 mRNA in the liver of wild-type mice following administration of a single dose of 1 mg/kg, 3 mg/kg or 10 mg/kg of the iRNA agent AD-59743.

Figure 2 is a graph showing relative levels of hepcidin mRNA in the liver of wild-type mice following administration of a single dose of 1 mg/kg, 3 mg/kg or 10 mg/kg of the iRNA agent AD-59743.

Figures 3A-3E show the levels of hepatic TMPRSS6 mRNA (Figure 3A), hepatic hepcidin mRNA (Figure 3B), serum hepcidin (Figure 3C), total serum iron (Figure 3D), and percent transferrin saturation (Figure 3E) in C57BL/6 mice at various time points following a

single subcutaneous injection of AD-60940 at a dose of 0.3 mg/kg, 1.0 mg/kg or 3.0 mg/kg, or PBS alone (control). Each data point represents the mean value from three mice. The standard deviation of the mean is represented by error bars. Figure 3F demonstrates the relative hepatic TMPRSS6 mRNA concentration as a function of AD-60940 dose at 11 days following administration. Each data point represents the maximum suppression of TMPRSS6 mRNA concentration observed at each dose level. The data were fit to the Hill equation.

Figure 4A is a schematic depicting the adminstration regimen of one dose per week for three weeks followed by sacrifice of the mice at day 21. Figure 4B is a graph showing the levels of hepatic TMPRSS6 mRNA, hepatic hepcidin mRNA, and percent transferrin saturation in C57BL/6 mice administered a subcutaneous injection of AD-60940 at a dose of 0.3 mg/kg, 1.0 mg/kg, or PBS (control) according to the regimen shown in Figure 4A. Each bar represents the mean value from three mice. The standard deviation of the mean is represented by error bars. Figure 4C demonstrates the relative hepatic TMPRSS6 mRNA concentration as a function of AD-60940 dose. The data were fit to the Hill equation.

Figures 5A-5D are graphs showing the relationships between serum hepcidin concentration and relative TMPRSS6 mRNA levels (Figure 5A), between percent transferrin saturation and relative TMPRSS6 mRNA levels (Figure 5B), between serum hepcidin concentration and relative hepcidin mRNA levels (Figure 5C) and between percent transferrin saturation and serum hepcidin concentration (Figure 5D).

Figure 6 is a graph showing relative levels of TMPRSS6 mRNA in the liver of C57BL/6 mice following administration of a single subcutaneous dose of 3 mg/kg of the indicated iRNA agent or PBS (control). The bars represent the mean from three mice and the error bars represent the standard deviation of the mean.

Figure 7 is a graph showing relative levels of TMPRSS6 mRNA in the liver of C57BL/6 mice following a subcutaneous dose of 0.3 mg/kg or 1.0 mg/kg of the indicated iRNA agent, or PBS (control), once a week for three weeks. The bars represent the mean from three mice and the error bars represent the standard deviation of the mean.

Figure 8 shows the nucleotide sequence of *Homo sapiens* TMPRSS6 (SEQ ID NO:1).

Figure 9 shows the nucleotide sequence of *Mus musculus* TMPRSS6 (SEQ ID NO:2).

Figure 10 shows the nucleotide sequence of *Rattus norvegicus* TMPRSS6 (SEQ ID NO:3).

Figure 11 shows the nucleotide sequence of *Macaca mulatta* TMPRSS6 (SEQ ID NO:4).

Figure 12 shows the nucleotide sequence of *Macaca mulatta* TMPRSS6 (SEQ ID NO:5).

Figure 13 shows the reverse complement of SEQ ID NO:1 (SEQ ID NO:6).

Figure 14 shows the reverse complement of SEQ ID NO:2 (SEQ ID NO:7).

Figure 15 shows the reverse complement of SEQ ID NO:3 (SEQ ID NO:8).

Figure 16 shows the reverse complement of SEQ ID NO:4 (SEQ ID NO:9).

Figure 17 shows the reverse complement of SEQ ID NO:5 (SEQ ID NO:10).

Detailed Description of the Invention

The present invention provides compositions comprising RNAi agents, *e.g.*, double-stranded iRNA agents, targeting TMPRSS6. The present invention also provides methods using the compositions of the invention for inhibiting TMPRSS6 expression and for treating TMPRSS6 associated disorders, *e.g.*, β-thalassemia or hemochromatosis.

TMPRSS6 plays an important role in iron homeostasis as an inhibitor of HAMP gene expression. The HAMP gene encodes the liver hormone hepcidin, which is a central regulator of iron homeostasis. Hepcidin binds to the iron exporter protein ferroportin (FPN1), which is localized mainly on absorptive enterocytes, hepatocytes and macrophages. Hepcidin binding to the extracellular domain of ferroportin leads to the internalization and degradation of ferroportin, thus decreasing the absorption of dietary iron from the intestine, and the release of iron from macrophages and hepatocytes. HAMP gene expression can be stimulated in response to iron through Bone Morphogenetic Protein (BMP)/Sons of Mothers Against Decapentaplegic (SMAD)-dependent signal transduction cascade mediated by the BMP-co-receptor hemojuvelin (HJV). The key role of TMPRSS6 in HAMP regulation is in the inhibition of BMP-mediated HAMP upregulation. TMPRSS6 inhibits BMP-mediated HAMP upregulation by cleaving the BMP co-receptor HJV, which is essential for BMP-mediated HAMP upregulation; thus preventing BMP signaling, SMAD translocation to the nucleus, and HAMP transcriptional activation.

Several human and mouse studies have confirmed the role of TMPRSS6 in HAMP regulation and iron homeostasis (Du *et al. Science* 2008, Vol. 320, ppl088-1092; Folgueras *et al. Blood* 2008, Vol. 112, pp2539-45). Studies have shown that loss of function mutations in TMPRSS6 can lead to the upregulation of hepcidin expression, causing an inherited iron deficiency anemia called iron refractory iron deficiency anemia (IRIDA) (Finberg. Seminars in *Hematology* 2009, Vol. 46, pp378-86), which is characterized by elevated hepcidin levels, hypochromic microcytic anemia, low mean corpuscular volume (MCV), low transferrin saturation, poor absorption of oral iron, and incomplete response to parenteral iron. However, loss of function mutations in positive regulators of HAMP (*e.g.*, BMP1, BMP4, and HFE) have been shown to downregulate hepcidin expression and cause iron overload disorders (Milet *et al. Am J Hum Gen* 2007, Vol. 81, pp799-807; Finberg *et al. Blood* 2011, Vol. 117, pp4590-9). In the primary iron overload disorders, collectively called hereditary hemochromatosis (HH), in anemias characterized by massive ineffective hematopoiesis, and in iron overload (secondary hemochromatosis), such as β-thalassemia intermedia (TI), hepcidin levels are low despite elevated serum iron concentrations and iron stores. A mouse model of β-thalassemia intermedia has demonstrated that the loss of TMPRSS6 expression

leads to elevated levels of hepcidin (Finberg 2010 Oral Presentation: "TMPRSS6, an inhibitor of Hepatic BMP/Smad Signaling, is required for Hepcidin Suppression and Iron Loading in a Mouse Model of β-Thalassemia." American Society of Hematology Annual Meeting 2010, Abstract No.: 164).

The present invention describes iRNA agents, compositions and methods for modulating the expression of a TMPRSS6 gene. In certain embodiments, expression of TMPRSS6 is reduced or inhibited using a TMPRSS6-specific iRNA agent, thereby leading to increase HAMP expression, and decreased serum iron levels. Thus, inhibition of TMPRSS6 gene expression or activity using the iRNA compositions featured in the invention can be a useful approach to therapies aimed at reducing the iron levels in a subject. Such inhibition can be useful for treating iron overload associated disorders, such as hemochromatosis or thalassemia, *e.g.*, β-thalassemia (*e.g.,* β-thalassemia major and β-thalassemia intermiedia).

I. Definitions

In order that the present invention may be more readily understood, certain terms are first defined. In addition, it should be noted that whenever a value or range of values of a parameter are recited, it is intended that values and ranges intermediate to the recited values are also intended to be part of this invention.

The articles "a" and "an" are used herein to refer to one or to more than one (*i.e.*, to at least one) of the grammatical object of the article. By way of example, "an element" means one element or more than one element, *e.g.*, a plurality of elements.

The term "including" is used herein to mean, and is used interchangeably with, the phrase "including but not limited to".

The term "or" is used herein to mean, and is used interchangeably with, the term "and/or," unless context clearly indicates otherwise.

As used herein, "TMPRSS6" refers to the type II plasma membrane serine protease (TTSP) gene or protein. TMPRSS6 is also known as matriptase-2, IRIDA (iron refractory iron-deficiency anemia), transmembrane protease serine 6, type II transmembrane serine protease 6, and membrane-bound mosaic serine proteinase matriptase-2. TMPRSS6 is a serine protease Type II transmembrane protein of approximately 899 amino acids in length. TMPRSS6 contains multiple domains, *e.g.*, a short endo domain, a transmembrane domain, a sea urchin sperm protein/enteropeptidase domain/agrin (SEA) domain, two complement factor/urchin embryonic growth factor/BMP domains (CUB), three LDL-R class a domains (LDLa), and a trypsin-like serine protease domain with conserved His-Asp-Ser triad (HDS). The term "TMPRSS6" includes human TMPRSS6, the amino acid and nucleotide sequence of which may be found in, for example, GenBank Accession No. GI:56682967; mouse TMPRSS6, the amino acid and nucleotide sequence of which may be found in, for example, GenBank Accession No. GI:125656151; rat TMPRSS6, the amino acid and nucleotide

sequence of which may be found in, for example, GenBank Accession No. GI:194474097; rhesus TMPRSS6, the amino acid and nucleotide sequence of which may be found in, for example, GenBank Accession No. XM_001085203.2 (GI:297260989) and XM_001085319.1 (GI:109094061). Additional examples of AGT mRNA sequences are readily available using publicly available databases, *e.g.*, GenBank, UniProt, OMIM, and the *Macaca* genome project web site.

The term"TMPRSS6," as used herein, also refers to naturally occurring DNA sequence variations of the TMPRSS6 gene, such as a single nucleotide polymorphism (SNP) in the TMPRSS6 gene. Exemplary SNPs may be found in the dbSNP database available at www.ncbi.nlm.nih.gov/projects/SNP.

As used herein, "target sequence" refers to a contiguous portion of the nucleotide sequence of an mRNA molecule formed during the transcription of a TMPRSS6 gene, including mRNA that is a product of RNA processing of a primary transcription product.

As used herein, the term "strand comprising a sequence" refers to an oligonucleotide comprising a chain of nucleotides that is described by the sequence referred to using the standard nucleotide nomenclature.

"G," "C," "A" and "U" each generally stand for a nucleotide that contains guanine, cytosine, adenine, and uracil as a base, respectively. "T" and "dT" are used interchangeably herein and refer to a deoxyribonucleotide wherein the nucleobase is thymine, e.g., deoxyribothymine, 2'-deoxythymidine or thymidine. However, it will be understood that the term "ribonucleotide" or "nucleotide" or "deoxyribonucleotide" can also refer to a modified nucleotide, as further detailed below, or a surrogate replacement moiety. The skilled person is well aware that guanine, cytosine, adenine, and uracil may be replaced by other moieties without substantially altering the base pairing properties of an oligonucleotide comprising a nucleotide bearing such replacement moiety. For example, without limitation, a nucleotide comprising inosine as its base may base pair with nucleotides containing adenine, cytosine, or uracil. Hence, nucleotides containing uracil, guanine, or adenine may be replaced in the nucleotide sequences of the invention by a nucleotide containing, for example, inosine. Sequences comprising such replacement moieties are embodiments of the invention.

The terms "iRNA", "RNAi agent," "iRNA agent,", "RNA interference agent" as used interchangeably herein, refer to an agent that contains RNA as that term is defined herein, and which mediates the targeted cleavage of an RNA transcript *via* an RNA-induced silencing complex (RISC) pathway. iRNA directs the sequence-specific degradation of mRNA through a process known as RNA interference (RNAi). The iRNA modulates, *e.g.*, inhibits, the expression of TMPRSS6 in a cell, *e.g.*, a cell within a subject, such as a mammalian subject.

In one embodiment, an RNAi agent of the invention includes a single stranded RNA that interacts with a target RNA sequence, *e.g.*, a TMPRSS6 target mRNA sequence, to direct

the cleavage of the target RNA. Without wishing to be bound by theory, it is believed that long double stranded RNA introduced into cells is broken down into siRNA by a Type III endonuclease known as Dicer (Sharp *et al.* (2001) *Genes Dev.* 15:485). Dicer, a ribonuclease-III-like enzyme, processes the dsRNA into 19-23 base pair short interfering RNAs with characteristic two base 3' overhangs (Bernstein, *et al.*, (2001) *Nature* 409:363). The siRNAs are then incorporated into an RNA-induced silencing complex (RISC) where one or more helicases unwind the siRNA duplex, enabling the complementary antisense strand to guide target recognition (Nykanen, *et al.*, (2001) *Cell* 107:309). Upon binding to the appropriate target mRNA, one or more endonucleases within the RISC cleave the target to induce silencing (Elbashir, *et al.*, (2001) *Genes Dev.* 15:188). Thus, in one aspect the invention relates to a single stranded RNA (siRNA) generated within a cell and which promotes the formation of a RISC complex to effect silencing of the target gene, *i.e.,* a TMPRSS6 gene. Accordingly, the term "siRNA" is also used herein to refer to an RNAi as described above.

In another embodiment, the RNAi agent may be a single-stranded siRNA that is introduced into a cell or organism to inhibit a target mRNA. Single-stranded RNAi agents bind to the RISC endonuclease Argonaute 2, which then cleaves the target mRNA. The single-stranded siRNAs are generally 15-30 nucleotides and are chemically modified. The design and testing of single-stranded siRNAs are described in U.S. Patent No. 8,101,348 and in Lima *et al.*, (2012) *Cell* 150: 883-894, the entire contents of each of which are hereby incorporated herein by reference. Any of the antisense nucleotide sequences described herein may be used as a single-stranded siRNA as described herein or as chemically modified by the methods described in Lima *et al.*, (2012) *Cell* 150;:883-894.

In yet another embodiment, the present invention provides single-stranded antisense oligonucleotide molecules targeting TMPRSS6. A "single-stranded antisense oligonucleotide molecule" is complementary to a sequence within the target mRNA (*i.e.,* TMPRSS6). Single-stranded antisense oligonucleotide molecules can inhibit translation in a stoichiometric manner by base pairing to the mRNA and physically obstructing the translation machinery, see Dias, N. *et al.*, (2002) *Mol Cancer Ther* 1:347-355. Alternatively, the single-stranded antisense oligonucleotide molecules inhibit a target mRNA by hydridizing to the target and cleaving the target through an RNaseH cleavage event. The single-stranded antisense oligonucleotide molecule may be about 10 to about 30 nucleotides in length and have a sequence that is complementary to a target sequence. For example, the single-stranded antisense oligonucleotide molecule may comprise a sequence that is at least about 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, or more contiguous nucleotides from any one of the antisense nucleotide sequences described herein, *e.g.*, the sequences provided in any one of Tables, 1, 2, 4, 5, 8, 10, and 12, or bind any of the target sites described herein. The single-stranded antisense oligonucleotide molecules may comprise modified RNA, DNA, or a combination thereof.

In another embodiment, an "iRNA" for use in the compositions, uses, and methods of the invention is a double-stranded RNA and is referred to herein as a "double stranded RNAi agent," "double-stranded RNA (dsRNA) molecule," "dsRNA agent," or "dsRNA". The term "dsRNA", refers to a complex of ribonucleic acid molecules, having a duplex structure comprising two anti-parallel and substantially complementary nucleic acid strands, referred to as having "sense" and "antisense" orientations with respect to a target RNA, *i.e.,* a TMPRSS6 gene. In some embodiments of the invention, a double-stranded RNA (dsRNA) triggers the degradation of a target RNA, *e.g.,* an mRNA, through a post-transcriptional gene-silencing mechanism referred to herein as RNA interference or RNAi.

In general, the majority of nucleotides of each strand of a dsRNA molecule are ribonucleotides, but as described in detail herein, each or both strands can also include one or more non-ribonucleotides, *e.g.*, a deoxyribonucleotide and/or a modified nucleotide. In addition, as used in this specification, an "RNAi agent" may include ribonucleotides with chemical modifications; an RNAi agent may include substantial modifications at multiple nucleotides. Such modifications may include all types of modifications disclosed herein or known in the art. Any such modifications, as used in a siRNA type molecule, are encompassed by "RNAi agent" for the purposes of this specification and claims.

The two strands forming the duplex structure may be different portions of one larger RNA molecule, or they may be separate RNA molecules. Where the two strands are part of one larger molecule, and therefore are connected by an uninterrupted chain of nucleotides between the 3'-end of one strand and the 5'-end of the respective other strand forming the duplex structure, the connecting RNA chain is referred to as a "hairpin loop." Where the two strands are connected covalently by means other than an uninterrupted chain of nucleotides between the 3'-end of one strand and the 5'-end of the respective other strand forming the duplex structure, the connecting structure is referred to as a "linker." The RNA strands may have the same or a different number of nucleotides. The maximum number of base pairs is the number of nucleotides in the shortest strand of the dsRNA minus any overhangs that are present in the duplex. In addition to the duplex structure, an RNAi agent may comprise one or more nucleotide overhangs.

In one embodiment, an RNAi agent of the invention is a dsRNA of 24-30 nucleotides that interacts with a target RNA sequence, e.g., a TMPRSS6 target mRNA sequence, to direct the cleavage of the target RNA. Without wishing to be bound by theory, long double stranded RNA introduced into cells is broken down into siRNA by a Type III endonuclease known as Dicer (Sharp et al. (2001) Genes Dev. 15:485). Dicer, a ribonuclease-III-like enzyme, processes the dsRNA into 19-23 base pair short interfering RNAs with characteristic two base 3' overhangs (Bernstein, et al., (2001) Nature 409:363). The siRNAs are then incorporated into an RNA-induced silencing complex (RISC) where one or more helicases unwind the siRNA duplex, enabling the complementary antisense strand to guide target

recognition (Nykanen, et al., (2001) Cell 107:309). Upon binding to the appropriate target mRNA, one or more endonucleases within the RISC cleave the target to induce silencing (Elbashir, et al., (2001) Genes Dev. 15:188). As used herein, a "nucleotide overhang" refers to the unpaired nucleotide or nucleotides that protrude from the duplex structure of an RNAi agent when a 3'-end of one strand of the RNAi agent extends beyond the 5'-end of the other strand, or vice versa. "Blunt" or "blunt end" means that there are no unpaired nucleotides at that end of the double stranded RNAi agent, i.e., no nucleotide overhang. A "blunt ended" RNAi agent is a dsRNA that is double-stranded over its entire length, i.e., no nucleotide overhang at either end of the molecule. The RNAi agents of the invention include RNAi agents with nucleotide overhangs at one end (*i.e.*, agents with one overhang and one blunt end) or with nucleotide overhangs at both ends.

The term "antisense strand" refers to the strand of a double stranded RNAi agent which includes a region that is substantially complementary to a target sequence (*e.g.*, a human TMPRSS6 mRNA). As used herein, the term "region complementary to part of an mRNA encoding transthyretin" refers to a region on the antisense strand that is substantially complementary to part of a TMPRSS6 mRNA sequence. Where the region of complementarity is not fully complementary to the target sequence, the mismatches are most tolerated in the terminal regions and, if present, are generally in a terminal region or regions, *e.g.*, within 6, 5, 4, 3, or 2 nucleotides of the 5' and/or 3' terminus.

The term "sense strand," as used herein, refers to the strand of a dsRNA that includes a region that is substantially complementary to a region of the antisense strand.

As used herein, the term "cleavage region" refers to a region that is located immediately adjacent to the cleavage site. The cleavage site is the site on the target at which cleavage occurs. In some embodiments, the cleavage region comprises three bases on either end of, and immediately adjacent to, the cleavage site. In some embodiments, the cleavage region comprises two bases on either end of, and immediately adjacent to, the cleavage site. In some embodiments, the cleavage site specifically occurs at the site bound by nucleotides 10 and 11 of the antisense strand, and the cleavage region comprises nucleotides 11, 12 and 13.

As used herein, and unless otherwise indicated, the term "complementary," when used to describe a first nucleotide sequence in relation to a second nucleotide sequence, refers to the ability of an oligonucleotide or polynucleotide comprising the first nucleotide sequence to hybridize and form a duplex structure under certain conditions with an oligonucleotide or polynucleotide comprising the second nucleotide sequence, as will be understood by the skilled person. Such conditions can, for example, be stringent conditions, where stringent conditions may include: 400 mM NaCl, 40 mM PIPES pH 6.4, 1 mM EDTA, 50°C or 70°C for 12-16 hours followed by washing. Other conditions, such as physiologically relevant conditions as may be encountered inside an organism, can apply. For example, a

complementary sequence is sufficient to allow the relevant function of the nucleic acid to proceed, *e.g.,* RNAi. The skilled person will be able to determine the set of conditions most appropriate for a test of complementarity of two sequences in accordance with the ultimate application of the hybridized nucleotides.

Sequences can be "fully complementary" with respect to each when there is base-pairing of the nucleotides of the first nucleotide sequence with the nucleotides of the second nucleotide sequence over the entire length of the first and second nucleotide sequences. However, where a first sequence is referred to as "substantially complementary" with respect to a second sequence herein, the two sequences can be fully complementary, or they may form one or more, but generally not more than 4, 3 or 2 mismatched base pairs upon hybridization, while retaining the ability to hybridize under the conditions most relevant to their ultimate application. However, where two oligonucleotides are designed to form, upon hybridization, one or more single stranded overhangs, such overhangs shall not be regarded as mismatches with regard to the determination of complementarity. For example, a dsRNA comprising one oligonucleotide 21 nucleotides in length and another oligonucleotide 23 nucleotides in length, wherein the longer oligonucleotide comprises a sequence of 21 nucleotides that is fully complementary to the shorter oligonucleotide, may yet be referred to as "fully complementary" for the purposes described herein.

"Complementary" sequences, as used herein, may also include, or be formed entirely from, non-Watson-Crick base pairs and/or base pairs formed from non-natural and modified nucleotides, in as far as the above requirements with respect to their ability to hybridize are fulfilled. Such non-Watson-Crick base pairs includes, but not limited to, G:U Wobble or Hoogstein base pairing.

The terms "complementary," "fully complementary" and "substantially complementary" herein may be used with respect to the base matching between the sense strand and the antisense strand of a dsRNA, or between the antisense strand of a dsRNA and a target sequence, as will be understood from the context of their use.

As used herein, a polynucleotide that is "substantially complementary to at least part of" a messenger RNA (mRNA) refers to a polynucleotide that is substantially complementary to a contiguous portion of the mRNA of interest (*e.g.*, an mRNA encoding TMPRSS6) including a 5' UTR, an open reading frame (ORF), or a 3' UTR. For example, a polynucleotide is complementary to at least a part of a TMPRSS6 mRNA if the sequence is substantially complementary to a non-interrupted portion of an mRNA encoding TMPRSS6.

The term "inhibiting," as used herein, is used interchangeably with "reducing," "silencing," "downregulating," "suppressing" and other similar terms, and includes any level of inhibition.

The phrase "inhibiting expression of a TMPRSS6," as used herein, includes inhibition of expression of any TMPRSS6 gene (such as, *e.g.*, a mouse TMPRSS6 gene, a rat

TMPRSS6 gene, a monkey TMPRSS6 gene, or a human TMPRSS6 gene) as well as variants, (*e.g.,* naturally occurring variants), or mutants of a TMPRSS6 gene. Thus, the TMPRSS6 gene may be a wild-type TMPRSS6 gene, a mutant TMPRSS6 gene, or a transgenic TMPRSS6 gene in the context of a genetically manipulated cell, group of cells, or organism.

"Inhibiting expression of a TMPRSS6 gene" includes any level of inhibition of a TMPRSS6 gene, *e.g.*, at least partial suppression of the expression of a TMPRSS6 gene, such as an inhibition of at least about 5%, at least about 10%, at least about 15%, at least about 20%, at least about 25%, at least about 30%, at least about 35%,at least about 40%, at least about 45%, at least about 50%, at least about 55%, at least about 60%, at least about 65%, at least about 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 91%, at least about 92%, at least about 93%, at least about 94%. at least about 95%, at least about 96%, at least about 97%, at least about 98%, or at least about 99%.

The expression of a TMPRSS6 gene may be assessed based on the level of any variable associated with TMPRSS6 gene expression, *e.g.*, TMPRSS6 mRNA level, TMPRSS6 protein level, hepcidin mRNA level, hepcidin protein level, or iron levels in tissues or serum. Inhibition may be assessed by a decrease in an absolute or relative level of one or more of these variables compared with a control level. The control level may be any type of control level that is utilized in the art, *e.g.*, a pre-dose baseline level, or a level determined from a similar subject, cell, or sample that is untreated or treated with a control (such as, *e.g.*, buffer only control or inactive agent control).

The phrase "contacting a cell with a double stranded RNAi agent," as used herein, includes contacting a cell by any possible means. Contacting a cell with a double stranded RNAi agent includes contacting a cell *in vitro* with the RNAi agent or contacting a cell *in vivo* with the RNAi agent. The contacting may be done directly or indirectly. Thus, for example, the RNAi agent may be put into physical contact with the cell by the individual performing the method, or alternatively, the RNAi agent may be put into a situation that will permit or cause it to subsequently come into contact with the cell.

Contacting a cell *in vitro* may be done, for example, by incubating the cell with the RNAi agent. Contacting a cell *in vivo* may be done, for example, by injecting the RNAi agent into or near the tissue where the cell is located, or by injecting the RNAi agent into another area, the bloodstream or the subcutaneous space, such that the agent will subsequently reach the tissue where the cell to be contacted is located. For example, the RNAi agent may contain and/or be coupled to a ligand, *e.g.*, a GalNAc3 ligand, that directs the RNAi agent to a site of interest, e.g., the liver. Combinations of i*n vitro* and *in vivo* methods of contacting are also possible. In connection with the methods of the invention, a cell might also be contacted *in vitro* with an RNAi agent and subsequently transplanted into a subject.

A "patient" or "subject," as used herein, is intended to include either a human or non-human animal, preferably a mammal, *e.g.*, human or a monkey. Most preferably, the subject or patient is a human.

A "TMPRSS6 associated disorder", as used herein, is intended to include any disorder that can be treated or prevented, or the symptoms of which can be alleviated, by inhibiting the expression of TMPRSS6. In some embodiments, the TMPRSS6 associated disorder is also associated with iron overload, a condition characterized by elevated iron levels, or iron dysregulation. Iron overload may be caused, for example, by hereditary conditions, by elevated iron uptake from diet, or by excess iron administered parenterally that includes intravenous injection of excess iron, and transfusional iron overload.

TMPRSS6 associated disorders include, but are not limited to, hereditary hemochromatosis, idiopathic hemochromatosis, primary hemochromatosis, secondary hemochromatosis, severe juvenile hemochromatosis, neonatal hemochromatosis, sideroblastic anemia, hemolytic anemia, dyserythropoietic anemia, sickle-cell anemia, hemoglobinopathy, thalassemia (*e.g.*, β-thalassemia and α-thalassemia), chronic liver diseases, porphyria cutanea tarda, erythropoietic porphyria, atransferrinemia, hereditary tyrosinemia, cerebrohepatorenal syndrome, idiopathic pulmonary hemosiderosis, renal hemosiderosis.

TMPRSS6 associated disorders include disorders associated with oral administration of excess iron, transfusional iron overload and intravenous injection of excess iron.

TMPRSS6 associated disorders also include disorders with symptoms that are associated with or may be caused by iron overload. Such symptoms include increased risk for liver disease (cirrhosis, cancer), heart attack or heart failure, diabetes mellitus, osteoarthritis, osteoporosis, metabolic syndrome, hypothyroidism, hypogonadism, and in some cases premature death. In one embodiment, TMPRSS6 associated disorders include neurodegenerative disorders associated with iron overload and/or iron dysregulation, such as Alzheimer's Disease, Parkinson's Disease, Huntington's Disease, Friedreich's Ataxia, epilepsy and multiple sclerosis. Administration of an iRNA that targets TMPRSS6, *e.g.*, an iRNA described in any one of Tables 1, 2, 4, 5, 8, 10, and 12 can treat one or more of these symptoms, or prevent the development or progression of a disease or disorder that is aggravated by increased iron levels.

In one embodiment, a TMPRSS6 associated disorder is a β-thalassemia. A β-thalassemia is any one of a group of hereditary disorders characterized by a genetic deficiency in the synthesis of beta-globin chains. In the homozygous state, beta thalassemia ("thalassemia major") causes severe, transfusion-dependent anemia. In the heterozygous state, the beta thalassemia trait ("thalassemia minor") causes mild to moderate microcytic anemia.

"Thalassemia intermedia" is a β-thalassemia that results in subjects in whom the clinical severity of the disease is somewhere between the mild symptoms of β-thalassemia minor and the β-thalassemia major. The diagnosis is a clinical one that is based on the patient maintaining a satisfactory hemoglobin (Hb) level of at least 6-7 g/dL at the time of diagnosis without the need for regular blood transfusions.

In one embodiment, a β-thalassemia is thalassemia major. In another embodiment, a β-thalassemia is thalassemia intermedia.

"Therapeutically effective amount," as used herein, is intended to include the amount of an RNAi agent that, when administered to a patient for treating a TMPRSS6 associated disease, is sufficient to effect treatment of the disease (*e.g.*, by diminishing, ameliorating or maintaining the existing disease or one or more symptoms of disease). The "therapeutically effective amount" may vary depending on the RNAi agent, how the agent is administered, the disease and its severity and the history, age, weight, family history, genetic makeup, stage of pathological processes mediated by TMPRSS6 expression, the types of preceding or concomitant treatments, if any, and other individual characteristics of the patient to be treated.

"Prophylactically effective amount," as used herein, is intended to include the amount of an RNAi agent that, when administered to a subject who does not yet experience or display symptoms of a TMPRSS6-associated disease, but who may be predisposed to the disease, is sufficient to prevent or ameliorate the disease or one or more symptoms of the disease. Ameliorating the disease includes slowing the course of the disease or reducing the severity of later-developing disease. The "prophylactically effective amount" may vary depending on the RNAi agent, how the agent is administered, the degree of risk of disease, and the history, age, weight, family history, genetic makeup, the types of preceding or concomitant treatments, if any, and other individual characteristics of the patient to be treated.

A "therapeutically-effective amount" or "prophylacticaly effective amount" also includes an amount of an RNAi agent that produces some desired local or systemic effect at a reasonable benefit/risk ratio applicable to any treatment. RNAi gents employed in the methods of the present invention may be administered in a sufficient amount to produce a reasonable benefit/risk ratio applicable to such treatment.

The term "sample," as used herein, includes a collection of similar fluids, cells, or tissues isolated from a subject, as well as fluids, cells, or tissues present within a subject. Examples of biological fluids include blood, serum and serosal fluids, plasma, cerebrospinal fluid, ocular fluids, lymph, urine, saliva, and the like. Tissue samples may include samples from tissues, organs or localized regions. For example, samples may be derived from particular organs, parts of organs, or fluids or cells within those organs. In certain embodiments, samples may be derived from the liver (*e.g.*, whole liver or certain segments of

liver or certain types of cells in the liver, such as, *e.g.*, hepatocytes). In preferred embodiments, a "sample derived from a subject" refers to blood or plasma drawn from the subject. In further embodiments, a "sample derived from a subject" refers to liver tissue (or subcomponents thereof) derived from the subject.

II. iRNAs of the Invention

Described herein are improved double-stranded RNAi agents which inhibit the expression of a TMPRSS6 gene in a cell, such as a cell within a subject, *e.g.*, a mammal, such as a human having a TMPRSS6 associated disorder, *e.g.*, β-thalassemia (*e.g.*, β-thalassemia major and β-thalassemia intermiedia) or hemochromatosis, and uses of such double-stranded RNAi agents.

Accordingly, the invention provides double-stranded RNAi agents with chemical modifications capable of inhibiting the expression of a target gene (*i.e.*, a TMPRSS6 gene) *in vivo*. In certain aspects of the invention, substantially all of the nucleotides of an iRNA of the invention are modified. In other embodiments of the invention, all of the nucleotides of an iRNA of the invention are modified. iRNAs of the invention in which "substantially all of the nucleotides are modified" are largely but not wholly modified and can include not more than 5, 4, 3, 2, or 1 unmodified nucleotides.

The RNAi agent comprises a sense strand and an antisense strand. Each strand of the RNAi agent may range from 12-30 nucleotides in length. For example, each strand may be between 14-30 nucleotides in length, 17-30 nucleotides in length, 19-30 nucleotides in length, 25-30 nucleotides in length, 27-30 nucleotides in length, 17-23 nucleotides in length, 17-21 nucleotides in length, 17-19 nucleotides in length, 19-25 nucleotides in length, 19-23 nucleotides in length, 19-21 nucleotides in length, 21-25 nucleotides in length, or 21-23 nucleotides in length.

The sense strand and antisense strand typically form a duplex double stranded RNA ("dsRNA"), also referred to herein as an "RNAi agent." The duplex region of an RNAi agent may be 12-30 nucleotide pairs in length. For example, the duplex region can be between 14-30 nucleotide pairs in length, 17-30 nucleotide pairs in length, 27-30 nucleotide pairs in length, 17 - 23 nucleotide pairs in length, 17-21 nucleotide pairs in length, 17-19 nucleotide pairs in length, 19-25 nucleotide pairs in length, 19-23 nucleotide pairs in length, 19- 21 nucleotide pairs in length, 21-25 nucleotide pairs in length, or 21-23 nucleotide pairs in length. In another example, the duplex region is selected from 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, and 27 nucleotides in length.

In one embodiment, the RNAi agent may contain one or more overhang regions and/or capping groups at the 3'-end, 5'-end, or both ends of one or both strands. The overhang can be 1-6 nucleotides in length, for instance 2-6 nucleotides in length, 1-5 nucleotides in length, 2-5 nucleotides in length, 1-4 nucleotides in length, 2-4 nucleotides in

length, 1-3 nucleotides in length, 2-3 nucleotides in length, or 1-2 nucleotides in length. The overhangs can be the result of one strand being longer than the other, or the result of two strands of the same length being staggered. The overhang can form a mismatch with the target mRNA or it can be complementary to the gene sequences being targeted or can be another sequence. The first and second strands can also be joined, *e.g.*, by additional bases to form a hairpin, or by other non-base linkers.

In one embodiment, the nucleotides in the overhang region of the RNAi agent can each independently be a modified or unmodified nucleotide including, but no limited to 2'-sugar modified, such as, 2-F, 2'-O-methyl, thymidine (T), 2`-O-methoxyethyl-5-methyluridine (Teo), 2`-O-methoxyethyladenosine (Aeo), 2`-O-methoxyethyl-5-methylcytidine (m5Ceo), and any combinations thereof. For example, TT can be an overhang sequence for either end on either strand. The overhang can form a mismatch with the target mRNA or it can be complementary to the gene sequences being targeted or can be another sequence.

The 5'- or 3'- overhangs at the sense strand, antisense strand or both strands of the RNAi agent may be phosphorylated. In some embodiments, the overhang region(s) contains two nucleotides having a phosphorothioate between the two nucleotides, where the two nucleotides can be the same or different. In one embodiment, the overhang is present at the 3'-end of the sense strand, antisense strand, or both strands. In one embodiment, this 3'-overhang is present in the antisense strand. In one embodiment, this 3'-overhang is present in the sense strand.

The RNAi agent may contain only a single overhang, which can strengthen the interference activity of the RNAi, without affecting its overall stability. For example, the single-stranded overhang may be located at the 3'-terminal end of the sense strand or, alternatively, at the 3'-terminal end of the antisense strand. The RNAi may also have a blunt end, located at the 5'-end of the antisense strand (or the 3'-end of the sense strand) or *vice versa*. Generally, the antisense strand of the RNAi has a nucleotide overhang at the 3'-end, and the 5'-end is blunt. While not wishing to be bound by theory, the asymmetric blunt end at the 5'-end of the antisense strand and 3'-end overhang of the antisense strand favor the guide strand loading into RISC process.

Any of the nucleic acids featured in the invention can be synthesized and/or modified by methods well established in the art, such as those described in "Current protocols in nucleic acid chemistry," Beaucage, S.L. *et al.* (Edrs.), John Wiley & Sons, Inc., New York, NY, USA, which is hereby incorporated herein by reference. Modifications include, for example, end modifications, *e.g.*, 5'-end modifications (phosphorylation, conjugation, inverted linkages) or 3'-end modifications (conjugation, DNA nucleotides, inverted linkages, *etc.*); base modifications, *e.g.*, replacement with stabilizing bases, destabilizing bases, or bases that base pair with an expanded repertoire of partners, removal of bases (abasic

nucleotides), or conjugated bases; sugar modifications (*e.g.*, at the 2'-position or 4'-position) or replacement of the sugar; and/or backbone modifications, including modification or replacement of the phosphodiester linkages. Specific examples of iRNA compounds useful in the embodiments described herein include, but are not limited to RNAs containing modified backbones or no natural internucleoside linkages. RNAs having modified backbones include, among others, those that do not have a phosphorus atom in the backbone. For the purposes of this specification, and as sometimes referenced in the art, modified RNAs that do not have a phosphorus atom in their internucleoside backbone can also be considered to be oligonucleosides. In some embodiments, a modified iRNA will have a phosphorus atom in its internucleoside backbone.

Modified RNA backbones include, for example, phosphorothioates, chiral phosphorothioates, phosphorodithioates, phosphotriesters, aminoalkylphosphotriesters, methyl and other alkyl phosphonates including 3'-alkylene phosphonates and chiral phosphonates, phosphinates, phosphoramidates including 3'-amino phosphoramidate and aminoalkylphosphoramidates, thionophosphoramidates, thionoalkylphosphonates, thionoalkylphosphotriesters, and boranophosphates having normal 3'-5' linkages, 2'-5'-linked analogs of these, and those having inverted polarity wherein the adjacent pairs of nucleoside units are linked 3'-5' to 5'-3' or 2'-5' to 5'-2'. Various salts, mixed salts and free acid forms are also included.

Representative U.S. patents that teach the preparation of the above phosphorus-containing linkages include, but are not limited to, U.S. Patent Nos. 3,687,808; 4,469,863; 4,476,301; 5,023,243; 5,177,195; 5,188,897; 5,264,423; 5,276,019; 5,278,302; 5,286,717; 5,321,131; 5,399,676; 5,405,939; 5,453,496; 5,455,233; 5,466,677; 5,476,925; 5,519,126; 5,536,821; 5,541,316; 5,550,111; 5,563,253; 5,571,799; 5,587,361; 5,625,050; 6,028,188; 6,124,445; 6,160,109; 6,169,170; 6,172,209; 6, 239,265; 6,277,603; 6,326,199; 6,346,614; 6,444,423; 6,531,590; 6,534,639; 6,608,035; 6,683,167; 6,858,715; 6,867,294; 6,878,805; 7,015,315; 7,041,816; 7,273,933; 7,321,029; and US Pat RE39464, the entire contents of each of which are hereby incorporated herein by reference.

Modified RNA backbones that do not include a phosphorus atom therein have backbones that are formed by short chain alkyl or cycloalkyl internucleoside linkages, mixed heteroatoms and alkyl or cycloalkyl internucleoside linkages, or one or more short chain heteroatomic or heterocyclic internucleoside linkages. These include those having morpholino linkages (formed in part from the sugar portion of a nucleoside); siloxane backbones; sulfide, sulfoxide and sulfone backbones; formacetyl and thioformacetyl backbones; methylene formacetyl and thioformacetyl backbones; alkene containing backbones; sulfamate backbones; methyleneimino and methylenehydrazino backbones; sulfonate and sulfonamide backbones; amide backbones; and others having mixed N, O, S and CH_2 component parts.

Representative U.S. patents that teach the preparation of the above oligonucleosides include, but are not limited to, U.S. Patent Nos. 5,034,506; 5,166,315; 5,185,444; 5,214,134; 5,216,141; 5,235,033; 5,64,562; 5,264,564; 5,405,938; 5,434,257; 5,466,677; 5,470,967; 5,489,677; 5,541,307; 5,561,225; 5,596,086; 5,602,240; 5,608,046; 5,610,289; 5,618,704; 5,623,070; 5,663,312; 5,633,360; 5,677,437; and, 5,677,439, the entire contents of each of which are hereby incorporated herein by reference.

In other embodiments, suitable RNA mimetics are contemplated for use in iRNAs, in which both the sugar and the internucleoside linkage, *i.e.*, the backbone, of the nucleotide units are replaced with novel groups. The base units are maintained for hybridization with an appropriate nucleic acid target compound. One such oligomeric compound, an RNA mimetic that has been shown to have excellent hybridization properties, is referred to as a peptide nucleic acid (PNA). In PNA compounds, the sugar backbone of an RNA is replaced with an amide containing backbone, in particular an aminoethylglycine backbone. The nucleobases are retained and are bound directly or indirectly to aza nitrogen atoms of the amide portion of the backbone. Representative U.S. patents that teach the preparation of PNA compounds include, but are not limited to, U.S. Patent Nos. 5,539,082; 5,714,331; and 5,719,262, the entire contents of each of which are hereby incorporated herein by reference. Additional PNA compounds suitable for use in the iRNAs of the invention are described in, for example, in Nielsen *et al.*, *Science*, 1991, 254, 1497-1500.

Some embodiments featured in the invention include RNAs with phosphorothioate backbones and oligonucleosides with heteroatom backbones, and in particular --CH_2--NH--CH_2-, --CH_2--N(CH_3)--O--CH_2--[known as a methylene (methylimino) or MMI backbone], --CH_2--O--N(CH_3)--CH_2--, --CH_2--N(CH_3)--N(CH_3)--CH_2-- and --N(CH_3)--CH_2--CH_2--[wherein the native phosphodiester backbone is represented as --O--P--O--CH_2--] of the above-referenced U.S. Patent No. 5,489,677, and the amide backbones of the above-referenced U.S. Patent No. 5,602,240. In some embodiments, the RNAs featured herein have morpholino backbone structures of the above-referenced U.S. Patent No. 5,034,506.

Modified RNAs can also contain one or more substituted sugar moieties. The iRNAs, *e.g.*, dsRNAs, featured herein can include one of the following at the 2'-position: OH; F; O-, S-, or N-alkyl; O-, S-, or N-alkenyl; O-, S- or N-alkynyl; or O-alkyl-O-alkyl, wherein the alkyl, alkenyl and alkynyl can be substituted or unsubstituted C_1 to C_{10} alkyl or C_2 to C_{10} alkenyl and alkynyl. Exemplary suitable modifications include $O[(CH_2)_nO]_mCH_3$, $O(CH_2)_nOCH_3$, $O(CH_2)_nNH_2$, $O(CH_2)_nCH_3$, $O(CH_2)_nONH_2$, and $O(CH_2)_nON[(CH_2)_nCH_3)]_2$, where n and m are from 1 to about 10. In other embodiments, dsRNAs include one of the following at the 2' position: C_1 to C_{10} lower alkyl, substituted lower alkyl, alkaryl, aralkyl, O-alkaryl or O-aralkyl, SH, SCH_3, OCN, Cl, Br, CN, CF_3, OCF_3, $SOCH_3$, SO_2CH_3, ONO_2, NO_2, N_3, NH_2, heterocycloalkyl, heterocycloalkaryl, aminoalkylamino, polyalkylamino, substituted silyl, an RNA cleaving group, a reporter group, an intercalator, a group for

improving the pharmacokinetic properties of an iRNA, or a group for improving the pharmacodynamic properties of an iRNA, and other substituents having similar properties. In some embodiments, the modification includes a 2'-methoxyethoxy (2'-O--$CH_2CH_2OCH_3$, also known as 2'-O-(2-methoxyethyl) or 2'-MOE) (Martin *et al.*, *Helv. Chim. Acta*, 1995, 78:486-504) *i.e.*, an alkoxy-alkoxy group. Another exemplary modification is 2'-dimethylaminooxyethoxy, *i.e.*, a $O(CH_2)_2ON(CH_3)_2$ group, also known as 2'-DMAOE, as described in examples herein below, and 2'-dimethylaminoethoxyethoxy (also known in the art as 2'-O-dimethylaminoethoxyethyl or 2'-DMAEOE), *i.e.*, 2'-O--CH_2--O--CH_2--$N(CH_2)_2$.

Other modifications include 2'-methoxy (2'-OCH_3), 2'-aminopropoxy (2'-$OCH_2CH_2CH_2NH_2$) and 2'-fluoro (2'-F). Similar modifications can also be made at other positions on the RNA of an iRNA, particularly the 3' position of the sugar on the 3' terminal nucleotide or in 2'-5' linked dsRNAs and the 5' position of 5' terminal nucleotide. iRNAs can also have sugar mimetics such as cyclobutyl moieties in place of the pentofuranosyl sugar. Representative U.S. patents that teach the preparation of such modified sugar structures include, but are not limited to, U.S. Pat. Nos. 4,981,957; 5,118,800; 5,319,080; 5,359,044; 5,393,878; 5,446,137; 5,466,786; 5,514,785; 5,519,134; 5,567,811; 5,576,427; 5,591,722; 5,597,909; 5,610,300; 5,627,053; 5,639,873; 5,646,265; 5,658,873; 5,670,633; and 5,700,920, certain of which are commonly owned with the instant application,. The entire contents of each of the foregoing are hereby incorporated herein by reference.

An iRNA can also include nucleobase (often referred to in the art simply as "base") modifications or substitutions. As used herein, "unmodified" or "natural" nucleobases include the purine bases adenine (A) and guanine (G), and the pyrimidine bases thymine (T), cytosine (C) and uracil (U). Modified nucleobases include other synthetic and natural nucleobases such as deoxy-thymine (dT), 5-methylcytosine (5-me-C), 5-hydroxymethyl cytosine, xanthine, hypoxanthine, 2-aminoadenine, 6-methyl and other alkyl derivatives of adenine and guanine, 2-propyl and other alkyl derivatives of adenine and guanine, 2-thiouracil, 2-thiothymine and 2-thiocytosine, 5-halouracil and cytosine, 5-propynyl uracil and cytosine, 6-azo uracil, cytosine and thymine, 5-uracil (pseudouracil), 4-thiouracil, 8-halo, 8-amino, 8-thiol, 8-thioalkyl, 8-hydroxyl anal other 8-substituted adenines and guanines, 5-halo, particularly 5-bromo, 5-trifluoromethyl and other 5-substituted uracils and cytosines, 7-methylguanine and 7-methyladenine, 8-azaguanine and 8-azaadenine, 7-deazaguanine and 7-daazaadenine and 3-deazaguanine and 3-deazaadenine. Further nucleobases include those disclosed in U.S. Pat. No. 3,687,808, those disclosed in Modified Nucleosides in Biochemistry, Biotechnology and Medicine, Herdewijn, P. ed. Wiley-VCH, 2008; those disclosed in The Concise Encyclopedia Of Polymer Science And Engineering, pages 858-859, Kroschwitz, J. L, ed. John Wiley & Sons, 1990, these disclosed by Englisch *et al.*, Angewandte Chemie, International Edition, 1991, 30, 613, and those disclosed by Sanghvi, Y S., Chapter 15, dsRNA Research and Applications, pages 289-302, Crooke, S. T. and Lebleu,

B., Ed., CRC Press, 1993. Certain of these nucleobases are particularly useful for increasing the binding affinity of the oligomeric compounds featured in the invention. These include 5-substituted pyrimidines, 6-azapyrimidines and N-2, N-6 and 0-6 substituted purines, including 2-aminopropyladenine, 5-propynyluracil and 5-propynylcytosine. 5-methylcytosine substitutions have been shown to increase nucleic acid duplex stability by 0.6-1.2°C (Sanghvi, Y. S., Crooke, S. T. and Lebleu, B., Eds., dsRNA Research and Applications, CRC Press, Boca Raton, 1993, pp. 276-278) and are exemplary base substitutions, even more particularly when combined with 2'-O-methoxyethyl sugar modifications.

Representative U.S. patents that teach the preparation of certain of the above noted modified nucleobases as well as other modified nucleobases include, but are not limited to, the above noted U.S. Patent Nos. 3,687,808, 4,845,205; 5,130,30; 5,134,066; 5,175,273; 5,367,066; 5,432,272; 5,457,187; 5,459,255; 5,484,908; 5,502,177; 5,525,711; 5,552,540; 5,587,469; 5,594,121, 5,596,091; 5,614,617; 5,681,941; 5,750,692; 6,015,886; 6,147,200; 6,166,197; 6,222,025; 6,235,887; 6,380,368; 6,528,640; 6,639,062; 6,617,438; 7,045,610; 7,427,672; and 7,495,088, the entire contents of each of which are hereby incorporated herein by reference.

The RNA of an iRNA can also be modified to include one or more locked nucleic acids (LNA). A locked nucleic acid is a nucleotide having a modified ribose moiety in which the ribose moiety comprises an extra bridge connecting the 2' and 4' carbons. This structure effectively "locks" the ribose in the 3'-endo structural conformation. The addition of locked nucleic acids to siRNAs has been shown to increase siRNA stability in serum, and to reduce off-target effects (Elmen, J. *et al.*, (2005) *Nucleic Acids Research* 33(1):439-447; Mook, OR. *et al.*, (2007) *Mol Canc Ther* 6(3):833-843; Grunweller, A. *et al.*, (2003) *Nucleic Acids Research* 31(12):3185-3193).

Representative U.S. Patents that teach the preparation of locked nucleic acid nucleotides include, but are not limited to, the following: U.S. Patent Nos. 6,268,490; 6,670,461; 6,794,499; 6,998,484; 7,053,207; 7,084,125; and 7,399,845, the entire contents of each of which are hereby incorporated herein by reference.

Potentially stabilizing modifications to the ends of RNA molecules can include N-(acetylaminocaproyl)-4-hydroxyprolinol (Hyp-C6-NHAc), N-(caproyl-4-hydroxyprolinol (Hyp-C6), N-(acetyl-4-hydroxyprolinol (Hyp-NHAc), thymidine-2'-0-deoxythymidine (ether), N-(aminocaproyl)-4-hydroxyprolinol (Hyp-C6-amino), 2-docosanoyl-uridine-3"-phosphate, inverted base dT(idT) and others. Disclosure of this modification can be found in PCT Publication No. WO 2011/005861.

A. Modified iRNAs Comprising Motifs of the Invention

In certain aspects of the invention, the double-stranded RNAi agents of the invention include agents with chemical modifications as disclosed, for example, in U.S. Provisional Application No. 61/561,710, filed on November 18, 2011, or in PCT/US2012/065691, filed

on November 16, 2012, the entire contents of each of which are incorporated herein by reference.

As shown herein and in Provisional Application No. 61/561,710, a superior result may be obtained by introducing one or more motifs of three identical modifications on three consecutive nucleotides into a sense strand and/or antisense strand of a RNAi agent, particularly at or near the cleavage site. In some embodiments, the sense strand and antisense strand of the RNAi agent may otherwise be completely modified. The introduction of these motifs interrupts the modification pattern, if present, of the sense and/or antisense strand. The RNAi agent may be optionally conjugated with a GalNAc derivative ligand, for instance on the sense strand. The resulting RNAi agents present superior gene silencing activity.

More specifically, it has been surprisingly discovered that when the sense strand and antisense strand of the double-stranded RNAi agent are modified to have one or more motifs of three identical modifications on three consecutive nucleotides at or near the cleavage site of at least one strand of an RNAi agent, the gene silencing acitivity of the RNAi agent was superiorly enhanced.

In one embodiment, the RNAi agent is a double ended bluntmer of 19 nucleotides in length, wherein the sense strand contains at least one motif of three 2'-F modifications on three consecutive nucleotides at positions 7, 8, 9 from the 5'end. The antisense strand contains at least one motif of three 2'-O-methyl modifications on three consecutive nucleotides at positions 11, 12, 13 from the 5'end.

In another embodiment, the RNAi agent is a double ended bluntmer of 20 nucleotides in length, wherein the sense strand contains at least one motif of three 2'-F modifications on three consecutive nucleotides at positions 8, 9, 10 from the 5'end. The antisense strand contains at least one motif of three 2'-O-methyl modifications on three consecutive nucleotides at positions 11, 12, 13 from the 5'end.

In yet another embodiment, the RNAi agent is a double ended bluntmer of 21 nucleotides in length, wherein the sense strand contains at least one motif of three 2'-F modifications on three consecutive nucleotides at positions 9, 10, 11 from the 5'end. The antisense strand contains at least one motif of three 2'-O-methyl modifications on three consecutive nucleotides at positions 11, 12, 13 from the 5'end.

In one embodiment, the RNAi agent comprises a 21 nucleotide sense strand and a 23 nucleotide antisense strand, wherein the sense strand contains at least one motif of three 2'-F modifications on three consecutive nucleotides at positions 9, 10, 11 from the 5'end; the antisense strand contains at least one motif of three 2'-O-methyl modifications on three consecutive nucleotides at positions 11, 12, 13 from the 5'end, wherein one end of the RNAi agent is blunt, while the other end comprises a 2 nucleotide overhang. Preferably, the 2 nucleotide overhang is at the 3'-end of the antisense strand. When the 2 nucleotide overhang is at the 3'-end of the antisense strand, there may be two phosphorothioate internucleotide

linkages between the terminal three nucleotides, wherein two of the three nucleotides are the overhang nucleotides, and the third nucleotide is a paired nucleotide next to the overhang nucleotide. In one embodiment, the RNAi agent additionally has two phosphorothioate internucleotide linkages between the terminal three nucleotides at both the 5'-end of the sense strand and at the 5'-end of the antisense strand. In one embodiment, every nucleotide in the sense strand and the antisense strand of the RNAi agent, including the nucleotides that are part of the motifs are modified nucleotides. In one embodiment each residue is independently modified with a 2'-O-methyl or 3'-fluoro, *e.g.,* in an alternating motif. Optionally, the RNAi agent further comprises a ligand (preferably $GalNAc_3$).

In one embodiment, the RNAi agent comprises sense and antisense strands, wherein the RNAi agent comprises a first strand having a length which is at least 25 and at most 29 nucleotides and a second strand having a length which is at most 30 nucleotides with at least one motif of three 2'-O-methyl modifications on three consecutive nucleotides at position 11, 12, 13 from the 5' end; wherein the 3' end of the first strand and the 5' end of the second strand form a blunt end and the second strand is 1-4 nucleotides longer at its 3' end than the first strand, wherein the duplex region region which is at least 25 nucleotides in length, and the second strand is sufficiently complemenatary to a target mRNA along at least 19 nucleotide of the second strand length to reduce target gene expression when the RNAi agent is introduced into a mammalian cell, and wherein dicer cleavage of the RNAi agent preferentially results in an siRNA comprising the 3' end of the second strand, thereby reducing expression of the target gene in the mammal. Optionally, the RNAi agent further comprises a ligand.

In one embodiment, the sense strand of the RNAi agent contains at least one motif of three identical modifications on three consecutive nucleotides, where one of the motifs occurs at the cleavage site in the sense strand.

In one embodiment, the antisense strand of the RNAi agent can also contain at least one motif of three identical modifications on three consecutive nucleotides, where one of the motifs occurs at or near the cleavage site in the antisense strand

For an RNAi agent having a duplex region of 17-23 nucleotide in length, the cleavage site of the antisense strand is typically around the 10, 11 and 12 positions from the 5'-end. Thus the motifs of three identical modifications may occur at the 9, 10, 11 positions; 10, 11, 12 positions; 11, 12, 13 positions; 12, 13, 14 positions; or 13, 14, 15 positions of the antisense strand, the count starting from the 1^{st} nucleotide from the 5'-end of the antisense strand, or, the count starting from the 1^{st} paired nucleotide within the duplex region from the 5'- end of the antisense strand. The cleavage site in the antisense strand may also change according to the length of the duplex region of the RNAi from the 5'-end.

The sense strand of the RNAi agent may contain at least one motif of three identical modifications on three consecutive nucleotides at the cleavage site of the strand; and the

antisense strand may have at least one motif of three identical modifications on three consecutive nucleotides at or near the cleavage site of the strand. When the sense strand and the antisense strand form a dsRNA duplex, the sense strand and the antisense strand can be so aligned that one motif of the three nucleotides on the sense strand and one motif of the three nucleotides on the antisense strand have at least one nucleotide overlap, *i.e.*, at least one of the three nucleotides of the motif in the sense strand forms a base pair with at least one of the three nucleotides of the motif in the antisense strand. Alternatively, at least two nucleotides may overlap, or all three nucleotides may overlap.

In one embodiment, the sense strand of the RNAi agent may contain more than one motif of three identical modifications on three consecutive nucleotides. The first motif may occur at or near the cleavage site of the strand and the other motifs may be a wing modification. The term "wing modification" herein refers to a motif occurring at another portion of the strand that is separated from the motif at or near the cleavage site of the same strand. The wing modification is either adajacent to the first motif or is separated by at least one or more nucleotides. When the motifs are immediately adjacent to each other then the chemistry of the motifs are distinct from each other and when the motifs are separated by one or more nucleotide than the chemistries can be the same or different. Two or more wing modifications may be present. For instance, when two wing modifications are present, each wing modification may occur at one end relative to the first motif which is at or near cleavage site or on either side of the lead motif.

Like the sense strand, the antisense strand of the RNAi agent may contain more than one motifs of three identical modifications on three consecutive nucleotides, with at least one of the motifs occurring at or near the cleavage site of the strand. This antisense strand may also contain one or more wing modifications in an alignment similar to the wing modifications that may be present on the sense strand.

In one embodiment, the wing modification on the sense strand or antisense strand of the RNAi agent typically does not include the first one or two terminal nucleotides at the 3'-end, 5'-end or both ends of the strand.

In another embodiment, the wing modification on the sense strand or antisense strand of the RNAi agent typically does not include the first one or two paired nucleotides within the duplex region at the 3'-end, 5'-end or both ends of the strand.

When the sense strand and the antisense strand of the RNAi agent each contain at least one wing modification, the wing modifications may fall on the same end of the duplex region, and have an overlap of one, two or three nucleotides.

When the sense strand and the antisense strand of the RNAi agent each contain at least two wing modifications, the sense strand and the antisense strand can be so aligned that two modifications each from one strand fall on one end of the duplex region, having an overlap of one, two or three nucleotides; two modifications each from one strand fall on the

other end of the duplex region, having an overlap of one, two or three nucleotides; two modifications one strand fall on each side of the lead motif, having an overlap of one, two or three nucleotides in the duplex region.

In one embodiment, every nucleotide in the sense strand and antisense strand of the RNAi agent, including the nucleotides that are part of the motifs, may be modified. Each nucleotide may be modified with the same or different modification which can include one or more alteration of one or both of the non-linking phosphate oxygens and/or of one or more of the linking phosphate oxygens; alteration of a constituent of the ribose sugar, *e.g.*, of the 2′ hydroxyl on the ribose sugar; wholesale replacement of the phosphate moiety with "dephospho" linkers; modification or replacement of a naturally occurring base; and replacement or modification of the ribose-phosphate backbone.

As nucleic acids are polymers of subunits, many of the modifications occur at a position which is repeated within a nucleic acid, *e.g.*, a modification of a base, or a phosphate moiety, or a non-linking O of a phosphate moiety. In some cases the modification will occur at all of the subject positions in the nucleic acid but in many cases it will not. By way of example, a modification may only occur at a 3' or 5' terminal position, may only occur in a terminal region, *e.g.,* at a position on a terminal nucleotide or in the last 2, 3, 4, 5, or 10 nucleotides of a strand. A modification may occur in a double strand region, a single strand region, or in both. A modification may occur only in the double strand region of a RNA or may only occur in a single strand region of a RNA. For example, a phosphorothioate modification at a non-linking O position may only occur at one or both termini, may only occur in a terminal region, *e.g.*, at a position on a terminal nucleotide or in the last 2, 3, 4, 5, or 10 nucleotides of a strand, or may occur in double strand and single strand regions, particularly at termini. The 5' end or ends can be phosphorylated.

It may be possible, *e.g.*, to enhance stability, to include particular bases in overhangs, or to include modified nucleotides or nucleotide surrogates, in single strand overhangs, *e.g.*, in a 5' or 3' overhang, or in both. For example, it can be desirable to include purine nucleotides in overhangs. In some embodiments all or some of the bases in a 3' or 5' overhang may be modified, *e.g.*, with a modification described herein. Modifications can include, *e.g.*, the use of modifications at the 2' position of the ribose sugar with modifications that are known in the art, *e.g.*, the use of deoxyribonucleotides, , 2'-deoxy-2'-fluoro (2'-F) or 2'-O-methyl modified instead of the ribosugar of the nucleobase , and modifications in the phosphate group, *e.g.*, phosphorothioate modifications. Overhangs need not be homologous with the target sequence.

In one embodiment, each residue of the sense strand and antisense strand is independently modified with LNA, HNA, CeNA, 2'-methoxyethyl, 2'- O-methyl, 2'-O-allyl, 2'-C- allyl, 2'-deoxy, 2'-hydroxyl, or 2'-fluoro. The strands can contain more than one

modification. In one embodiment, each residue of the sense strand and antisense strand is independently modified with 2'- O-methyl or 2'-fluoro.

At least two different modifications are typically present on the sense strand and antisense strand. Those two modifications may be the 2'- O-methyl or 2'-fluoro modifications, or others.

In one embodiment, the N_a and/or N_b comprise modifications of an alternating pattern. The term "alternating motif" as used herein refers to a motif having one or more modifications, each modification occurring on alternating nucleotides of one strand. The alternating nucleotide may refer to one per every other nucleotide or one per every three nucleotides, or a similar pattern. For example, if A, B and C each represent one type of modification to the nucleotide, the alternating motif can be "ABABABABABAB...," "AABBAABBAABB...," "AABAABAABAAB...," "AAABAAABAAAB...," "AAABBBAAABBB...," or "ABCABCABCABC...," etc.

The type of modifications contained in the alternating motif may be the same or different. For example, if A, B, C, D each represent one type of modification on the nucleotide, the alternating pattern, *i.e.*, modifications on every other nucleotide, may be the same, but each of the sense strand or antisense strand can be selected from several possibilities of modifications within the alternating motif such as "ABABAB...", "ACACAC..." "BDBDBD..." or "CDCDCD...," etc.

In one embodiment, the RNAi agent of the invention comprises the modification pattern for the alternating motif on the sense strand relative to the modification pattern for the alternating motif on the antisense strand is shifted. The shift may be such that the modified group of nucleotides of the sense strand corresponds to a differently modified group of nucleotides of the antisense strand and *vice versa*. For example, the sense strand when paired with the antisense strand in the dsRNA duplex, the alternating motif in the sense strand may start with "ABABAB" from 5'-3' of the strand and the alternating motif in the antisense strand may start with "BABABA" from 5'-3'of the strand within the duplex region. As another example, the alternating motif in the sense strand may start with "AABBAABB" from 5'-3' of the strand and the alternating motif in the antisenese strand may start with "BBAABBAA" from 5'-3' of the strand within the duplex region, so that there is a complete or partial shift of the modification patterns between the sense strand and the antisense strand.

In one embodiment, the RNAi agent comprises the pattern of the alternating motif of 2'-O-methyl modification and 2'-F modification on the sense strand initially has a shift relative to the pattern of the alternating motif of 2'-O-methyl modification and 2'-F modification on the antisense strand initially, *i.e.*, the 2'-O-methyl modified nucleotide on the sense strand base pairs with a 2'-F modified nucleotide on the antisense strand and vice versa. The 1 position of the sense strand may start with the 2'-F modification, and the 1 position of the antisense strand may start with the 2'- O-methyl modification.

The introduction of one or more motifs of three identical modifications on three consecutive nucleotides to the sense strand and/or antisense strand interrupts the initial modification pattern present in the sense strand and/or antisense strand. This interruption of the modification pattern of the sense and/or antisense strand by introducing one or more motifs of three identical modifications on three consecutive nucleotides to the sense and/or antisense strand surprisingly enhances the gene silencing acitivty to the target gene.

In one embodiment, when the motif of three identical modifications on three consecutive nucleotides is introduced to any of the strands, the modification of the nucleotide next to the motif is a different modification than the modification of the motif. For example, the portion of the sequence containing the motif is "...N_aYYYN_b...," where "Y" represents the modification of the motif of three identical modifications on three consecutive nucleotide, and "N_a" and "N_b" represent a modification to the nucleotide next to the motif "YYY" that is different than the modification of Y, and where N_a and N_b can be the same or different modifications. Altnernatively, N_a and/or N_b may be present or absent when there is a wing modification present.

The RNAi agent may further comprise at least one phosphorothioate or methylphosphonate internucleotide linkage. The phosphorothioate or methylphosphonate internucleotide linkage modification may occur on any nucleotide of the sense strand or antisense strand or both strands in any position of the strand. For instance, the internucleotide linkage modification may occur on every nucleotide on the sense strand and/or antisense strand; each internucleotide linkage modification may occur in an alternating pattern on the sense strand and/or antisense strand; or the sense strand or antisense strand may contain both internucleotide linkage modifications in an alternating pattern. The alternating pattern of the internucleotide linkage modification on the sense strand may be the same or different from the antisense strand, and the alternating pattern of the internucleotide linkage modification on the sense strand may have a shift relative to the alternating pattern of the internucleotide linkage modification on the antisense strand.

In one embodiment, the RNAi comprises a phosphorothioate or methylphosphonate internucleotide linkage modification in the overhang region. For example, the overhang region may contain two nucleotides having a phosphorothioate or methylphosphonate internucleotide linkage between the two nucleotides. Internucleotide linkage modifications also may be made to link the overhang nucleotides with the terminal paired nucleotides within the duplex region. For example, at least 2, 3, 4, or all the overhang nucleotides may be linked through phosphorothioate or methylphosphonate internucleotide linkage, and optionally, there may be additional phosphorothioate or methylphosphonate internucleotide linkages linking the overhang nucleotide with a paired nucleotide that is next to the overhang nucleotide. For instance, there may be at least two phosphorothioate internucleotide linkages between the terminal three nucleotides, in which two of the three nucleotides are overhang

nucleotides, and the third is a paired nucleotide next to the overhang nucleotide. These terminal three nucleotides may be at the 3'-end of the antisense strand, the 3'-end of the sense strand, the 5'-end of the antisense strand, and/or the 5'end of the antisense strand.

In one embodiment, the 2 nucleotide overhang is at the 3'-end of the antisense strand, and there are two phosphorothioate internucleotide linkages between the terminal three nucleotides, wherein two of the three nucleotides are the overhang nucleotides, and the third nucleotide is a paired nucleotide next to the overhang nucleotide. Optionally, the RNAi agent may additionally have two phosphorothioate internucleotide linkages between the terminal three nucleotides at both the 5'-end of the sense strand and at the 5'-end of the antisense strand.

In one embodiment, the RNAi agent comprises mismatch(es) with the target, within the duplex, or combinations thereof. The mistmatch may occur in the overhang region or the duplex region. The base pair may be ranked on the basis of their propensity to promote dissociation or melting (*e.g.*, on the free energy of association or dissociation of a particular pairing, the simplest approach is to examine the pairs on an individual pair basis, though next neighbor or similar analysis can also be used). In terms of promoting dissociation: A:U is preferred over G:C; G:U is preferred over G:C; and I:C is preferred over G:C (I=inosine). Mismatches, *e.g.*, non-canonical or other than canonical pairings (as described elsewhere herein) are preferred over canonical (A:T, A:U, G:C) pairings; and pairings which include a universal base are preferred over canonical pairings.

In one embodiment, the RNAi agent comprises at least one of the first 1, 2, 3, 4, or 5 base pairs within the duplex regions from the 5'- end of the antisense strand independently selected from the group of: A:U, G:U, I:C, and mismatched pairs, *e.g.*, non-canonical or other than canonical pairings or pairings which include a universal base, to promote the dissociation of the antisense strand at the 5'-end of the duplex.

In one embodiment, the nucleotide at the 1 position within the duplex region from the 5'-end in the antisense strand is selected from the group consisting of A, dA, dU, U, and dT. Alternatively, at least one of the first 1, 2 or 3 base pair within the duplex region from the 5'-end of the antisense strand is an AU base pair. For example, the first base pair within the duplex region from the 5'- end of the antisense strand is an AU base pair.

In one embodiment, the sense strand sequence may be represented by formula (I):

$5'\ n_p\text{-}N_a\text{-}(X\ X\ X)_i\text{-}N_b\text{-}Y\ Y\ Y\text{-}N_b\text{-}(Z\ Z\ Z)_j\text{-}N_a\text{-}n_q\ 3'$ (I)

wherein:

i and j are each independently 0 or 1;

p and q are each independently 0-6;

each N_a independently represents an oligonucleotide sequence comprising 0-25 modified nucleotides, each sequence comprising at least two differently modified nucleotides;

each N_b independently represents an oligonucleotide sequence comprising 0-10 modified nucleotides;

each n_p and n_q independently represent an overhang nucleotide;

wherein Nb and Y do not have the same modification; and

XXX, YYY and ZZZ each independently represent one motif of three identical modifications on three consecutive nucleotides. Preferably YYY is all 2'-F modified nucleotides.

In one embodiment, the N_a and/or N_b comprise modifications of alternating pattern.

In one embodiment, the YYY motif occurs at or near the cleavage site of the sense strand. For example, when the RNAi agent has a duplex region of 17-23 nucleotides in length, the YYY motif can occur at or the vicinity of the cleavage site (*e.g.*: can occur at positions 6, 7, 8, 7, 8, 9, 8, 9, 10, 9, 10, 11, 10, 11,12 or 11, 12, 13) of - the sense strand, the count starting from the 1st nucleotide, from the 5'-end; or optionally, the count starting at the 1st paired nucleotide within the duplex region, from the 5'- end.

In one embodiment, i is 1 and j is 0, or i is 0 and j is 1, or both i and j are 1. The sense strand can therefore be represented by the following formulas:

5' n_p-N_a-YYY-N_b-ZZZ-N_a-n_q 3' (Ib);

5' n_p-N_a-XXX-N_b-YYY-N_a-n_q 3' (Ic); or

5' n_p-N_a-XXX-N_b-YYY-N_b-ZZZ-N_a-n_q 3' (Id).

When the sense strand is represented by formula (Ib), N_b represents an oligonucleotide sequence comprising 0-10, 0-7, 0-5, 0-4, 0-2 or 0 modified nucleotides. Each N_a independently can represent an oligonucleotide sequence comprising 2-20, 2-15, or 2-10 modified nucleotides.

When the sense strand is represented as formula (Ic), N_b represents an oligonucleotide sequence comprising 0-10, 0-7, 0-10, 0-7, 0-5, 0-4, 0-2 or 0 modified nucleotides. Each N_a can independently represent an oligonucleotide sequence comprising 2-20, 2-15, or 2-10 modified nucleotides.

When the sense strand is represented as formula (Id), each N_b independently represents an oligonucleotide sequence comprising 0-10, 0-7, 0-5, 0-4, 0-2 or 0 modified nucleotides. Preferably, N_b is 0, 1, 2, 3, 4, 5 or 6 Each N_a can independently represent an oligonucleotide sequence comprising 2-20, 2-15, or 2-10 modified nucleotides.

Each of X, Y and Z may be the same or different from each other.

In other embodiments, i is 0 and j is 0, and the sense strand may be represented by the formula:

5' n_p-N_a-YYY- N_a-n_q 3' (Ia).

When the sense strand is represented by formula (Ia), each N_a independently can represent an oligonucleotide sequence comprising 2-20, 2-15, or 2-10 modified nucleotides.

In one embodiment, the antisense strand sequence of the RNAi may be represented by formula (II):

5' $n_{q'}$-N_a'-$(Z'Z'Z')_k$-N_b'-$Y'Y'Y'$-N_b'-$(X'X'X')_l$-N'_a-n_p' 3' (II)

wherein:

k and l are each independently 0 or 1;

p' and q' are each independently 0-6;

each N_a' independently represents an oligonucleotide sequence comprising 0-25 modified nucleotides, each sequence comprising at least two differently modified nucleotides;

each N_b' independently represents an oligonucleotide sequence comprising 0-10 modified nucleotides;

each n_p' and n_q' independently represent an overhang nucleotide;

wherein N_b' and Y' do not have the same modification;

and

X'X'X', Y'Y'Y' and Z'Z'Z' each independently represent one motif of three identical modifications on three consecutive nucleotides.

In one embodiment, the N_a' and/or N_b' comprise modifications of alternating pattern.

The Y'Y'Y' motif occurs at or near the cleavage site of the antisense strand. For example, when the RNAi agent has a duplex region of 17-23nucleotidein length, the Y'Y'Y' motif can occur at positions 9, 10, 11;10, 11, 12; 11, 12, 13; 12, 13, 14 ; or 13, 14, 15 of the antisense strand, with the count starting from the 1st nucleotide, from the 5'-end; or optionally, the count starting at the 1st paired nucleotide within the duplex region, from the 5'- end. Preferably, the Y'Y'Y' motif occurs at positions 11, 12, 13.

In one embodiment, Y'Y'Y' motif is all 2'-OMe modified nucleotides.

In one embodiment, k is 1 and l is 0, or k is 0 and l is 1, or both k and l are 1.

The antisense strand can therefore be represented by the following formulas:

5' $n_{q'}$-N_a'-Z'Z'Z'-N_b'-Y'Y'Y'-N_a'-$n_{p'}$ 3' (IIb);

5' $n_{q'}$-N_a'-Y'Y'Y'-N_b'-X'X'X'-$n_{p'}$ 3' (IIc); or

5' $n_{q'}$-N_a'- Z'Z'Z'-N_b'-Y'Y'Y'-N_b'- X'X'X'-N_a'-$n_{p'}$ 3' (IId).

When the antisense strand is represented by formula (IIb), N_b' represents an oligonucleotide sequence comprising 0-10, 0-7, 0-10, 0-7, 0-5, 0-4, 0-2 or 0 modified nucleotides. Each N_a' independently represents an oligonucleotide sequence comprising 2-20, 2-15, or 2-10 modified nucleotides.

When the antisense strand is represented as formula (IIc), N_b' represents an oligonucleotide sequence comprising 0-10, 0-7, 0-10, 0-7, 0-5, 0-4, 0-2 or 0 modified nucleotides. Each N_a' independently represents an oligonucleotide sequence comprising 2-20, 2-15, or 2-10 modified nucleotides.

When the antisense strand is represented as formula (IId), each N_b' independently represents an oligonucleotide sequence comprising 0-10, 0-7, 0-10, 0-7, 0-5, 0-4, 0-2 or 0 modified nucleotides. Each N_a' independently represents an oligonucleotide sequence comprising 2-20, 2-15, or 2-10 modified nucleotides. Preferably, N_b is 0, 1, 2, 3, 4, 5 or 6.

In other embodiments, k is 0 and l is 0 and the antisense strand may be represented by the formula:

5' $n_{p'}$-$N_{a'}$-Y'Y'Y'- $N_{a'}$-$n_{q'}$ 3' (Ia).

When the antisense strand is represented as formula (IIa), each N_a' independently represents an oligonucleotide sequence comprising 2-20, 2-15, or 2-10 modified nucleotides.

Each of X′, Y′ and Z′ may be the same or different from each other.

Each nucleotide of the sense strand and antisense strand may be independently modified with LNA, HNA, CeNA, 2'-methoxyethyl, 2'-O-methyl, 2'-O-allyl, 2'-C- allyl, 2'-hydroxyl, or 2'-fluoro. For example, each nucleotide of the sense strand and antisense strand is independently modified with 2'-O-methyl or 2'-fluoro. Each X, Y, Z, X′, Y′ and Z′, in particular, may represent a 2'-O-methyl modification or a 2'-fluoro modification.

In one embodiment, the sense strand of the RNAi agent may contain YYY motif occurring at 9, 10 and 11 positions of the strand when the duplex region is 21 nt, the count starting from the 1st nucleotide from the 5'-end, or optionally, the count starting at the 1st paired nucleotide within the duplex region, from the 5'- end; and Y represents 2'-F modification. The sense strand may additionally contain XXX motif or ZZZ motifs as wing modifications at the opposite end of the duplex region; and XXX and ZZZ each independently represents a 2'-OMe modification or 2'-F modification.

In one embodiment the antisense strand may contain Y′Y′Y′ motif occurring at positions 11, 12, 13 of the strand, the count starting from the 1st nucleotide from the 5'-end, or optionally, the count starting at the 1st paired nucleotide within the duplex region, from the 5'- end; and Y′ represents 2'-O-methyl modification. The antisense strand may additionally contain X′X′X′ motif or Z′Z′Z′ motifs as wing modifications at the opposite end of the duplex region; and X′X′X′ and Z′Z′Z′ each independently represents a 2'-OMe modification or 2'-F modification.

The sense strand represented by any one of the above formulas (Ia), (Ib), (Ic), and (Id) forms a duplex with a antisense strand being represented by any one of formulas (IIa), (IIb), (IIc), and (IId), respectively.

Accordingly, the RNAi agents for use in the methods of the invention may comprise a sense strand and an antisense strand, each strand having 14 to 30 nucleotides, the RNAi duplex represented by formula (III):

sense: 5' n_p -N_a-(X X X)$_i$ -N_b- Y Y Y -N_b -(Z Z Z)$_j$-N_a-n_q 3'

antisense: 3' n_p'-N_a'-(X'X'X')$_k$-N_b'-Y'Y'Y'-N_b'-(Z'Z'Z')$_l$-N_a'-n_q' 5'

(III)

wherein:

i, j, k, and l are each independently 0 or 1;

p, p′, q, and q′ are each independently 0-6;

each N_a and N_a' independently represents an oligonucleotide sequence comprising 0-25 modified nucleotides, each sequence comprising at least two differently modified nucleotides;

each N_b and N_b' independently represents an oligonucleotide sequence comprising 0-10 modified nucleotides;

wherein

each n_p', n_p, n_q', and n_q, each of which may or may not be present, independently represents an overhang nucleotide; and

XXX, YYY, ZZZ, X′X′X′, Y′Y′Y′, and Z′Z′Z′ each independently represent one motif of three identical modifications on three consecutive nucleotides.

In one embodiment, i is 0 and j is 0; or i is 1 and j is 0; or i is 0 and j is 1; or both i and j are 0; or both i and j are 1. In another embodiment, k is 0 and l is 0; or k is 1 and l is 0; k is 0 and l is 1; or both k and l are 0; or both k and l are 1.

Exemplary combinations of the sense strand and antisense strand forming a RNAi duplex include the formulas below:

5' n_p - N_a -Y Y Y -N_a-n_q 3'

3' n_p'-N_a'-Y′Y′Y′ -$N_a'$$n_q'$ 5'

(IIIa)

5' n_p -N_a -Y Y Y -N_b -Z Z Z -N_a-n_q 3'

3' n_p'-N_a'-Y′Y′Y′-N_b'-Z′Z′Z′-$N_a'$$n_q'$ 5'

(IIIb)

5' n_p-N_a- X X X -N_b -Y Y Y - N_a-n_q 3'

3' n_p'-N_a'-X′X′X′-N_b'-Y′Y′Y′-N_a'-n_q' 5'

(IIIc)

5' n_p -N_a -X X X -N_b-Y Y Y -N_b- Z Z Z -N_a-n_q 3'

3' n_p'-N_a'-X′X′X′-N_b'-Y′Y′Y′-N_b'-Z′Z′Z′-N_a-n_q' 5'

(IIId)

When the RNAi agent is represented by formula (IIIa), each N_a independently represents an oligonucleotide sequence comprising 2-20, 2-15, or 2-10 modified nucleotides.

When the RNAi agent is represented by formula (IIIb), each N_b independently represents an oligonucleotide sequence comprising 1-10, 1-7, 1-5 or 1-4 modified nucleotides. Each N_a independently represents an oligonucleotide sequence comprising 2-20, 2-15, or 2-10 modified nucleotides.

When the RNAi agent is represented as formula (IIIc), each N_b, N_b' independently represents an oligonucleotide sequence comprising 0-10, 0-7, 0-10, 0-7, 0-5, 0-4, 0-2 or

0modified nucleotides. Each N_a independently represents an oligonucleotide sequence comprising 2-20, 2-15, or 2-10 modified nucleotides.

When the RNAi agent is represented as formula (IIId), each N_b, N_b' independently represents an oligonucleotide sequence comprising 0-10, 0-7, 0-10, 0-7, 0-5, 0-4, 0-2 or 0modified nucleotides. Each N_a, N_a' independently represents an oligonucleotide sequence comprising 2-20, 2-15, or 2-10 modified nucleotides. Each of N_a, N_a', N_b and N_b' independently comprises modifications of alternating pattern.

Each of X, Y and Z in formulas (III), (IIIa), (IIIb), (IIIc), and (IIId) may be the same or different from each other.

When the RNAi agent is represented by formula (III), (IIIa), (IIIb), (IIIc), and (IIId), at least one of the Y nucleotides may form a base pair with one of the Y′ nucleotides. Alternatively, at least two of the Y nucleotides form base pairs with the corresponding Y′ nucleotides; or all three of the Y nucleotides all form base pairs with the corresponding Y′ nucleotides.

When the RNAi agent is represented by formula (IIIb) or (IIId), at least one of the Z nucleotides may form a base pair with one of the Z′ nucleotides. Alternatively, at least two of the Z nucleotides form base pairs with the corresponding Z′ nucleotides; or all three of the Z nucleotides all form base pairs with the corresponding Z′ nucleotides.

When the RNAi agent is represented as formula (IIIc) or (IIId), at least one of the X nucleotides may form a base pair with one of the X′ nucleotides. Alternatively, at least two of the X nucleotides form base pairs with the corresponding X′ nucleotides; or all three of the X nucleotides all form base pairs with the corresponding X′ nucleotides.

In one embodiment, the modification on the Y nucleotide is different than the modification on the Y' nucleotide, the modification on the Z nucleotide is different than the modification on the Z' nucleotide, and/or the modification on the X nucleotide is different than the modification on the X' nucleotide.

In one embodiment, when the RNAi agent is represented by formula (IIId), the N_a modifications are 2′-O-methyl or 2′-fluoro modifications. In another embodiment, when the RNAi agent is represented by formula (IIId), the N_a modifications are 2′-O-methyl or 2′-fluoro modifications and $n_p' > 0$ and at least one n_p' is linked to a neighboring nucleotide a via phosphorothioate linkage. In yet another embodiment, when the RNAi agent is represented by formula (IIId), the N_a modifications are 2′-O-methyl or 2′-fluoro modifications , $n_p' > 0$ and at least one n_p' is linked to a neighboring nucleotide via phosphorothioate linkage, and the sense strand is conjugated to one or more GalNAc derivatives attached through a bivalent or trivalent branched linker. In another embodiment, when the RNAi agent is represented by formula (IIId), the N_a modifications are 2′-O-methyl or 2′-fluoro modifications , $n_p' > 0$ and at least one n_p' is linked to a neighboring nucleotide via phosphorothioate linkage, the sense

strand comprises at least one phosphorothioate linkage, and the sense strand is conjugated to one or more GalNAc derivatives attached through a bivalent or trivalent branched linker.

In one embodiment, when the RNAi agent is represented by formula (IIIa), the N_a modifications are 2′-O-methyl or 2′-fluoro modifications , $n_p' > 0$ and at least one n_p' is linked to a neighboring nucleotide via phosphorothioate linkage, the sense strand comprises at least one phosphorothioate linkage, and the sense strand is conjugated to one or more GalNAc derivatives attached through a bivalent or trivalent branched linker.

In one embodiment, the RNAi agent is a multimer containing at least two duplexes represented by formula (III), (IIIa), (IIIb), (IIIc), and (IIId), wherein the duplexes are connected by a linker. The linker can be cleavable or non-cleavable. Optionally, the multimer further comprises a ligand. Each of the duplexes can target the same gene or two different genes; or each of the duplexes can target same gene at two different target sites.

In one embodiment, the RNAi agent is a multimer containing three, four, five, six or more duplexes represented by formula (III), (IIIa), (IIIb), (IIIc), and (IIId), wherein the duplexes are connected by a linker. The linker can be cleavable or non-cleavable. Optionally, the multimer further comprises a ligand. Each of the duplexes can target the same gene or two different genes; or each of the duplexes can target same gene at two different target sites.

In one embodiment, two RNAi agents represented by formula (III), (IIIa), (IIIb), (IIIc), and (IIId) are linked to each other at the 5' end, and one or both of the 3' ends and are optionally conjugated to to a ligand. Each of the agents can target the same gene or two different genes; or each of the agents can target same gene at two different target sites.

Various publications describe multimeric RNAi agents that can be used in the methods of the invention. Such publications include WO2007/091269, US Patent No. 7858769, WO2010/141511, WO2007/117686, WO2009/014887 and WO2011/031520 the entire contents of each of which are hereby incorporated herein by reference.

The RNAi agent that contains conjugations of one or more carbohydrate moieties to a RNAi agent can optimize one or more properties of the RNAi agent. In many cases, the carbohydrate moiety will be attached to a modified subunit of the RNAi agent. For example, the ribose sugar of one or more ribonucleotide subunits of a dsRNA agent can be replaced with another moiety, *e.g.*, a non-carbohydrate (preferably cyclic) carrier to which is attached a carbohydrate ligand. A ribonucleotide subunit in which the ribose sugar of the subunit has been so replaced is referred to herein as a ribose replacement modification subunit (RRMS). A cyclic carrier may be a carbocyclic ring system, *i.e.*, all ring atoms are carbon atoms, or a heterocyclic ring system, *i.e.*, one or more ring atoms may be a heteroatom, *e.g.*, nitrogen, oxygen, sulfur. The cyclic carrier may be a monocyclic ring system, or may contain two or more rings, *e.g.* fused rings. The cyclic carrier may be a fully saturated ring system, or it may contain one or more double bonds.

The ligand may be attached to the polynucleotide via a carrier. The carriers include (i) at least one "backbone attachment point," preferably two "backbone attachment points" and (ii) at least one "tethering attachment point." A "backbone attachment point" as used herein refers to a functional group, *e.g.* a hydroxyl group, or generally, a bond available for, and that is suitable for incorporation of the carrier into the backbone, *e.g.*, the phosphate, or modified phosphate, *e.g.*, sulfur containing, backbone, of a ribonucleic acid. A "tethering attachment point" (TAP) in some embodiments refers to a constituent ring atom of the cyclic carrier, *e.g.*, a carbon atom or a heteroatom (distinct from an atom which provides a backbone attachment point), that connects a selected moiety. The moiety can be, *e.g.*, a carbohydrate, *e.g.* monosaccharide, disaccharide, trisaccharide, tetrasaccharide, oligosaccharide and polysaccharide. Optionally, the selected moiety is connected by an intervening tether to the cyclic carrier. Thus, the cyclic carrier will often include a functional group, *e.g.*, an amino group, or generally, provide a bond, that is suitable for incorporation or tethering of another chemical entity, *e.g.*, a ligand to the constituent ring.

The RNAi agents may be conjugated to a ligand *via* a carrier, wherein the carrier can be cyclic group or acyclic group; preferably, the cyclic group is selected from pyrrolidinyl, pyrazolinyl, pyrazolidinyl, imidazolinyl, imidazolidinyl, piperidinyl, piperazinyl, [1,3]dioxolane, oxazolidinyl, isoxazolidinyl, morpholinyl, thiazolidinyl, isothiazolidinyl, quinoxalinyl, pyridazinonyl, tetrahydrofuryl and and decalin; preferably, the acyclic group is selected from serinol backbone or diethanolamine backbone.

In certain specific embodiments, the RNAi agent for use in the methods of the invention is an agent selected from the group of agents listed in any one of Tables 1, 2, 4, 5, 8, 10, and 12. In one embodiment, when the agent is an agent listed in Table 12, the agent may lack a terminal dT.

The present invention further includes double-stranded RNAi agents comprising any one of the sequences listed in any one of Tables 1, 2, 4, 5, 8, 10, and 12 which comprise a 5' phosphate or phosphate mimetic on the antisense strand (see, *e.g.,* PCT Publication No. WO 2011005860). Further, the present invention includes double-stranded RNAi agents comprising any one of the sequences listed in any one of Tables 1, 2, 4, 5, 8, 10, and 12 which include a 2'fluoro group in place of a 2'-OMe group at the 5'end of the sense strand.

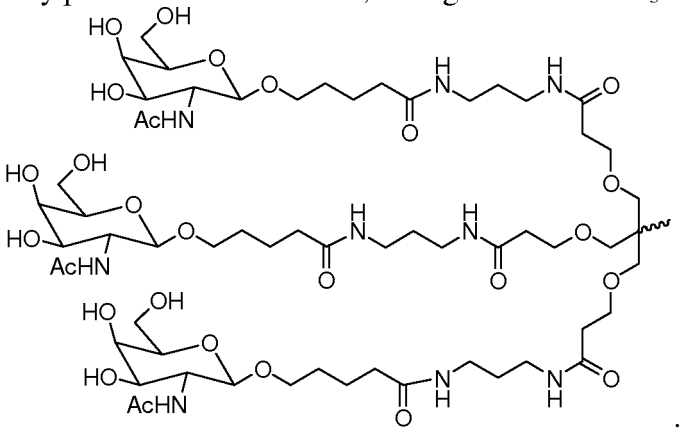
These agents may further comprise a ligand.

In one embodiment, the agent is AD-60940 (sense strand: CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96; antisense strand: usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg).

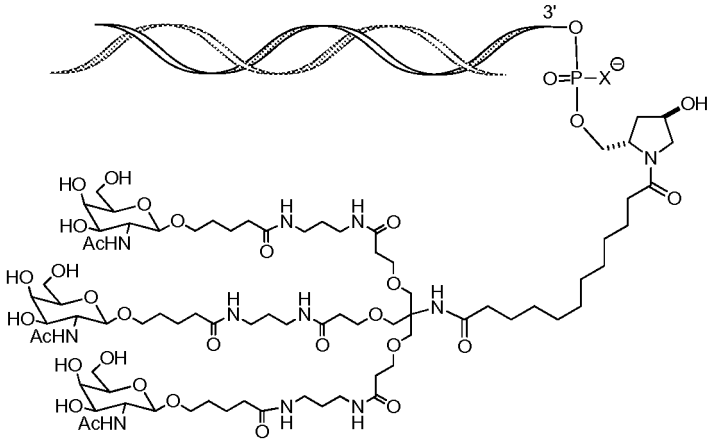
A. Ligands

The double-stranded RNA (dsRNA) agents of the invention may optionally be conjugated to one or more ligands. The ligand can be attached to the sense strand, antisense strand or both strands, at the 3'-end, 5'-end or both ends. For instance, the ligand may be

conjugated to the sense strand. In preferred embodiments, the ligand is conjgated to the 3'-end of the sense strand. In one preferred embodiment, the ligand is a GalNAc ligand. In particularly preferred embodiments, the ligand is $GalNAc_3$:



In some embodiments, the ligand, *e.g.*, GalNAc ligand, is attached to the 3′ end of the RNAi agent. In one embodiment, the RNAi agent is conjugated to the ligand, *e.g.*, GalNAc ligand, as shown in the following schematic



wherein X is O or S. In one embodiment, X is O.

A wide variety of entities can be coupled to the RNAi agents of the present invention. Preferred moieties are ligands, which are coupled, preferably covalently, either directly or indirectly *via* an intervening tether.

In preferred embodiments, a ligand alters the distribution, targeting or lifetime of the molecule into which it is incorporated. In preferred embodiments a ligand provides an enhanced affinity for a selected target, *e.g.*, molecule, cell or cell type, compartment, receptor *e.g.*, a cellular or organ compartment, tissue, organ or region of the body, as, *e.g.*, compared to a species absent such a ligand. Ligands providing enhanced affinity for a selected target are also termed targeting ligands.

Some ligands can have endosomolytic properties. The endosomolytic ligands promote the lysis of the endosome and/or transport of the composition of the invention, or its components, from the endosome to the cytoplasm of the cell. The endosomolytic ligand may be a polyanionic peptide or peptidomimetic which shows pH-dependent membrane activity

and fusogenicity. In one embodiment, the endosomolytic ligand assumes its active conformation at endosomal pH. The "active" conformation is that conformation in which the endosomolytic ligand promotes lysis of the endosome and/or transport of the composition of the invention, or its components, from the endosome to the cytoplasm of the cell. Exemplary endosomolytic ligands include the GALA peptide (Subbarao *et al.*, *Biochemistry*, 1987, 26: 2964-2972), the EALA peptide (Vogel *et al.*, *J. Am. Chem. Soc.*, 1996, 118: 1581-1586), and their derivatives (Turk *et al.*, *Biochem. Biophys. Acta*, 2002, 1559: 56-68). In one embodiment, the endosomolytic component may contain a chemical group (*e.g.*, an amino acid) which will undergo a change in charge or protonation in response to a change in pH. The endosomolytic component may be linear or branched.

Ligands can improve transport, hybridization, and specificity properties and may also improve nuclease resistance of the resultant natural or modified oligoribonucleotide, or a polymeric molecule comprising any combination of monomers described herein and/or natural or modified ribonucleotides.

Ligands in general can include therapeutic modifiers, *e.g.*, for enhancing uptake; diagnostic compounds or reporter groups *e.g.*, for monitoring distribution; cross-linking agents; and nuclease-resistance conferring moieties. General examples include lipids, steroids, vitamins, sugars, proteins, peptides, polyamines, and peptide mimics.

Ligands can include a naturally occurring substance, such as a protein (*e.g.*, human serum albumin (HSA), low-density lipoprotein (LDL), high-density lipoprotein (HDL), or globulin); a carbohydrate (*e.g.*, a dextran, pullulan, chitin, chitosan, inulin, cyclodextrin or hyaluronic acid); or a lipid. The ligand may also be a recombinant or synthetic molecule, such as a synthetic polymer, *e.g.*, a synthetic polyamino acid, an oligonucleotide (*e.g.*, an aptamer). Examples of polyamino acids include polyamino acid is a polylysine (PLL), poly L-aspartic acid, poly L-glutamic acid, styrene-maleic acid anhydride copolymer, poly(L-lactide-co-glycolied) copolymer, divinyl ether-maleic anhydride copolymer, N-(2-hydroxypropyl)methacrylamide copolymer (HMPA), polyethylene glycol (PEG), polyvinyl alcohol (PVA), polyurethane, poly(2-ethylacryllic acid), N-isopropylacrylamide polymers, or polyphosphazine. Example of polyamines include: polyethylenimine, polylysine (PLL), spermine, spermidine, polyamine, pseudopeptide-polyamine, peptidomimetic polyamine, dendrimer polyamine, arginine, amidine, protamine, cationic lipid, cationic porphyrin, quaternary salt of a polyamine, or an alpha helical peptide.

Ligands can also include targeting groups, *e.g.*, a cell or tissue targeting agent, *e.g.*, a lectin, glycoprotein, lipid or protein, *e.g.*, an antibody, that binds to a specified cell type such as a kidney cell. A targeting group can be a thyrotropin, melanotropin, lectin, glycoprotein, surfactant protein A, Mucin carbohydrate, multivalent lactose, multivalent galactose, N-acetyl-galactosamine, N-acetyl-gulucosamine multivalent mannose, multivalent fucose, glycosylated polyaminoacids, multivalent galactose, transferrin, bisphosphonate,

polyglutamate, polyaspartate, a lipid, cholesterol, a steroid, bile acid, folate, vitamin B12, biotin, an RGD peptide, an RGD peptide mimetic or an aptamer.

Other examples of ligands include dyes, intercalating agents (*e.g.*, acridines), cross-linkers (*e.g.*, psoralene, mitomycin C), porphyrins (TPPC4, texaphyrin, Sapphyrin), polycyclic aromatic hydrocarbons (*e.g.*, phenazine, dihydrophenazine), artificial endonucleases or a chelator (*e.g.*, EDTA), lipophilic molecules, *e.g.*, cholesterol, cholic acid, adamantane acetic acid, 1-pyrene butyric acid, dihydrotestosterone, 1,3-Bis-O(hexadecyl)glycerol, geranyloxyhexyl group, hexadecylglycerol, borneol, menthol, 1,3-propanediol, heptadecyl group, palmitic acid, myristic acid,O3-(oleoyl)lithocholic acid, O3-(oleoyl)cholenic acid, dimethoxytrityl, or phenoxazine)and peptide conjugates (*e.g.*, antennapedia peptide, Tat peptide), alkylating agents, phosphate, amino, mercapto, PEG (*e.g.*, PEG-40K), MPEG, $[MPEG]_2$, polyamino, alkyl, substituted alkyl, radiolabeled markers, enzymes, haptens (*e.g.*, biotin), transport/absorption facilitators (*e.g.*, aspirin, vitamin E, folic acid), synthetic ribonucleases (*e.g.*, imidazole, bisimidazole, histamine, imidazole clusters, acridine-imidazole conjugates, Eu3+ complexes of tetraazamacrocycles), dinitrophenyl, HRP, or AP.

Ligands can be proteins, *e.g.*, glycoproteins, or peptides, *e.g.*, molecules having a specific affinity for a co-ligand, or antibodies *e.g.*, an antibody, that binds to a specified cell type such as a cancer cell, endothelial cell, or bone cell. Ligands may also include hormones and hormone receptors. They can also include non-peptidic species, such as lipids, lectins, carbohydrates, vitamins, cofactors, multivalent lactose, multivalent galactose, N-acetyl-galactosamine, N-acetyl-gulucosamine multivalent mannose, multivalent fucose, or aptamers. The ligand can be, for example, a lipopolysaccharide, an activator of p38 MAP kinase, or an activator of NF-κB.

The ligand can be a substance, *e.g.*, a drug, which can increase the uptake of the iRNA agent into the cell, for example, by disrupting the cell's cytoskeleton, *e.g.*, by disrupting the cell's microtubules, microfilaments, and/or intermediate filaments. The drug can be, for example, taxon, vincristine, vinblastine, cytochalasin, nocodazole, japlakinolide, latrunculin A, phalloidin, swinholide A, indanocine, or myoservin.

The ligand can increase the uptake of the oligonucleotide into the cell by, for example, activating an inflammatory response. Exemplary ligands that would have such an effect include tumor necrosis factor alpha (TNFalpha), interleukin-1 beta, or gamma interferon.

In one aspect, the ligand is a lipid or lipid-based molecule. Such a lipid or lipid-based molecule preferably binds a serum protein, *e.g.*, human serum albumin (HSA). An HSA binding ligand allows for distribution of the conjugate to a target tissue, *e.g.*, a non-kidney target tissue of the body. For example, the target tissue can be the liver, including parenchymal cells of the liver. Other molecules that can bind HSA can also be used as

ligands. For example, naproxen or aspirin can be used. A lipid or lipid-based ligand can (a) increase resistance to degradation of the conjugate, (b) increase targeting or transport into a target cell or cell membrane, and/or (c) can be used to adjust binding to a serum protein, *e.g.*, HSA.

A lipid based ligand can be used to modulate, *e.g.*, control the binding of the conjugate to a target tissue. For example, a lipid or lipid-based ligand that binds to HSA more strongly will be less likely to be targeted to the kidney and therefore less likely to be cleared from the body. A lipid or lipid-based ligand that binds to HSA less strongly can be used to target the conjugate to the kidney.

In a preferred embodiment, the lipid based ligand binds HSA. Preferably, it binds HSA with a sufficient affinity such that the conjugate will be preferably distributed to a non-kidney tissue. However, it is preferred that the affinity not be so strong that the HSA-ligand binding cannot be reversed.

In another preferred embodiment, the lipid based ligand binds HSA weakly or not at all, such that the conjugate will be preferably distributed to the kidney. Other moieties that target to kidney cells can also be used in place of or in addition to the lipid based ligand.

In another aspect, the ligand is a moiety, *e.g.*, a vitamin, which is taken up by a target cell, *e.g.*, a proliferating cell. These are particularly useful for treating disorders characterized by unwanted cell proliferation, *e.g.*, of the malignant or non-malignant type, *e.g.*, cancer cells. Exemplary vitamins include vitamin A, E, and K. Other exemplary vitamins include B vitamins, *e.g.*, folic acid, B12, riboflavin, biotin, pyridoxal or other vitamins or nutrients taken up by cancer cells. Also included are HAS, low density lipoprotein (LDL) and high-density lipoprotein (HDL).

In another aspect, the ligand is a cell-permeation agent, preferably a helical cell-permeation agent. Preferably, the agent is amphipathic. An exemplary agent is a peptide such as tat or antennopedia. If the agent is a peptide, it can be modified, including a peptidylmimetic, invertomers, non-peptide or pseudo-peptide linkages, and use of D-amino acids. The helical agent is preferably an alpha-helical agent, which preferably has a lipophilic and a lipophobic phase.

The ligand can be a peptide or peptidomimetic. A peptidomimetic (also referred to herein as an oligopeptidomimetic) is a molecule capable of folding into a defined three-dimensional structure similar to a natural peptide. The peptide or peptidomimetic moiety can be about 5-50 amino acids long, *e.g.*, about 5, 10, 15, 20, 25, 30, 35, 40, 45, or 50 amino acids long. A peptide or peptidomimetic can be, for example, a cell permeation peptide, cationic peptide, amphipathic peptide, or hydrophobic peptide (*e.g.*, consisting primarily of Tyr, Trp or Phe). The peptide moiety can be a dendrimer peptide, constrained peptide or crosslinked peptide. In another alternative, the peptide moiety can include a hydrophobic membrane translocation sequence (MTS). An exemplary hydrophobic MTS-containing

peptide is RFGF having the amino acid sequence AAVALLPAVLLALLAP (SEQ ID NO: 11). An RFGF analogue (*e.g.*, amino acid sequence AALLPVLLAAP (SEQ ID NO: 12)) containing a hydrophobic MTS can also be a targeting moiety. The peptide moiety can be a "delivery" peptide, which can carry large polar molecules including peptides, oligonucleotides, and protein across cell membranes. For example, sequences from the HIV Tat protein (GRKKRRQRRRPPQ) (SEQ ID NO: 13) and the Drosophila Antennapedia protein (RQIKIWFQNRRMKWKK) (SEQ ID NO: 14) have been found to be capable of functioning as delivery peptides. A peptide or peptidomimetic can be encoded by a random sequence of DNA, such as a peptide identified from a phage-display library, or one-bead-one-compound (OBOC) combinatorial library (Lam *et al.*, *Nature*, 354:82-84, 1991). Preferably the peptide or peptidomimetic tethered to an iRNA agent via an incorporated monomer unit is a cell targeting peptide such as an arginine-glycine-aspartic acid (RGD)-peptide, or RGD mimic. A peptide moiety can range in length from about 5 amino acids to about 40 amino acids. The peptide moieties can have a structural modification, such as to increase stability or direct conformational properties. Any of the structural modifications described below can be utilized.An RGD peptide moiety can be used to target a tumor cell, such as an endothelial tumor cell or a breast cancer tumor cell (Zitzmann *et al.*, *Cancer Res.*, 62:5139-43, 2002). An RGD peptide can facilitate targeting of an iRNA agent to tumors of a variety of other tissues, including the lung, kidney, spleen, or liver (Aoki *et al.*, *Cancer Gene Therapy* 8:783-787, 2001). Preferably, the RGD peptide will facilitate targeting of an iRNA agent to the kidney. The RGD peptide can be linear or cyclic, and can be modified, *e.g.*, glycosylated or methylated to facilitate targeting to specific tissues. For example, a glycosylated RGD peptide can deliver an iRNA agent to a tumor cell expressing $\alpha_V\beta_3$ (Haubner *et al.*, *Jour. Nucl. Med.*, 42:326-336, 2001). Peptides that target markers enriched in proliferating cells can be used. For example, RGD containing peptides and peptidomimetics can target cancer cells, in particular cells that exhibit an integrin. Thus, one could use RGD peptides, cyclic peptides containing RGD, RGD peptides that include D-amino acids, as well as synthetic RGD mimics. In addition to RGD, one can use other moieties that target the integrin ligand. Generally, such ligands can be used to control proliferating cells and angiogeneis. Preferred conjugates of this type of ligand target PECAM-1, VEGF, or other cancer gene, *e.g.*, a cancer gene described herein.

A "cell permeation peptide" is capable of permeating a cell, *e.g.*, a microbial cell, such as a bacterial or fungal cell, or a mammalian cell, such as a human cell. A microbial cell-permeating peptide can be, for example, an α-helical linear peptide (*e.g.*, LL-37 or Ceropin P1), a disulfide bond-containing peptide (*e.g.*, α -defensin, β-defensin or bactenecin), or a peptide containing only one or two dominating amino acids (*e.g.*, PR-39 or indolicidin). A cell permeation peptide can also include a nuclear localization signal (NLS). For example, a cell permeation peptide can be a bipartite amphipathic peptide, such as MPG, which is

derived from the fusion peptide domain of HIV-1 gp41 and the NLS of SV40 large T antigen (Simeoni et al., Nucl. Acids Res. 31:2717-2724, 2003).

In one embodiment, a targeting peptide can be an amphipathic α-helical peptide. Exemplary amphipathic α-helical peptides include, but are not limited to, cecropins, lycotoxins, paradaxins, buforin, CPF, bombinin-like peptide (BLP), cathelicidins, ceratotoxins, S. clava peptides, hagfish intestinal antimicrobial peptides (HFIAPs), magainines, brevinins-2, dermaseptins, melittins, pleurocidin, H_2A peptides, Xenopus peptides, esculentinis-1, and caerins. A number of factors will preferably be considered to maintain the integrity of helix stability. For example, a maximum number of helix stabilization residues will be utilized (*e.g.*, leu, ala, or lys), and a minimum number helix destabilization residues will be utilized (*e.g.*, proline, or cyclic monomeric units. The capping residue will be considered (for example Gly is an exemplary N-capping residue and/or C-terminal amidation can be used to provide an extra H-bond to stabilize the helix. Formation of salt bridges between residues with opposite charges, separated by i ± 3, or i ± 4 positions can provide stability. For example, cationic residues such as lysine, arginine, homo-arginine, ornithine or histidine can form salt bridges with the anionic residues glutamate or aspartate.

Peptide and peptidomimetic ligands include those having naturally occurring or modified peptides, *e.g.*, D or L peptides; α, β, or γ peptides; N-methyl peptides; azapeptides; peptides having one or more amide, *i.e.*, peptide, linkages replaced with one or more urea, thiourea, carbamate, or sulfonyl urea linkages; or cyclic peptides.

The targeting ligand can be any ligand that is capable of targeting a specific receptor. Examples are: folate, GalNAc, galactose, mannose, mannose-6P, clusters of sugars such as GalNAc cluster, mannose cluster, galactose cluster, or an apatamer. A cluster is a combination of two or more sugar units. The targeting ligands also include integrin receptor ligands, Chemokine receptor ligands, transferrin, biotin, serotonin receptor ligands, PSMA, endothelin, GCPII, somatostatin, LDL and HDL ligands. The ligands can also be based on nucleic acid, *e.g.*, an aptamer. The aptamer can be unmodified or have any combination of modifications disclosed herein.

Endosomal release agents include imidazoles, poly or oligoimidazoles, PEIs, peptides, fusogenic peptides, polycaboxylates, polyacations, masked oligo or poly cations or anions, acetals, polyacetals, ketals/polyketyals, orthoesters, polymers with masked or unmasked cationic or anionic charges, dendrimers with masked or unmasked cationic or anionic charges.

PK modulator stands for pharmacokinetic modulator. PK modulators include lipophiles, bile acids, steroids, phospholipid analogues, peptides, protein binding agents, PEG, vitamins etc. Examplary PK modulators include, but are not limited to, cholesterol, fatty acids, cholic acid, lithocholic acid, dialkylglycerides, diacylglyceride, phospholipids,

sphingolipids, naproxen, ibuprofen, vitamin E, biotin etc. Oligonucleotides that comprise a number of phosphorothioate linkages are also known to bind to serum protein, thus short oligonucleotides, *e.g.*, oligonucleotides of about 5 bases, 10 bases, 15 bases or 20 bases, comprising multiple phosphorothioate linkages in the backbaone are also amenable to the present invention as ligands (*e.g.*, as PK modulating ligands).

In addition, aptamers that bind serum components (*e.g.*, serum proteins) are also amenable to the present invention as PK modulating ligands.

Other ligand conjugates amenable to the invention are described in U.S. Patent Applications USSN: 10/916,185, filed August 10, 2004; USSN: 10/946,873, filed September 21, 2004; USSN: 10/833,934, filed August 3, 2007; USSN: 11/115,989 filed April 27, 2005 and USSN: 11/944,227 filed November 21, 2007, which are incorporated by reference in their entireties for all purposes.

When two or more ligands are present, the ligands can all have same properties, all have different properties or some ligands have the same properties while others have different properties. For example, a ligand can have targeting properties, have endosomolytic activity or have PK modulating properties. In a preferred embodiment, all the ligands have different properties.

Ligands can be coupled to the oligonucleotides at various places, for example, 3'-end, 5'-end, and/or at an internal position. In preferred embodiments, the ligand is attached to the oligonucleotides *via* an intervening tether, *e.g.*, a carrier described herein. The ligand or tethered ligand may be present on a monomer when the monomer is incorporated into the growing strand. In some embodiments, the ligand may be incorporated via coupling to a "precursor" monomer after the "precursor" monomer has been incorporated into the growing strand. For example, a monomer having, *e.g.*, an amino-terminated tether (*i.e.*, having no associated ligand), *e.g.*, TAP-$(CH_2)_nNH_2$ may be incorporated into a growing oligonucelotide strand. In a subsequent operation, *i.e.*, after incorporation of the precursor monomer into the strand, a ligand having an electrophilic group, *e.g.*, a pentafluorophenyl ester or aldehyde group, can subsequently be attached to the precursor monomer by coupling the electrophilic group of the ligand with the terminal nucleophilic group of the precursor monomer's tether.

In another example, a monomer having a chemical group suitable for taking part in Click Chemistry reaction may be incorporated, *e.g.*, an azide or alkyne terminated tether/linker. In a subsequent operation, *i.e.*, after incorporation of the precursor monomer into the strand, a ligand having complementary chemical group, *e.g.* an alkyne or azide can be attached to the precursor monomer by coupling the alkyne and the azide together.

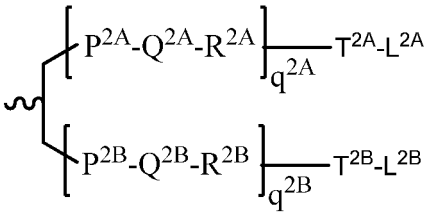
For double- stranded oligonucleotides, ligands can be attached to one or both strands. In some embodiments, a double-stranded iRNA agent contains a ligand conjugated to the sense strand. In other embodiments, a double-stranded iRNA agent contains a ligand conjugated to the antisense strand.

In some embodiments, ligand can be conjugated to nucleobases, sugar moieties, or internucleosidic linkages of nucleic acid molecules. Conjugation to purine nucleobases or derivatives thereof can occur at any position including, endocyclic and exocyclic atoms. In some embodiments, the 2-, 6-, 7-, or 8-positions of a purine nucleobase are attached to a conjugate moiety. Conjugation to pyrimidine nucleobases or derivatives thereof can also occur at any position. In some embodiments, the 2-, 5-, and 6-positions of a pyrimidine nucleobase can be substituted with a conjugate moiety. Conjugation to sugar moieties of nucleosides can occur at any carbon atom. Example carbon atoms of a sugar moiety that can be attached to a conjugate moiety include the 2', 3', and 5' carbon atoms. The 1' position can also be attached to a conjugate moiety, such as in an abasic residue. Internucleosidic linkages can also bear conjugate moieties. For phosphorus-containing linkages (*e.g.*, phosphodiester, phosphorothioate, phosphorodithiotate, phosphoroamidate, and the like), the conjugate moiety can be attached directly to the phosphorus atom or to an O, N, or S atom bound to the phosphorus atom. For amine- or amide-containing internucleosidic linkages (*e.g.*, PNA), the conjugate moiety can be attached to the nitrogen atom of the amine or amide or to an adjacent carbon atom.

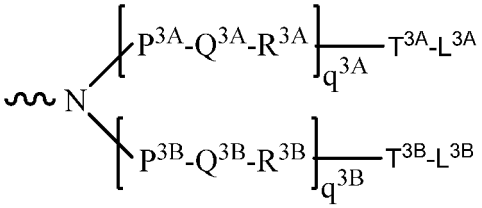
Any suitable ligand in the field of RNA interference may be used, although the ligand is typically a carbohydrate *e.g.* monosaccharide (such as GalNAc), disaccharide, trisaccharide, tetrasaccharide, polysaccharide.

Linkers that conjugate the ligand to the nucleic acid include those discussed above. For example, the ligand can be one or more GalNAc (*N*-acetylglucosamine) derivatives attached through a bivalent or trivalent branched linker.

In one embodiment, the dsRNA of the invention is conjugated to a bivalent and trivalent branched linkers include the structures shown in any of formula (IV) – (VII):

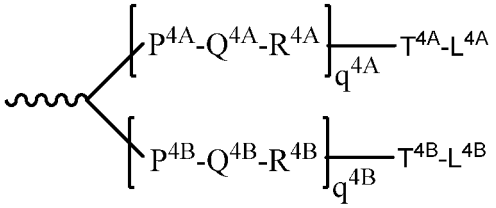


Formula (IV)



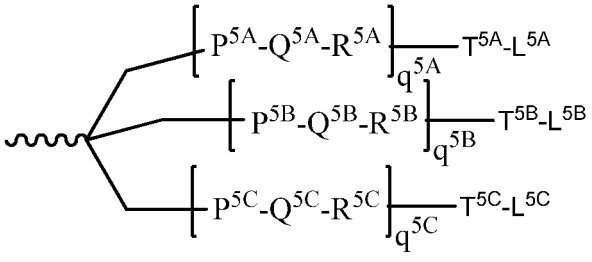
Formula (V)

,



Formula (VI)

, or



Formula (VII)

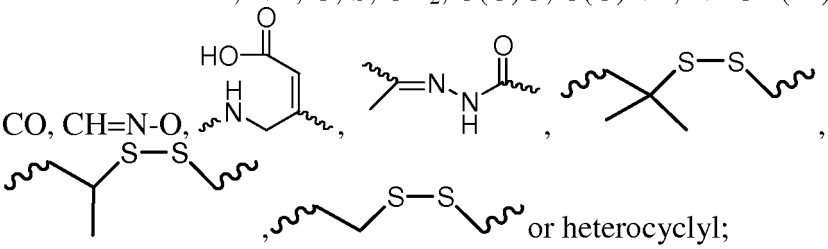
;

wherein:

q^{2A}, q^{2B}, q^{3A}, q^{3B}, $q4^{A}$, q^{4B}, q^{5A}, q^{5B} and q^{5C} represent independently for each occurrence 0-20 and wherein the repeating unit can be the same or different;

P^{2A}, P^{2B}, P^{3A}, P^{3B}, P^{4A}, P^{4B}, P^{5A}, P^{5B}, P^{5C}, T^{2A}, T^{2B}, T^{3A}, T^{3B}, T^{4A}, T^{4B}, T^{4A}, T^{5B}, T^{5C} are each independently for each occurrence absent, CO, NH, O, S, OC(O), NHC(O), CH_2, CH_2NH or CH_2O;

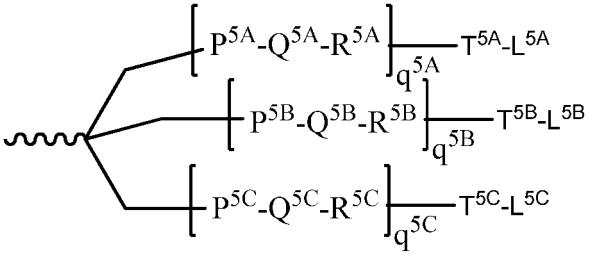
Q^{2A}, Q^{2B}, Q^{3A}, Q^{3B}, Q^{4A}, Q^{4B}, Q^{5A}, Q^{5B}, Q^{5C} are independently for each occurrence absent, alkylene, substituted alkylene wherin one or more methylenes can be interrupted or terminated by one or more of O, S, S(O), SO_2, $N(R^N)$, C(R')=C(R''), C≡C or C(O);

R^{2A}, R^{2B}, R^{3A}, R^{3B}, R^{4A}, R^{4B}, R^{5A}, R^{5B}, R^{5C} are each independently for each occurrence absent, NH, O, S, CH_2, C(O)O, C(O)NH, NHCH(R^a)C(O), -C(O)-CH(R^a)-NH-, CO, CH=N-O, , or heterocyclyl;

L^{2A}, L^{2B}, L^{3A}, L^{3B}, L^{4A}, L^{4B}, L^{5A}, L^{5B} and L^{5C} represent the ligand; *i.e.* each independently for each occurrence a monosaccharide (such as GalNAc), disaccharide, trisaccharide, tetrasaccharide, oligosaccharide, or polysaccharide; and

R^a is H or amino acid side chain.

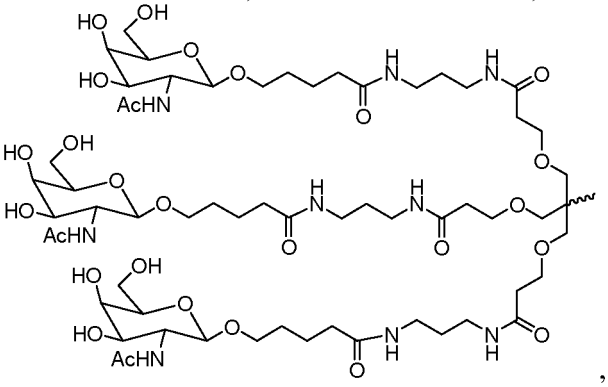
Trivalent conjugating GalNAc derivatives are particularly useful for use with RNAi agents for inhibiting the expression of a target gene, such as those of formula (VII):



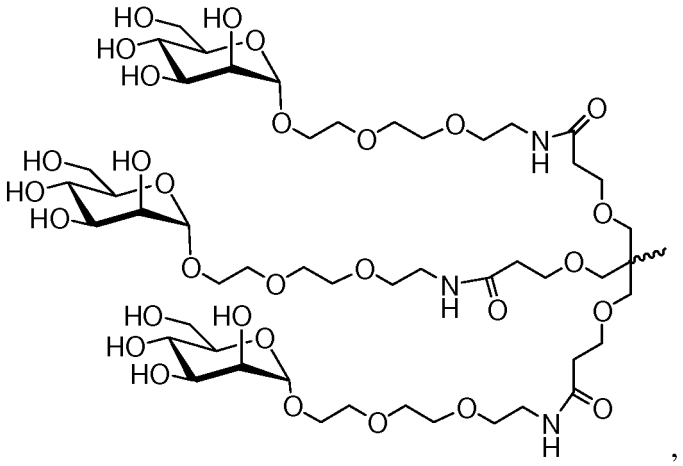
Formula (VII)

,

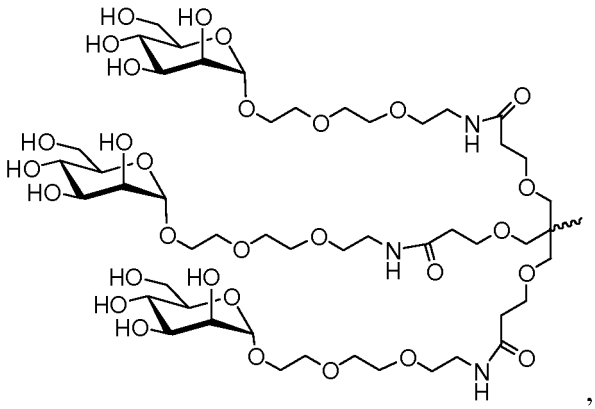
wherein L^{5A}, L^{5B} and L^{5C} represent a monosaccharide, such as GalNAc derivative. Examples of suitable bivalent and trivalent branched linker groups conjugating GalNAc derivatives include, but are not limited to, the following compounds:



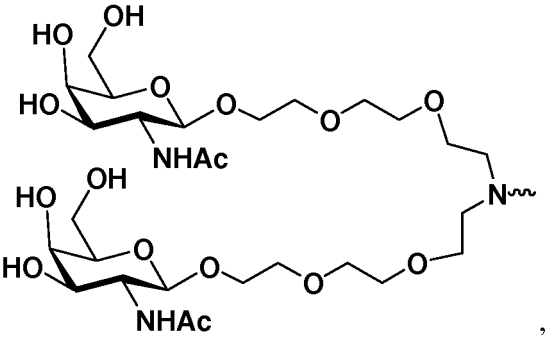
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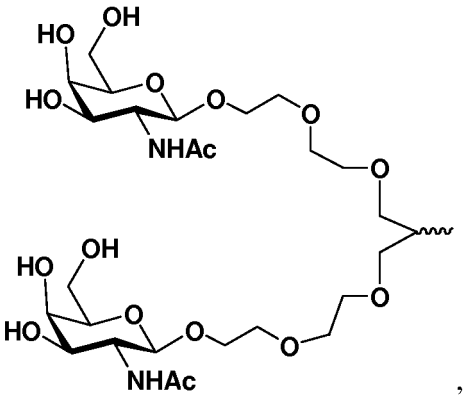
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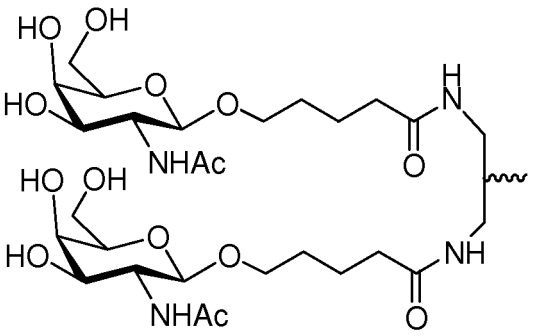
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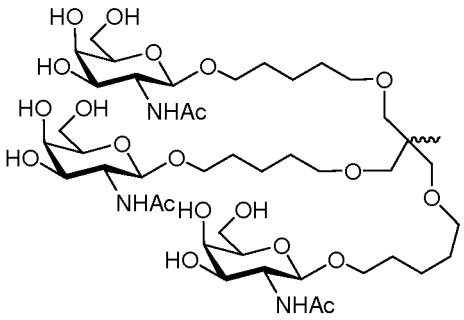
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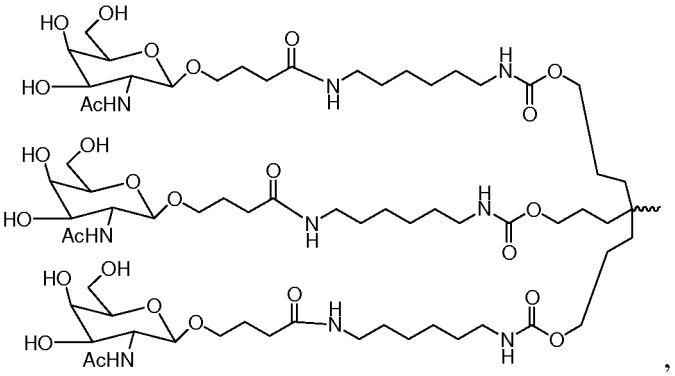


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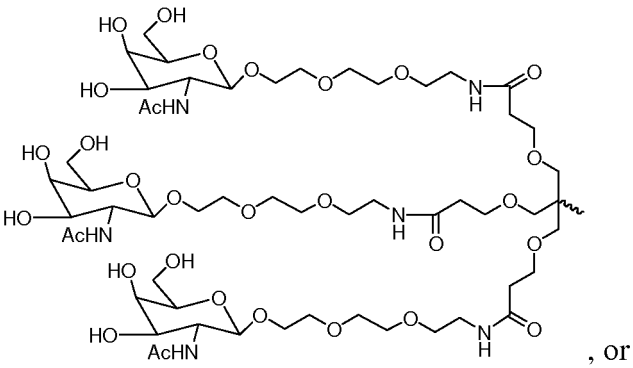


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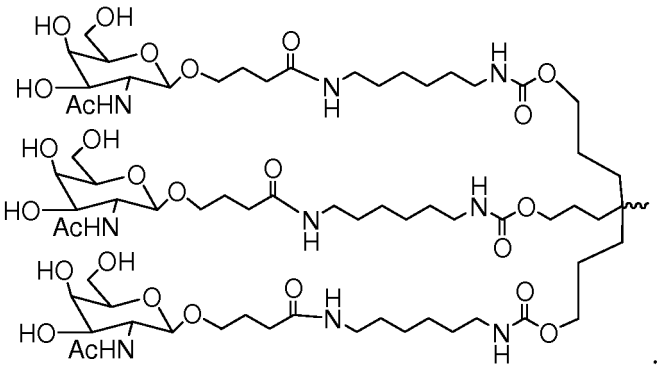




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, or



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In other embodiments, the RNAi agent for use in the methods of the invention is AD-59743.

III. Delivery of an iRNA of the Invention

The delivery of an iRNA agent of the invention to a cell *e.g.,* a cell within a subject, such as a human subject (*e.g.,* a subject in need thereof, such as a subject having a TMPRSS6 associated disorder, such as a hemochromatosis) can be achieved in a number of different ways. For example, delivery may be performed by contacting a cell with an iRNA of the invention either *in vitro* or *in vivo*. *In vivo* delivery may also be performed directly by administering a composition comprising an iRNA, *e.g.,* a dsRNA, to a subject. Alternatively, *in vivo* delivery may be performed indirectly by administering one or more vectors that encode and direct the expression of the iRNA. These alternatives are discussed further below.

In general, any method of delivering a nucleic acid molecule (*in vitro* or *in vivo*) can be adapted for use with an iRNA of the invention (see *e.g.*, Akhtar S. and Julian RL. (1992) *Trends Cell. Biol.* 2(5):139-144 and WO94/02595, which are incorporated herein by reference in their entireties). For *in vivo* delivery, factors to consider in order to deliver an iRNA molecule include, for example, biological stability of the delivered molecule, prevention of non-specific effects, and accumulation of the delivered molecule in the target tissue. The non-specific effects of an iRNA can be minimized by local administration, for example, by direct injection or implantation into a tissue or topically administering the preparation. Local administration to a treatment site maximizes local concentration of the agent, limits the exposure of the agent to systemic tissues that can otherwise be harmed by the agent or that can degrade the agent, and permits a lower total dose of the iRNA molecule to be administered. Several studies have shown successful knockdown of gene products when an iRNA is administered locally. For example, intraocular delivery of a VEGF dsRNA by intravitreal injection in cynomolgus monkeys (Tolentino, MJ., *et al* (2004) *Retina* 24:132-138) and subretinal injections in mice (Reich, SJ., *et al* (2003) *Mol. Vis.* 9:210-216) were both shown to prevent neovascularization in an experimental model of age-related macular degeneration. In addition, direct intratumoral injection of a dsRNA in mice reduces tumor volume (Pille, J., *et al* (2005) *Mol. Ther.*11:267-274) and can prolong survival of tumor-bearing mice (Kim, WJ., *et al* (2006) *Mol. Ther.* 14:343-350; Li, S., *et al* (2007) *Mol. Ther.* 15:515-523). RNA interference has also shown success with local delivery to the CNS by direct injection (Dorn, G., *et al.* (2004) *Nucleic Acids* 32:e49; Tan, PH., *et al* (2005) *Gene Ther.* 12:59-66; Makimura, H., *et al* (2002) *BMC Neurosci.* 3:18; Shishkina, GT., *et al* (2004) *Neuroscience* 129:521-528; Thakker, ER., *et al* (2004) *Proc. Natl. Acad. Sci. U.S.A.* 101:17270-17275; Akaneya,Y., *et al* (2005) *J. Neurophysiol.* 93:594-602) and to the lungs by intranasal administration (Howard, KA., *et al* (2006) *Mol. Ther.* 14:476-484; Zhang, X., *et al* (2004) *J. Biol. Chem.* 279:10677-10684; Bitko, V., *et al* (2005) *Nat. Med.* 11:50-55). For administering an iRNA systemically for the treatment of a disease, the RNA can be modified or alternatively delivered using a drug delivery system; both methods act to prevent the rapid degradation of the dsRNA by endo- and exo-nucleases *in vivo*. Modification of the RNA or the pharmaceutical carrier can also permit targeting of the iRNA composition to the target tissue and avoid undesirable off-target effects. iRNA molecules can be modified by chemical conjugation to lipophilic groups such as cholesterol to enhance cellular uptake and prevent degradation. For example, an iRNA directed against ApoB conjugated to a lipophilic cholesterol moiety was injected systemically into mice and resulted in knockdown of apoB mRNA in both the liver and jejunum (Soutschek, J., *et al* (2004) *Nature* 432:173-178). Conjugation of an iRNA to an aptamer has been shown to inhibit tumor growth and mediate tumor regression in a mouse model of prostate cancer (McNamara, JO., *et al* (2006) *Nat. Biotechnol.* 24:1005-1015). In an alternative embodiment, the iRNA can be delivered using

drug delivery systems such as a nanoparticle, a dendrimer, a polymer, liposomes, or a cationic delivery system. Positively charged cationic delivery systems facilitate binding of an iRNA molecule (negatively charged) and also enhance interactions at the negatively charged cell membrane to permit efficient uptake of an iRNA by the cell. Cationic lipids, dendrimers, or polymers can either be bound to an iRNA, or induced to form a vesicle or micelle (see *e.g.*, Kim SH., *et al* (2008) *Journal of Controlled Release* 129(2):107-116) that encases an iRNA. The formation of vesicles or micelles further prevents degradation of the iRNA when administered systemically. Methods for making and administering cationic- iRNA complexes are well within the abilities of one skilled in the art (see *e.g.*, Sorensen, DR., *et al* (2003) *J. Mol. Biol* 327:761-766; Verma, UN., *et al* (2003) Clin. *Cancer Res.* 9:1291-1300; Arnold, AS *et al* (2007) *J. Hypertens.* 25:197-205, which are incorporated herein by reference in their entirety). Some non-limiting examples of drug delivery systems useful for systemic delivery of iRNAs include DOTAP (Sorensen, DR., *et al* (2003), supra; Verma, UN., *et al* (2003), *supra*), Oligofectamine, "solid nucleic acid lipid particles" (Zimmermann, TS., *et al* (2006) *Nature* 441:111-114), cardiolipin (Chien, PY., *et al* (2005) *Cancer Gene Ther.* 12:321-328; Pal, A., *et al* (2005) *Int J. Oncol.* 26:1087-1091), polyethyleneimine (Bonnet ME., *et al* (2008) *Pharm. Res.* Aug 16 Epub ahead of print; Aigner, A. (2006) *J. Biomed. Biotechnol.* 71659), Arg-Gly-Asp (RGD) peptides (Liu, S. (2006) *Mol. Pharm.* 3:472-487), and polyamidoamines (Tomalia, DA., *et al* (2007) *Biochem. Soc. Trans.* 35:61-67; Yoo, H., *et al* (1999) *Pharm. Res.* 16:1799-1804). In some embodiments, an iRNA forms a complex with cyclodextrin for systemic administration. Methods for administration and pharmaceutical compositions of iRNAs and cyclodextrins can be found in U.S. Patent No. 7,427,605, which is herein incorporated by reference in its entirety.

A. Vector encoded iRNAs of the Invention

iRNA targeting the TMPRSS6 gene can be expressed from transcription units inserted into DNA or RNA vectors (see, *e.g.*, Couture, A, *et al.*, *TIG.* (1996), 12:5-10; Skillern, A., *et al.*, International PCT Publication No. WO 00/22113, Conrad, International PCT Publication No. WO 00/22114, and Conrad, U.S. Pat. No. 6,054,299). Expression can be transient (on the order of hours to weeks) or sustained (weeks to months or longer), depending upon the specific construct used and the target tissue or cell type. These transgenes can be introduced as a linear construct, a circular plasmid, or a viral vector, which can be an integrating or non-integrating vector. The transgene can also be constructed to permit it to be inherited as an extrachromosomal plasmid (Gassmann, *et al.*, *Proc. Natl. Acad. Sci. USA* (1995) 92:1292).

The individual strand or strands of an iRNA can be transcribed from a promoter on an expression vector. Where two separate strands are to be expressed to generate, for example, a dsRNA, two separate expression vectors can be co-introduced (*e.g.*, by transfection or infection) into a target cell. Alternatively each individual strand of a dsRNA can be transcribed by promoters both of which are located on the same expression plasmid. In one

embodiment, a dsRNA is expressed as inverted repeat polynucleotides joined by a linker polynucleotide sequence such that the dsRNA has a stem and loop structure.

iRNA expression vectors are generally DNA plasmids or viral vectors. Expression vectors compatible with eukaryotic cells, preferably those compatible with vertebrate cells, can be used to produce recombinant constructs for the expression of an iRNA as described herein. Eukaryotic cell expression vectors are well known in the art and are available from a number of commercial sources. Typically, such vectors are provided containing convenient restriction sites for insertion of the desired nucleic acid segment. Delivery of iRNA expressing vectors can be systemic, such as by intravenous or intramuscular administration, by administration to target cells ex-planted from the patient followed by reintroduction into the patient, or by any other means that allows for introduction into a desired target cell.

iRNA expression plasmids can be transfected into target cells as a complex with cationic lipid carriers (*e.g.,* Oligofectamine) or non-cationic lipid-based carriers (*e.g.,* Transit-TKO™). Multiple lipid transfections for iRNA-mediated knockdowns targeting different regions of a target RNA over a period of a week or more are also contemplated by the invention. Successful introduction of vectors into host cells can be monitored using various known methods. For example, transient transfection can be signaled with a reporter, such as a fluorescent marker, such as Green Fluorescent Protein (GFP). Stable transfection of cells *ex vivo* can be ensured using markers that provide the transfected cell with resistance to specific environmental factors (*e.g.*, antibiotics and drugs), such as hygromycin B resistance.

Viral vector systems which can be utilized with the methods and compositions described herein include, but are not limited to, (a) adenovirus vectors; (b) retrovirus vectors, including but not limited to lentiviral vectors, moloney murine leukemia virus, *etc.*; (c) adeno- associated virus vectors; (d) herpes simplex virus vectors; (e) SV 40 vectors; (f) polyoma virus vectors; (g) papilloma virus vectors; (h) picornavirus vectors; (i) pox virus vectors such as an orthopox, *e.g.*, vaccinia virus vectors or avipox, *e.g.* canary pox or fowl pox; and (j) a helper-dependent or gutless adenovirus. Replication-defective viruses can also be advantageous. Different vectors will or will not become incorporated into the cells' genome. The constructs can include viral sequences for transfection, if desired. Alternatively, the construct can be incorporated into vectors capable of episomal replication, *e.g.* EPV and EBV vectors. Constructs for the recombinant expression of an iRNA will generally require regulatory elements, *e.g.*, promoters, enhancers, *etc.*, to ensure the expression of the iRNA in target cells. Other aspects to consider for vectors and constructs are further described below.

Vectors useful for the delivery of an iRNA will include regulatory elements (promoter, enhancer, *etc.*) sufficient for expression of the iRNA in the desired target cell or tissue. The regulatory elements can be chosen to provide either constitutive or regulated/inducible expression.

Expression of the iRNA can be precisely regulated, for example, by using an inducible regulatory sequence that is sensitive to certain physiological regulators, *e.g.*, circulating glucose levels, or hormones (Docherty *et al.*, 1994, *FASEB J.* 8:20-24). Such inducible expression systems, suitable for the control of dsRNA expression in cells or in mammals include, for example, regulation by ecdysone, by estrogen, progesterone, tetracycline, chemical inducers of dimerization, and isopropyl-beta-D1 - thiogalactopyranoside (IPTG). A person skilled in the art would be able to choose the appropriate regulatory/promoter sequence based on the intended use of the iRNA transgene.

Viral vectors that contain nucleic acid sequences encoding an iRNA can be used. For example, a retroviral vector can be used (see Miller *et al.*, *Meth. Enzymol.* 217:581-599 (1993)). These retroviral vectors contain the components necessary for the correct packaging of the viral genome and integration into the host cell DNA. The nucleic acid sequences encoding an iRNA are cloned into one or more vectors, which facilitate delivery of the nucleic acid into a patient. More detail about retroviral vectors can be found, for example, in Boesen *et al.*, *Biotherapy* 6:291-302 (1994), which describes the use of a retroviral vector to deliver the mdr1 gene to hematopoietic stem cells in order to make the stem cells more resistant to chemotherapy. Other references illustrating the use of retroviral vectors in gene therapy are: Clowes *et al.*, *J. Clin. Invest.* 93:644-651 (1994); Kiem *et al.*, *Blood* 83:1467-1473 (1994); Salmons and Gunzberg, *Human Gene Therapy* 4:129-141 (1993); and Grossman and Wilson, *Curr. Opin. in Genetics and Devel.* 3:110-114 (1993). Lentiviral vectors contemplated for use include, for example, the HIV based vectors described in U.S. Patent Nos. 6,143,520; 5,665,557; and 5,981,276, which are herein incorporated by reference.

Adenoviruses are also contemplated for use in delivery of iRNAs of the invention. Adenoviruses are especially attractive vehicles, *e.g.*, for delivering genes to respiratory epithelia. Adenoviruses naturally infect respiratory epithelia where they cause a mild disease. Other targets for adenovirus-based delivery systems are liver, the central nervous system, endothelial cells, and muscle. Adenoviruses have the advantage of being capable of infecting non-dividing cells. Kozarsky and Wilson, *Current Opinion in Genetics and Development* 3:499-503 (1993) present a review of adenovirus-based gene therapy. Bout *et al.*, *Human Gene Therapy* 5:3-10 (1994) demonstrated the use of adenovirus vectors to transfer genes to the respiratory epithelia of rhesus monkeys. Other instances of the use of adenoviruses in gene therapy can be found in Rosenfeld *et al.*, *Science* 252:431-434 (1991); Rosenfeld *et al.*, *Cell* 68:143-155 (1992); Mastrangeli *et al.*, *J. Clin. Invest.* 91:225-234 (1993); PCT Publication WO94/12649; and Wang, *et al.*, *Gene Therapy* 2:775-783 (1995). A suitable AV vector for expressing an iRNA featured in the invention, a method for constructing the recombinant AV vector, and a method for delivering the vector into target cells, are described in Xia H *et al.* (2002), *Nat. Biotech.* 20: 1006-1010.

Adeno-associated virus (AAV) vectors may also be used to delivery an iRNA of the invention (Walsh *et al.*, Proc. Soc. Exp. Biol. Med. 204:289-300 (1993); U.S. Pat. No. 5,436,146). In one embodiment, the iRNA can be expressed as two separate, complementary single-stranded RNA molecules from a recombinant AAV vector having, for example, either the U6 or H1 RNA promoters, or the cytomegalovirus (CMV) promoter. Suitable AAV vectors for expressing the dsRNA featured in the invention, methods for constructing the recombinant AV vector, and methods for delivering the vectors into target cells are described in Samulski R *et al.* (1987), *J. Virol.* 61: 3096-3101; Fisher K J *et al.* (1996), *J. Virol*, 70: 520-532; Samulski R *et al.* (1989), *J. Virol.* 63: 3822-3826; U.S. Pat. No. 5,252,479; U.S. Pat. No. 5,139,941; International Patent Application No. WO 94/13788; and International Patent Application No. WO 93/24641, the entire disclosures of which are herein incorporated by reference.

Another viral vector suitable for delivery of an iRNA of the inevtion is a pox virus such as a vaccinia virus, for example an attenuated vaccinia such as Modified Virus Ankara (MVA) or NYVAC, an avipox such as fowl pox or canary pox.

The tropism of viral vectors can be modified by pseudotyping the vectors with envelope proteins or other surface antigens from other viruses, or by substituting different viral capsid proteins, as appropriate. For example, lentiviral vectors can be pseudotyped with surface proteins from vesicular stomatitis virus (VSV), rabies, Ebola, Mokola, and the like. AAV vectors can be made to target different cells by engineering the vectors to express different capsid protein serotypes; see, *e.g.*, Rabinowitz J E *et al.* (2002), *J Virol* 76:791-801, the entire disclosure of which is herein incorporated by reference.

The pharmaceutical preparation of a vector can include the vector in an acceptable diluent, or can include a slow release matrix in which the gene delivery vehicle is imbedded. Alternatively, where the complete gene delivery vector can be produced intact from recombinant cells, *e.g.*, retroviral vectors, the pharmaceutical preparation can include one or more cells which produce the gene delivery system.

IV. Pharmaceutical Compositions of the Invention

The present invention also includes pharmaceutical compositions and formulations which include the iRNAs of the invention. In one embodiment, provided herein are pharmaceutical compositions containing an iRNA, as described herein, and a pharmaceutically acceptable carrier. The pharmaceutical compositions containing the iRNA are useful for treating a TMPRSS6 associated disease or disorder, *e.g.* hemochromatosis. Such pharmaceutical compositions are formulated based on the mode of delivery. One example is compositions that are formulated for systemic administration *via* parenteral delivery, *e.g.*, by intravenous (IV) delivery. Another example is compositions that are

formulated for direct delivery into the brain parenchyma, *e.g.*, by infusion into the brain, such as by continuous pump infusion.

The pharmaceutical compositions comprising RNAi agents of the invention may be, for example, solutions with or without a buffer, or compositions containing pharmaceutically acceptable carriers. Such compositions include, for example, aqueous or crystalline compositions, liposomal formulations, micellar formulations, emulsions, and gene therapy vectors.

In the methods of the invention, the RNAi agent may be administered in a solution. A free RNAi agent may be administered in an unbuffered solution, e.g., in saline or in water. Alternatively, the free siRNA may also be administred in a suitable buffer solution. The buffer solution may comprise acetate, citrate, prolamine, carbonate, or phosphate, or any combination thereof. In a preferred embodiment, the buffer solution is phosphate buffered saline (PBS). The pH and osmolarity of the buffer solution containing the RNAi agent can be adjusted such that it is suitable for administering to a subject.

In some embodiments, the buffer solution further comprises an agent for controlling the osmolarity of the solution, such that the osmolarity is kept at a desired value, *e.g.*, at the physiologic values of the human plasma. Solutes which can be added to the buffer solution to control the osmolarity include, but are not limited to, proteins, peptides, amino acids, non-metabolized polymers, vitamins, ions, sugars, metabolites, organic acids, lipids, or salts. In some embodiments, the agent for controlling the osmolarity of the solution is a salt. In certain embodiments, the agent for controlling the osmolarity of the solution is sodium chloride or potassium chloride.

The pharmaceutical compositions of the invention may be administered in dosages sufficient to inhibit expression of a TMPRSS6 gene.

In general, a suitable dose of an iRNA of the invention will be in the range of about 0.001 to about 200.0 milligrams per kilogram body weight of the recipient per day, generally in the range of about 1 to 50 mg per kilogram body weight per day. For example, the dsRNA can be administered at about 0.01 mg/kg, about 0.05 mg/kg, about 0.5 mg/kg, about 1 mg/kg, about 1.5 mg/kg, about 2 mg/kg, about 3 mg/kg, about 4 mg/kg, about 5 mg/kg, about 6 mg/kg, about 7 mg/kg, about 8 mg/kg, about 9 mg/kg about 10 mg/kg, about 20 mg/kg, about 30 mg/kg, about 40 mg/kg, or about 50 mg/kg per single dose.

For example, the RNAi agent, *e.g.*, dsRNA, may be administered at a dose of about 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6, 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 7, 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 8, 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 9, 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, or about 10 mg/kg. Values and ranges intermediate to the recited values are also intended to be part of this invention.

In another embodiment, the RNAi agent, *e.g.*, dsRNA, is administered at a dose of about 0.1 to about 50 mg/kg, about 0.25 to about 50 mg/kg, about 0.5 to about 50 mg/kg, about 0.75 to about 50 mg/kg, about 1 to about 50 mg/mg, about 1.5 to about 50 mg/kb, about 2 to about 50 mg/kg, about 2.5 to about 50 mg/kg, about 3 to about 50 mg/kg, about 3.5 to about 50 mg/kg, about 4 to about 50 mg/kg, about 4.5 to about 50 mg/kg, about 5 to about 50 mg/kg, about 7.5 to about 50 mg/kg, about 10 to about 50 mg/kg, about 15 to about 50 mg/kg, about 20 to about 50 mg/kg, about 20 to about 50 mg/kg, about 25 to about 50 mg/kg, about 25 to about 50 mg/kg, about 30 to about 50 mg/kg, about 35 to about 50 mg/kg, about 40 to about 50 mg/kg, about 45 to about 50 mg/kg, about 0.1 to about 45 mg/kg, about 0.25 to about 45 mg/kg, about 0.5 to about 45 mg/kg, about 0.75 to about 45 mg/kg, about 1 to about 45 mg/mg, about 1.5 to about 45 mg/kb, about 2 to about 45 mg/kg, about 2.5 to about 45 mg/kg, about 3 to about 45 mg/kg, about 3.5 to about 45 mg/kg, about 4 to about 45 mg/kg, about 4.5 to about 45 mg/kg, about 5 to about 45 mg/kg, about 7.5 to about 45 mg/kg, about 10 to about 45 mg/kg, about 15 to about 45 mg/kg, about 20 to about 45 mg/kg, about 20 to about 45 mg/kg, about 25 to about 45 mg/kg, about 25 to about 45 mg/kg, about 30 to about 45 mg/kg, about 35 to about 45 mg/kg, about 40 to about 45 mg/kg, about 0.1 to about 40 mg/kg, about 0.25 to about 40 mg/kg, about 0.5 to about 40 mg/kg, about 0.75 to about 40 mg/kg, about 1 to about 40 mg/mg, about 1.5 to about 40 mg/kb, about 2 to about 40 mg/kg, about 2.5 to about 40 mg/kg, about 3 to about 40 mg/kg, about 3.5 to about 40 mg/kg, about 4 to about 40 mg/kg, about 4.5 to about 40 mg/kg, about 5 to about 40 mg/kg, about 7.5 to about 40 mg/kg, about 10 to about 40 mg/kg, about 15 to about 40 mg/kg, about 20 to about 40 mg/kg, about 20 to about 40 mg/kg, about 25 to about 40 mg/kg, about 25 to about 40 mg/kg, about 30 to about 40 mg/kg, about 35 to about 40 mg/kg, about 0.1 to about 30 mg/kg, about 0.25 to about 30 mg/kg, about 0.5 to about 30 mg/kg, about 0.75 to about 30 mg/kg, about 1 to about 30 mg/mg, about 1.5 to about 30 mg/kb, about 2 to about 30 mg/kg, about 2.5 to about 30 mg/kg, about 3 to about 30 mg/kg, about 3.5 to about 30 mg/kg, about 4 to about 30 mg/kg, about 4.5 to about 30 mg/kg, about 5 to about 30 mg/kg, about 7.5 to about 30 mg/kg, about 10 to about 30 mg/kg, about 15 to about 30 mg/kg, about 20 to about 30 mg/kg, about 20 to about 30 mg/kg, about 25 to about 30 mg/kg, about 0.1 to about 20 mg/kg, about 0.25 to about 20 mg/kg, about 0.5 to about 20 mg/kg, about 0.75 to about 20 mg/kg, about 1 to about 20 mg/mg, about 1.5 to about 20 mg/kb, about 2 to about 20 mg/kg, about 2.5 to about 20 mg/kg, about 3 to about 20 mg/kg, about 3.5 to about 20 mg/kg, about 4 to about 20 mg/kg, about 4.5 to about 20 mg/kg, about 5 to about 20 mg/kg, about 7.5 to about 20 mg/kg, about 10 to about 20 mg/kg, or about 15 to about 20 mg/kg. Values and ranges intermediate to the recited values are also intended to be part of this invention.

For example, the RNAi agent, *e.g.*, dsRNA, may be administered at a dose of about 0..01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3, 3.1, 3.2,

3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6, 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 7, 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 8, 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 9, 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, or about 10 mg/kg. Values and ranges intermediate to the recited values are also intended to be part of this invention.

In another embodiment, the RNAi agent, *e.g.*,dsRNA, is administered at a dose of about 0.5 to about 50 mg/kg, about 0.75 to about 50 mg/kg, about 1 to about 50 mg/mg, about 1.5 to about 50 mg/kg, about 2 to about 50 mg/kg, about 2.5 to about 50 mg/kg, about 3 to about 50 mg/kg, about 3.5 to about 50 mg/kg, about 4 to about 50 mg/kg, about 4.5 to about 50 mg/kg, about 5 to about 50 mg/kg, about 7.5 to about 50 mg/kg, about 10 to about 50 mg/kg, about 15 to about 50 mg/kg, about 20 to about 50 mg/kg, about 20 to about 50 mg/kg, about 25 to about 50 mg/kg, about 25 to about 50 mg/kg, about 30 to about 50 mg/kg, about 35 to about 50 mg/kg, about 40 to about 50 mg/kg, about 45 to about 50 mg/kg, about 0.5 to about 45 mg/kg, about 0.75 to about 45 mg/kg, about 1 to about 45 mg/mg, about 1.5 to about 45 mg/kb, about 2 to about 45 mg/kg, about 2.5 to about 45 mg/kg, about 3 to about 45 mg/kg, about 3.5 to about 45 mg/kg, about 4 to about 45 mg/kg, about 4.5 to about 45 mg/kg, about 5 to about 45 mg/kg, about 7.5 to about 45 mg/kg, about 10 to about 45 mg/kg, about 15 to about 45 mg/kg, about 20 to about 45 mg/kg, about 20 to about 45 mg/kg, about 25 to about 45 mg/kg, about 25 to about 45 mg/kg, about 30 to about 45 mg/kg, about 35 to about 45 mg/kg, about 40 to about 45 mg/kg, about 0.5 to about 40 mg/kg, about 0.75 to about 40 mg/kg, about 1 to about 40 mg/mg, about 1.5 to about 40 mg/kb, about 2 to about 40 mg/kg, about 2.5 to about 40 mg/kg, about 3 to about 40 mg/kg, about 3.5 to about 40 mg/kg, about 4 to about 40 mg/kg, about 4.5 to about 40 mg/kg, about 5 to about 40 mg/kg, about 7.5 to about 40 mg/kg, about 10 to about 40 mg/kg, about 15 to about 40 mg/kg, about 20 to about 40 mg/kg, about 20 to about 40 mg/kg, about 25 to about 40 mg/kg, about 25 to about 40 mg/kg, about 30 to about 40 mg/kg, about 35 to about 40 mg/kg, about 0.5 to about 30 mg/kg, about 0.75 to about 30 mg/kg, about 1 to about 30 mg/mg, about 1.5 to about 30 mg/kb, about 2 to about 30 mg/kg, about 2.5 to about 30 mg/kg, about 3 to about 30 mg/kg, about 3.5 to about 30 mg/kg, about 4 to about 30 mg/kg, about 4.5 to about 30 mg/kg, about 5 to about 30 mg/kg, about 7.5 to about 30 mg/kg, about 10 to about 30 mg/kg, about 15 to about 30 mg/kg, about 20 to about 30 mg/kg, about 20 to about 30 mg/kg, about 25 to about 30 mg/kg, about 0.5 to about 20 mg/kg, about 0.75 to about 20 mg/kg, about 1 to about 20 mg/mg, about 1.5 to about 20 mg/kb, about 2 to about 20 mg/kg, about 2.5 to about 20 mg/kg, about 3 to about 20 mg/kg, about 3.5 to about 20 mg/kg, about 4 to about 20 mg/kg, about 4.5 to about 20 mg/kg, about 5 to about 20 mg/kg, about 7.5 to about 20 mg/kg, about 10 to about 20 mg/kg, or about 15 to about 20 mg/kg. In one embodiment, the dsRNA is administered at a dose of about 10mg/kg to about 30 mg/kg. Values and ranges intermediate to the recited values are also intended to be part of this invention.

For example, subjects can be administered a therapeutic amount of iRNA, such as about 0.5, 0.6, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6, 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 7, 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 8, 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 9, 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, 10, 10.5, 11, 11.5, 12, 12.5, 13, 13.5, 14, 14.5, 15, 15.5, 16, 16.5, 17, 17.5, 18, 18.5, 19, 19.5, 20, 20.5, 21, 21.5, 22, 22.5, 23, 23.5, 24, 24.5, 25, 25.5, 26, 26.5, 27, 27.5, 28, 28.5, 29, 29.5, 30, 31, 32, 33, 34, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, or about 50 mg/kg. Values and ranges intermediate to the recited values are also intended to be part of this invention.

In certain embodiments, for example, when a composition of the invention comprises a dsRNA as described herein and a lipid, subjects can be administered a therapeutic amount of iRNA, such as about 0.01 mg/kg to about 5 mg/kg, about 0.01 mg/kg to about 10 mg/kg, about 0.05 mg/kg to about 5 mg/kg, about 0.05 mg/kg to about 10 mg/kg, about 0.1 mg/kg to about 5 mg/kg, about 0.1 mg/kg to about 10 mg/kg, about 0.2 mg/kg to about 5 mg/kg, about 0.2 mg/kg to about 10 mg/kg, about 0.3 mg/kg to about 5 mg/kg, about 0.3 mg/kg to about 10 mg/kg, about 0.4 mg/kg to about 5 mg/kg, about 0.4 mg/kg to about 10 mg/kg, about 0.5 mg/kg to about 5 mg/kg, about 0.5 mg/kg to about 10 mg/kg, about 1 mg/kg to about 5 mg/kg, about 1 mg/kg to about 10 mg/kg, about 1.5 mg/kg to about 5 mg/kg, about 1.5 mg/kg to about 10 mg/kg, about 2 mg/kg to about about 2.5 mg/kg, about 2 mg/kg to about 10 mg/kg, about 3 mg/kg to about 5 mg/kg, about 3 mg/kg to about 10 mg/kg, about 3.5 mg/kg to about 5 mg/kg, about 4 mg/kg to about 5 mg/kg, about 4.5 mg/kg to about 5 mg/kg, about 4 mg/kg to about 10 mg/kg, about 4.5 mg/kg to about 10 mg/kg, about 5 mg/kg to about 10 mg/kg, about 5.5 mg/kg to about 10 mg/kg, about 6 mg/kg to about 10 mg/kg, about 6.5 mg/kg to about 10 mg/kg, about 7 mg/kg to about 10 mg/kg, about 7.5 mg/kg to about 10 mg/kg, about 8 mg/kg to about 10 mg/kg, about 8.5 mg/kg to about 10 mg/kg, about 9 mg/kg to about 10 mg/kg, or about 9.5 mg/kg to about 10 mg/kg. Values and ranges intermediate to the recited values are also intended to be part of this invention.

For example, the dsRNA may be administered at a dose of about 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6, 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 7, 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 8, 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 9, 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, or about 10 mg/kg. Values and ranges intermediate to the recited values are also intended to be part of this invention.

In certain embodiments of the invention, for example, when a double-stranded RNAi agent includes modifications (*e.g.,* one or more motifs of three identical modifications on three consecutive nucleotides, including one such motif at or near the cleavage site of the

agent), six phosphorothioate linkages, and a ligand, such an agent is administered at a dose of about 0.01 to about 0.5 mg/kg, about 0.01 to about 0.4 mg/kg, about 0.01 to about 0.3 mg/kg, about 0.01 to about 0.2 mg/kg, about 0.01 to about 0.1 mg/kg, about 0.01 mg/kg to about 0.09 mg/kg, about 0.01 mg/kg to about 0.08 mg/kg, about 0.01 mg/kg to about 0.07 mg/kg, about 0.01 mg/kg to about 0.06 mg/kg, about 0.01 mg/kg to about 0.05 mg/kg, about 0.02 to about 0.5 mg/kg, about 0.02 to about 0.4 mg/kg, about 0.02 to about 0.3 mg/kg, about 0.02 to about 0.2 mg/kg, about 0.02 to about 0.1 mg/kg, about 0.02 mg/kg to about 0.09 mg/kg, about 0.02 mg/kg to about 0.08 mg/kg, about 0.02 mg/kg to about 0.07 mg/kg, about 0.02 mg/kg to about 0.06 mg/kg, about 0.02 mg/kg to about 0.05 mg/kg, about 0.03 to about 0.5 mg/kg, about 0.03 to about 0.4 mg/kg, about 0.03 to about 0.3 mg/kg, about 0.03 to about 0.2 mg/kg, about 0.03 to about 0.1 mg/kg, about 0.03 mg/kg to about 0.09 mg/kg, about 0.03 mg/kg to about 0.08 mg/kg, about 0.03 mg/kg to about 0.07 mg/kg, about 0.03 mg/kg to about 0.06 mg/kg, about 0.03 mg/kg to about 0.05 mg/kg, about 0.04 to about 0.5 mg/kg, about 0.04 to about 0.4 mg/kg, about 0.04 to about 0.3 mg/kg, about 0.04 to about 0.2 mg/kg, about 0.04 to about 0.1 mg/kg, about 0.04 mg/kg to about 0.09 mg/kg, about 0.04 mg/kg to about 0.08 mg/kg, about 0.04 mg/kg to about 0.07 mg/kg, about 0.04 mg/kg to about 0.06 mg/kg, about 0.05 to about 0.5 mg/kg, about 0.05 to about 0.4 mg/kg, about 0.05 to about 0.3 mg/kg, about 0.05 to about 0.2 mg/kg, about 0.05 to about 0.1 mg/kg, about 0.05 mg/kg to about 0.09 mg/kg, about 0.05 mg/kg to about 0.08 mg/kg, or about 0.05 mg/kg to about 0.07 mg/kg. Values and ranges intermediate to the foregoing recited values are also intended to be part of this invention, *e.g.*,, the RNAi agent may be administered to the subject at a dose of about 0.015 mg/kg to about 0.45 mg/mg.

For example, the RNAi agent, *e.g.*, RNAi agent in a pharmaceutical composition, may be administered at a dose of about 0.01 mg/kg, 0.0125 mg/kg, 0.015 mg/kg, 0.0175 mg/kg, 0.02 mg/kg, 0.0225 mg/kg, 0.025 mg/kg, 0.0275 mg/kg, 0.03 mg/kg, 0.0325 mg/kg, 0.035 mg/kg, 0.0375 mg/kg, 0.04 mg/kg, 0.0425 mg/kg, 0.045 mg/kg, 0.0475 mg/kg, 0.05 mg/kg, 0.0525 mg/kg, 0.055 mg/kg, 0.0575 mg/kg, 0.06 mg/kg, 0.0625 mg/kg, 0.065 mg/kg, 0.0675 mg/kg, 0.07 mg/kg, 0.0725 mg/kg, 0.075 mg/kg, 0.0775 mg/kg, 0.08 mg/kg, 0.0825 mg/kg, 0.085 mg/kg, 0.0875 mg/kg, 0.09 mg/kg, 0.0925 mg/kg, 0.095 mg/kg, 0.0975 mg/kg, 0.1 mg/kg, 0.125 mg/kg, 0.15 mg/kg, 0.175 mg/kg, 0.2 mg/kg, 0.225 mg/kg, 0.25 mg/kg, 0.275 mg/kg, 0.3 mg/kg, 0.325 mg/kg, 0.35 mg/kg, 0.375 mg/kg, 0.4 mg/kg, 0.425 mg/kg, 0.45 mg/kg, 0.475 mg/kg, or about 0.5 mg/kg. Values intermediate to the foregoing recited values are also intended to be part of this invention.

The pharmaceutical composition can be administered once daily, or the iRNA can be administered as two, three, or more sub-doses at appropriate intervals throughout the day or even using continuous infusion or delivery through a controlled release formulation. In that case, the iRNA contained in each sub-dose must be correspondingly smaller in order to achieve the total daily dosage. The dosage unit can also be compounded for delivery over

several days, *e.g.*, using a conventional sustained release formulation which provides sustained release of the iRNA over a several day period. Sustained release formulations are well known in the art and are particularly useful for delivery of agents at a particular site, such as could be used with the agents of the present invention. In this embodiment, the dosage unit contains a corresponding multiple of the daily dose.

In other embodiments, a single dose of the pharmaceutical compositions can be long lasting, such that subsequent doses are administered at not more than 3, 4, or 5 day intervals, or at not more than 1, 2, 3, or 4 week intervals. In some embodiments of the invention, a single dose of the pharmaceutical compositions of the invention is administered once per week. In other embodiments of the invention, a single dose of the pharmaceutical compositions of the invention is administered bi-monthly.

The skilled artisan will appreciate that certain factors can influence the dosage and timing required to effectively treat a subject, including but not limited to the severity of the disease or disorder, previous treatments, the general health and/or age of the subject, and other diseases present. Moreover, treatment of a subject with a therapeutically effective amount of a composition can include a single treatment or a series of treatments. Estimates of effective dosages and *in vivo* half-lives for the individual iRNAs encompassed by the invention can be made using conventional methodologies or on the basis of *in vivo* testing using an appropriate animal model, as described elsewhere herein.

Advances in mouse genetics have generated a number of mouse models for the study of various human diseases, such as a disorder associated with iron overload that would benefit from reduction in the expression of TMPRSS6. Such models can be used for *in vivo* testing of iRNA, as well as for determining a therapeutically effective dose. Suitable mouse models are known in the art and include, for example, the thalassemic Th3/+ mouse as a model of β-thalassemia (Douet *et al.*, *Am. J. Pathol.* (2011), 178(2):774-83), the HFE knockout mouse as a model of hereditary hemochromatosis (Zhou *et al.* (1998) *Proc. Natl. Acad. Sci USA*, 85:2492-2497); a Uros(mut248) mouse as a model of congenital erythropoietic porphyria (Ged *et al.* (2006) *Genomics*, 87(1):84-92).

The pharmaceutical compositions of the present invention can be administered in a number of ways depending upon whether local or systemic treatment is desired and upon the area to be treated. Administration can be topical (*e.g.*, by a transdermal patch), pulmonary, *e.g.*, by inhalation or insufflation of powders or aerosols, including by nebulizer; intratracheal, intranasal, epidermal and transdermal, oral or parenteral. Parenteral administration includes intravenous, intraarterial, subcutaneous, intraperitoneal or intramuscular injection or infusion; subdermal, *e.g.*, *via* an implanted device; or intracranial, *e.g.*, by intraparenchymal, intrathecal or intraventricular, administration

The iRNA can be delivered in a manner to target a particular tissue, such as the liver (*e.g.*, the hepatocytes of the liver).

Pharmaceutical compositions and formulations for topical administration can include transdermal patches, ointments, lotions, creams, gels, drops, suppositories, sprays, liquids and powders. Conventional pharmaceutical carriers, aqueous, powder or oily bases, thickeners and the like can be necessary or desirable. Coated condoms, gloves and the like can also be useful. Suitable topical formulations include those in which the iRNAs featured in the invention are in admixture with a topical delivery agent such as lipids, liposomes, fatty acids, fatty acid esters, steroids, chelating agents and surfactants. Suitable lipids and liposomes include neutral (*e.g.,* dioleoylphosphatidyl DOPE ethanolamine, dimyristoylphosphatidyl choline DMPC, distearolyphosphatidyl choline) negative (*e.g.,* dimyristoylphosphatidyl glycerol DMPG) and cationic (*e.g.,* dioleoyltetramethylaminopropyl DOTAP and dioleoylphosphatidyl ethanolamine DOTMA). iRNAs featured in the invention can be encapsulated within liposomes or can form complexes thereto, in particular to cationic liposomes. Alternatively, iRNAs can be complexed to lipids, in particular to cationic lipids. Suitable fatty acids and esters include but are not limited to arachidonic acid, oleic acid, eicosanoic acid, lauric acid, caprylic acid, capric acid, myristic acid, palmitic acid, stearic acid, linoleic acid, linolenic acid, dicaprate, tricaprate, monoolein, dilaurin, glyceryl 1-monocaprate, 1-dodecylazacycloheptan-2-one, an acylcarnitine, an acylcholine, or a C_{1-20} alkyl ester (*e.g.,* isopropylmyristate IPM), monoglyceride, diglyceride or pharmaceutically acceptable salt thereof). Topical formulations are described in detail in U.S. Patent No. 6,747,014, which is incorporated herein by reference.

A. iRNA Formulations Comprising Membranous Molecular Assemblies

An iRNA for use in the compositions and methods of the invention can be formulated for delivery in a membranous molecular assembly, *e.g.*, a liposome or a micelle. As used herein, the term "liposome" refers to a vesicle composed of amphiphilic lipids arranged in at least one bilayer, *e.g.*, one bilayer or a plurality of bilayers. Liposomes include unilamellar and multilamellar vesicles that have a membrane formed from a lipophilic material and an aqueous interior. The aqueous portion contains the iRNA composition. The lipophilic material isolates the aqueous interior from an aqueous exterior, which typically does not include the iRNA composition, although in some examples, it may. Liposomes are useful for the transfer and delivery of active ingredients to the site of action. Because the liposomal membrane is structurally similar to biological membranes, when liposomes are applied to a tissue, the liposomal bilayer fuses with bilayer of the cellular membranes. As the merging of the liposome and cell progresses, the internal aqueous contents that include the iRNA are delivered into the cell where the iRNA can specifically bind to a target RNA and can mediate RNAi. In some cases the liposomes are also specifically targeted, *e.g.*, to direct the iRNA to particular cell types.

A liposome containing a RNAi agent can be prepared by a variety of methods. In one example, the lipid component of a liposome is dissolved in a detergent so that micelles are

formed with the lipid component. For example, the lipid component can be an amphipathic cationic lipid or lipid conjugate. The detergent can have a high critical micelle concentration and may be nonionic. Exemplary detergents include cholate, CHAPS, octylglucoside, deoxycholate, and lauroyl sarcosine. The RNAi agent preparation is then added to the micelles that include the lipid component. The cationic groups on the lipid interact with the RNAi agent and condense around the RNAi agent to form a liposome. After condensation, the detergent is removed, *e.g.*, by dialysis, to yield a liposomal preparation of RNAi agent.

If necessary a carrier compound that assists in condensation can be added during the condensation reaction, *e.g.*, by controlled addition. For example, the carrier compound can be a polymer other than a nucleic acid (*e.g.*, spermine or spermidine). pH can also adjusted to favor condensation.

Methods for producing stable polynucleotide delivery vehicles, which incorporate a polynucleotide/cationic lipid complex as structural components of the delivery vehicle, are further described in, e.g., WO 96/37194, the entire contents of which are incorporated herein by reference. Liposome formation can also include one or more aspects of exemplary methods described in Felgner, P. L. *et al., Proc. Natl. Acad. Sci., USA* 8:7413-7417, 1987; U.S. Pat. No. 4,897,355; U.S. Pat. No. 5,171,678; Bangham, *et al. M. Mol. Biol.* 23:238, 1965; Olson, *et al. Biochim. Biophys. Acta* 557:9, 1979; Szoka, *et al. Proc. Natl. Acad. Sci.* 75: 4194, 1978; Mayhew, e*t al. Biochim. Biophys. Acta* 775:169, 1984; Kim, *et al. Biochim. Biophys. Acta* 728:339, 1983; and Fukunaga, *et al. Endocrinol.* 115:757, 1984. Commonly used techniques for preparing lipid aggregates of appropriate size for use as delivery vehicles include sonication and freeze-thaw plus extrusion (see, *e.g.,* Mayer, *et al. Biochim. Biophys. Acta* 858:161, 1986). Microfluidization can be used when consistently small (50 to 200 nm) and relatively uniform aggregates are desired (Mayhew, *et al. Biochim. Biophys. Acta* 775:169, 1984). These methods are readily adapted to packaging RNAi agent preparations into liposomes.

Liposomes fall into two broad classes. Cationic liposomes are positively charged liposomes which interact with the negatively charged nucleic acid molecules to form a stable complex. The positively charged nucleic acid/liposome complex binds to the negatively charged cell surface and is internalized in an endosome. Due to the acidic pH within the endosome, the liposomes are ruptured, releasing their contents into the cell cytoplasm (Wang *et al., Biochem. Biophys. Res. Commun.*, 1987, 147, 980-985).

Liposomes which are pH-sensitive or negatively-charged, entrap nucleic acids rather than complex with it. Since both the nucleic acid and the lipid are similarly charged, repulsion rather than complex formation occurs. Nevertheless, some nucleic acid is entrapped within the aqueous interior of these liposomes. pH-sensitive liposomes have been used to deliver nucleic acids encoding the thymidine kinase gene to cell monolayers in culture.

Expression of the exogenous gene was detected in the target cells (Zhou *et al.*, *Journal of Controlled Release*, 1992, 19, 269-274).

One major type of liposomal composition includes phospholipids other than naturally-derived phosphatidylcholine. Neutral liposome compositions, for example, can be formed from dimyristoyl phosphatidylcholine (DMPC) or dipalmitoyl phosphatidylcholine (DPPC). Anionic liposome compositions generally are formed from dimyristoyl phosphatidylglycerol, while anionic fusogenic liposomes are formed primarily from dioleoyl phosphatidylethanolamine (DOPE). Another type of liposomal composition is formed from phosphatidylcholine (PC) such as, for example, soybean PC, and egg PC. Another type is formed from mixtures of phospholipid and/or phosphatidylcholine and/or cholesterol.

Examples of other methods to introduce liposomes into cells *in vitro* and *in vivo* include U.S. Pat. No. 5,283,185; U.S. Pat. No. 5,171,678; WO 94/00569; WO 93/24640; WO 91/16024; Felgner, *J. Biol. Chem.* 269:2550, 1994; Nabel, *Proc. Natl. Acad. Sci.* 90:11307, 1993; Nabel, *Human Gene Ther.* 3:649, 1992; Gershon, *Biochem.* 32:7143, 1993; and Strauss *EMBO J.* 11:417, 1992.

Non-ionic liposomal systems have also been examined to determine their utility in the delivery of drugs to the skin, in particular systems comprising non-ionic surfactant and cholesterol. Non-ionic liposomal formulations comprising Novasome™ I (glyceryl dilaurate/cholesterol/polyoxyethylene-10-stearyl ether) and Novasome™ II (glyceryl distearate/cholesterol/polyoxyethylene-10-stearyl ether) were used to deliver cyclosporin-A into the dermis of mouse skin. Results indicated that such non-ionic liposomal systems were effective in facilitating the deposition of cyclosporine A into different layers of the skin (Hu *et al. S.T.P.Pharma. Sci.*, 1994, 4(6) 466).

Liposomes also include "sterically stabilized" liposomes, a term which, as used herein, refers to liposomes comprising one or more specialized lipids that, when incorporated into liposomes, result in enhanced circulation lifetimes relative to liposomes lacking such specialized lipids. Examples of sterically stabilized liposomes are those in which part of the vesicle-forming lipid portion of the liposome (A) comprises one or more glycolipids, such as monosialoganglioside G_{M1}, or (B) is derivatized with one or more hydrophilic polymers, such as a polyethylene glycol (PEG) moiety. While not wishing to be bound by any particular theory, it is thought in the art that, at least for sterically stabilized liposomes containing gangliosides, sphingomyelin, or PEG-derivatized lipids, the enhanced circulation half-life of these sterically stabilized liposomes derives from a reduced uptake into cells of the reticuloendothelial system (RES) (Allen *et al.*, *FEBS Letters*, 1987, 223, 42; Wu *et al.*, *Cancer Research*, 1993, 53, 3765).

Various liposomes comprising one or more glycolipids are known in the art. Papahadjopoulos *et al.* (*Ann. N.Y. Acad. Sci.*, 1987, 507, 64) reported the ability of monosialoganglioside G_{M1}, galactocerebroside sulfate and phosphatidylinositol to improve

blood half-lives of liposomes. These findings were expounded upon by Gabizon *et al.* (*Proc. Natl. Acad. Sci. U.S.A.*, 1988, 85, 6949). U.S. Pat. No. 4,837,028 and WO 88/04924, both to Allen *et al.*, disclose liposomes comprising (1) sphingomyelin and (2) the ganglioside G_{M1} or a galactocerebroside sulfate ester. U.S. Pat. No. 5,543,152 (Webb *et al.*) discloses liposomes comprising sphingomyelin. Liposomes comprising 1,2-sn-dimyristoylphosphatidylcholine are disclosed in WO 97/13499 (Lim *et al*).

In one embodiment, cationic liposomes are used. Cationic liposomes possess the advantage of being able to fuse to the cell membrane. Non-cationic liposomes, although not able to fuse as efficiently with the plasma membrane, are taken up by macrophages in vivo and can be used to deliver RNAi agents to macrophages.

Further advantages of liposomes include: liposomes obtained from natural phospholipids are biocompatible and biodegradable; liposomes can incorporate a wide range of water and lipid soluble drugs; liposomes can protect encapsulated RNAi agents in their internal compartments from metabolism and degradation (Rosoff, in "Pharmaceutical Dosage Forms," Lieberman, Rieger and Banker (Eds.), 1988, volume 1, p. 245). Important considerations in the preparation of liposome formulations are the lipid surface charge, vesicle size and the aqueous volume of the liposomes.

A positively charged synthetic cationic lipid, N-[1-(2,3-dioleyloxy)propyl]-N,N,N-trimethylammonium chloride (DOTMA) can be used to form small liposomes that interact spontaneously with nucleic acid to form lipid-nucleic acid complexes which are capable of fusing with the negatively charged lipids of the cell membranes of tissue culture cells, resulting in delivery of RNAi agent (see, e.g., Felgner, P. L. et al., Proc. Natl. Acad. Sci., USA 8:7413-7417, 1987 and U.S. Pat. No. 4,897,355 for a description of DOTMA and its use with DNA).

A DOTMA analogue, 1,2-bis(oleoyloxy)-3-(trimethylammonia)propane (DOTAP) can be used in combination with a phospholipid to form DNA-complexing vesicles. Lipofectin™ Bethesda Research Laboratories, Gaithersburg, Md.) is an effective agent for the delivery of highly anionic nucleic acids into living tissue culture cells that comprise positively charged DOTMA liposomes which interact spontaneously with negatively charged polynucleotides to form complexes. When enough positively charged liposomes are used, the net charge on the resulting complexes is also positive. Positively charged complexes prepared in this way spontaneously attach to negatively charged cell surfaces, fuse with the plasma membrane, and efficiently deliver functional nucleic acids into, for example, tissue culture cells. Another commercially available cationic lipid, 1,2-bis(oleoyloxy)-3,3-(trimethylammonia)propane ("DOTAP") (Boehringer Mannheim, Indianapolis, Indiana) differs from DOTMA in that the oleoyl moieties are linked by ester, rather than ether linkages.

Other reported cationic lipid compounds include those that have been conjugated to a variety of moieties including, for example, carboxyspermine which has been conjugated to one of two types of lipids and includes compounds such as 5-carboxyspermylglycine dioctaoleoylamide ("DOGS") (Transfectam™, Promega, Madison, Wisconsin) and dipalmitoylphosphatidylethanolamine 5-carboxyspermyl-amide ("DPPES") (see, e.g., U.S. Pat. No. 5,171,678).

Another cationic lipid conjugate includes derivatization of the lipid with cholesterol ("DC-Chol") which has been formulated into liposomes in combination with DOPE (See, Gao, X. and Huang, L., *Biochim. Biophys. Res. Commun.* 179:280, 1991). Lipopolylysine, made by conjugating polylysine to DOPE, has been reported to be effective for transfection in the presence of serum (Zhou, X. et al., *Biochim. Biophys. Acta* 1065:8, 1991). For certain cell lines, these liposomes containing conjugated cationic lipids, are said to exhibit lower toxicity and provide more efficient transfection than the DOTMA-containing compositions. Other commercially available cationic lipid products include DMRIE and DMRIE-HP (Vical, La Jolla, California) and Lipofectamine (DOSPA) (Life Technology, Inc., Gaithersburg, Maryland). Other cationic lipids suitable for the delivery of oligonucleotides are described in WO 98/39359 and WO 96/37194.

Liposomal formulations are particularly suited for topical administration, liposomes present several advantages over other formulations. Such advantages include reduced side effects related to high systemic absorption of the administered drug, increased accumulation of the administered drug at the desired target, and the ability to administer RNAi agent into the skin. In some implementations, liposomes are used for delivering RNAi agent to epidermal cells and also to enhance the penetration of RNAi agent into dermal tissues, e.g., into skin. For example, the liposomes can be applied topically. Topical delivery of drugs formulated as liposomes to the skin has been documented (see, *e.g.*, Weiner *et al., Journal of Drug Targeting,* 1992, vol. 2,405-410 and du Plessis *et al., Antiviral Research*, 18, 1992, 259-265; Mannino, R. J. and Fould-Fogerite, S., *Biotechniques* 6:682-690, 1988; Itani, T. *et al. Gene* 56:267-276. 1987; Nicolau, C. *et al. Meth. Enz.* 149:157-176, 1987; Straubinger, R. M. and Papahadjopoulos, D. *Meth. Enz.* 101:512-527, 1983; Wang, C. Y. and Huang, L., P*roc. Natl. Acad. Sci. USA* 84:7851-7855, 1987).

Non-ionic liposomal systems have also been examined to determine their utility in the delivery of drugs to the skin, in particular systems comprising non-ionic surfactant and cholesterol. Non-ionic liposomal formulations comprising Novasome I (glyceryl dilaurate/cholesterol/polyoxyethylene-10-stearyl ether) and Novasome II (glyceryl distearate/ cholesterol/polyoxyethylene-10-stearyl ether) were used to deliver a drug into the dermis of mouse skin. Such formulations with RNAi agent are useful for treating a dermatological disorder.

Liposomes that include iRNA can be made highly deformable. Such deformability can enable the liposomes to penetrate through pore that are smaller than the average radius of the liposome. For example, transfersomes are a type of deformable liposomes. Transferosomes can be made by adding surface edge activators, usually surfactants, to a standard liposomal composition. Transfersomes that include RNAi agent can be delivered, for example, subcutaneously by infection in order to deliver RNAi agent to keratinocytes in the skin. In order to cross intact mammalian skin, lipid vesicles must pass through a series of fine pores, each with a diameter less than 50 nm, under the influence of a suitable transdermal gradient. In addition, due to the lipid properties, these transferosomes can be self-optimizing (adaptive to the shape of pores, *e.g.*, in the skin), self-repairing, and can frequently reach their targets without fragmenting, and often self-loading.

Other formulations amenable to the present invention are described in United States provisional application serial Nos. 61/018,616, filed January 2, 2008; 61/018,611, filed January 2, 2008; 61/039,748, filed March 26, 2008; 61/047,087, filed April 22, 2008 and 61/051,528, filed May 8, 2008. PCT application no PCT/US2007/080331, filed October 3, 2007 also describes formulations that are amenable to the present invention.

Transfersomes are yet another type of liposomes, and are highly deformable lipid aggregates which are attractive candidates for drug delivery vehicles. Transfersomes can be described as lipid droplets which are so highly deformable that they are easily able to penetrate through pores which are smaller than the droplet. Transfersomes are adaptable to the environment in which they are used, *e.g.,* they are self-optimizing (adaptive to the shape of pores in the skin), self-repairing, frequently reach their targets without fragmenting, and often self-loading. To make transfersomes it is possible to add surface edge-activators, usually surfactants, to a standard liposomal composition. Transfersomes have been used to deliver serum albumin to the skin. The transfersome-mediated delivery of serum albumin has been shown to be as effective as subcutaneous injection of a solution containing serum albumin.

Surfactants find wide application in formulations such as emulsions (including microemulsions) and liposomes. The most common way of classifying and ranking the properties of the many different types of surfactants, both natural and synthetic, is by the use of the hydrophile/lipophile balance (HLB). The nature of the hydrophilic group (also known as the "head") provides the most useful means for categorizing the different surfactants used in formulations (Rieger, in Pharmaceutical Dosage Forms, Marcel Dekker, Inc., New York, N.Y., 1988, p. 285).

If the surfactant molecule is not ionized, it is classified as a nonionic surfactant. Nonionic surfactants find wide application in pharmaceutical and cosmetic products and are usable over a wide range of pH values. In general their HLB values range from 2 to about 18 depending on their structure. Nonionic surfactants include nonionic esters such as ethylene

glycol esters, propylene glycol esters, glyceryl esters, polyglyceryl esters, sorbitan esters, sucrose esters, and ethoxylated esters. Nonionic alkanolamides and ethers such as fatty alcohol ethoxylates, propoxylated alcohols, and ethoxylated/propoxylated block polymers are also included in this class. The polyoxyethylene surfactants are the most popular members of the nonionic surfactant class.

If the surfactant molecule carries a negative charge when it is dissolved or dispersed in water, the surfactant is classified as anionic. Anionic surfactants include carboxylates such as soaps, acyl lactylates, acyl amides of amino acids, esters of sulfuric acid such as alkyl sulfates and ethoxylated alkyl sulfates, sulfonates such as alkyl benzene sulfonates, acyl isethionates, acyl taurates and sulfosuccinates, and phosphates. The most important members of the anionic surfactant class are the alkyl sulfates and the soaps.

If the surfactant molecule carries a positive charge when it is dissolved or dispersed in water, the surfactant is classified as cationic. Cationic surfactants include quaternary ammonium salts and ethoxylated amines. The quaternary ammonium salts are the most used members of this class.

If the surfactant molecule has the ability to carry either a positive or negative charge, the surfactant is classified as amphoteric. Amphoteric surfactants include acrylic acid derivatives, substituted alkylamides, N-alkylbetaines and phosphatides.

The use of surfactants in drug products, formulations and in emulsions has been reviewed (Rieger, in Pharmaceutical Dosage Forms, Marcel Dekker, Inc., New York, N.Y., 1988, p. 285).

The iRNA for use in the methods of the invention can also be provided as micellar formulations. "Micelles" are defined herein as a particular type of molecular assembly in which amphipathic molecules are arranged in a spherical structure such that all the hydrophobic portions of the molecules are directed inward, leaving the hydrophilic portions in contact with the surrounding aqueous phase. The converse arrangement exists if the environment is hydrophobic.

A mixed micellar formulation suitable for delivery through transdermal membranes may be prepared by mixing an aqueous solution of the siRNA composition, an alkali metal C_8 to C_{22} alkyl sulphate, and a micelle forming compounds. Exemplary micelle forming compounds include lecithin, hyaluronic acid, pharmaceutically acceptable salts of hyaluronic acid, glycolic acid, lactic acid, chamomile extract, cucumber extract, oleic acid, linoleic acid, linolenic acid, monoolein, monooleates, monolaurates, borage oil, evening of primrose oil, menthol, trihydroxy oxo cholanyl glycine and pharmaceutically acceptable salts thereof, glycerin, polyglycerin, lysine, polylysine, triolein, polyoxyethylene ethers and analogues thereof, polidocanol alkyl ethers and analogues thereof, chenodeoxycholate, deoxycholate, and mixtures thereof. The micelle forming compounds may be added at the same time or after addition of the alkali metal alkyl sulphate. Mixed micelles will form with substantially

any kind of mixing of the ingredients but vigorous mixing in order to provide smaller size micelles.

In one method a first micellar composition is prepared which contains the siRNA composition and at least the alkali metal alkyl sulphate. The first micellar composition is then mixed with at least three micelle forming compounds to form a mixed micellar composition. In another method, the micellar composition is prepared by mixing the siRNA composition, the alkali metal alkyl sulphate and at least one of the micelle forming compounds, followed by addition of the remaining micelle forming compounds, with vigorous mixing.

Phenol and/or m-cresol may be added to the mixed micellar composition to stabilize the formulation and protect against bacterial growth. Alternatively, phenol and/or m-cresol may be added with the micelle forming ingredients. An isotonic agent such as glycerin may also be added after formation of the mixed micellar composition.

For delivery of the micellar formulation as a spray, the formulation can be put into an aerosol dispenser and the dispenser is charged with a propellant. The propellant, which is under pressure, is in liquid form in the dispenser. The ratios of the ingredients are adjusted so that the aqueous and propellant phases become one, *i.e.*, there is one phase. If there are two phases, it is necessary to shake the dispenser prior to dispensing a portion of the contents, *e.g.*, through a metered valve. The dispensed dose of pharmaceutical agent is propelled from the metered valve in a fine spray.

Propellants may include hydrogen-containing chlorofluorocarbons, hydrogen-containing fluorocarbons, dimethyl ether and diethyl ether. In certain embodiments, HFA 134a (1,1,1,2 tetrafluoroethane) may be used.

The specific concentrations of the essential ingredients can be determined by relatively straightforward experimentation. For absorption through the oral cavities, it is often desirable to increase, *e.g.*, at least double or triple, the dosage for through injection or administration through the gastrointestinal tract.

B. *Lipid particles*

iRNAs, *e.g.*, dsRNAs of in the invention may be fully encapsulated in a lipid formulation, *e.g.*, a LNP, or other nucleic acid-lipid particle.

As used herein, the term "LNP" refers to a stable nucleic acid-lipid particle. LNPs contain a cationic lipid, a non-cationic lipid, and a lipid that prevents aggregation of the particle (*e.g.*, a PEG-lipid conjugate). LNPs are extremely useful for systemic applications, as they exhibit extended circulation lifetimes following intravenous (i.v.) injection and accumulate at distal sites (*e.g.*, sites physically separated from the administration site). LNPs include "pSPLP," which include an encapsulated condensing agent-nucleic acid complex as set forth in PCT Publication No. WO 00/03683. The particles of the present invention typically have a mean diameter of about 50 nm to about 150 nm, more typically about 60 nm

to about 130 nm, more typically about 70 nm to about 110 nm, most typically about 70 nm to about 90 nm, and are substantially nontoxic. In addition, the nucleic acids when present in the nucleic acid- lipid particles of the present invention are resistant in aqueous solution to degradation with a nuclease. Nucleic acid-lipid particles and their method of preparation are disclosed in, *e.g.*, U.S. Patent Nos. 5,976,567; 5,981,501; 6,534,484; 6,586,410; 6,815,432; U.S. Publication No. 2010/0324120 and PCT Publication No. WO 96/40964.

In one embodiment, the lipid to drug ratio (mass/mass ratio) (*e.g.*, lipid to dsRNA ratio) will be in the range of from about 1:1 to about 50:1, from about 1:1 to about 25:1, from about 3:1 to about 15:1, from about 4:1 to about 10:1, from about 5:1 to about 9:1, or about 6:1 to about 9:1. Ranges intermediate to the above recited ranges are also contemplated to be part of the invention.

The cationic lipid can be, for example, N,N-dioleyl-N,N-dimethylammonium chloride (DODAC), N,N-distearyl-N,N-dimethylammonium bromide (DDAB), N-(I -(2,3-dioleoyloxy)propyl)-N,N,N-trimethylammonium chloride (DOTAP), N-(I -(2,3-dioleyloxy)propyl)-N,N,N-trimethylammonium chloride (DOTMA), N,N-dimethyl-2,3-dioleyloxy)propylamine (DODMA), 1,2-DiLinoleyloxy-N,N-dimethylaminopropane (DLinDMA), l,2-Dilinolenyloxy-N,N-dimethylaminopropane (DLenDMA), 1,2-Dilinoleylcarbamoyloxy-3-dimethylaminopropane (DLin-C-DAP), 1,2-Dilinoleyoxy-3-(dimethylamino)acetoxypropane (DLin-DAC), 1,2-Dilinoleyoxy-3-morpholinopropane (DLin-MA), 1,2-Dilinoleoyl-3-dimethylaminopropane (DLinDAP), 1,2-Dilinoleylthio-3-dimethylaminopropane (DLin-S-DMA), 1-Linoleoyl-2-linoleyloxy-3-dimethylaminopropane (DLin-2-DMAP), 1,2-Dilinoleyloxy-3-trimethylaminopropane chloride salt (DLin-TMA.Cl), 1,2-Dilinoleoyl-3-trimethylaminopropane chloride salt (DLin-TAP.Cl), 1,2-Dilinoleyloxy-3-(N-methylpiperazino)propane (DLin-MPZ), or 3-(N,N-Dilinoleylamino)-1,2-propanediol (DLinAP), 3-(N,N-Dioleylamino)-1,2-propanedio (DOAP), 1,2-Dilinoleyloxo-3-(2-N,N-dimethylamino)ethoxypropane (DLin-EG-DMA), l,2-Dilinolenyloxy-N,N-dimethylaminopropane (DLinDMA), 2,2-Dilinoleyl-4-dimethylaminomethyl-[1,3]-dioxolane (DLin-K-DMA) or analogs thereof, (3aR,5s,6aS)-N,N-dimethyl-2,2-di((9Z,12Z)-octadeca-9,12-dienyl)tetrahydro-3aH-cyclopenta[d][1,3]dioxol-5-amine (ALN100), (6Z,9Z,28Z,31Z)-heptatriaconta-6,9,28,31-tetraen-19-yl 4-(dimethylamino)butanoate (MC3), 1,1'-(2-(4-(2-((2-(bis(2-hydroxydodecyl)amino)ethyl)(2-hydroxydodecyl)amino)ethyl)piperazin-1-yl)ethylazanediyl)didodecan-2-ol (Tech G1), or a mixture thereof. The cationic lipid can comprise from about 20 mol % to about 50 mol % or about 40 mol % of the total lipid present in the particle.

In another embodiment, the compound 2,2-Dilinoleyl-4-dimethylaminoethyl-[1,3]-dioxolane can be used to prepare lipid-siRNA nanoparticles. Synthesis of 2,2-Dilinoleyl-4-dimethylaminoethyl-[1,3]-dioxolane is described in United States provisional patent

application number 61/107,998 filed on October 23, 2008, which is herein incorporated by reference.

In one embodiment, the lipid-siRNA particle includes 40% 2, 2-Dilinoleyl-4-dimethylaminoethyl-[1,3]-dioxolane: 10% DSPC: 40% Cholesterol: 10% PEG-C-DOMG (mole percent) with a particle size of 63.0 ± 20 nm and a 0.027 siRNA/Lipid Ratio.

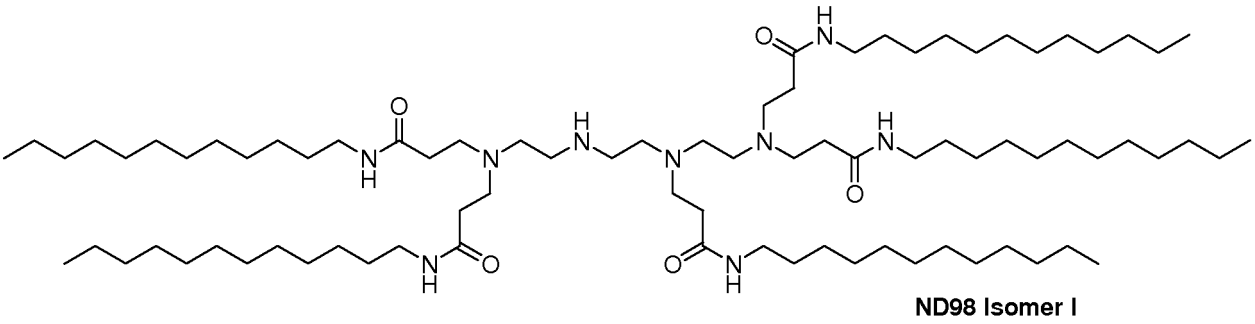
The ionizable/non-cationic lipid can be an anionic lipid or a neutral lipid including, but not limited to, distearoylphosphatidylcholine (DSPC), dioleoylphosphatidylcholine (DOPC), dipalmitoylphosphatidylcholine (DPPC), dioleoylphosphatidylglycerol (DOPG), dipalmitoylphosphatidylglycerol (DPPG), dioleoyl-phosphatidylethanolamine (DOPE), palmitoyloleoylphosphatidylcholine (POPC), palmitoyloleoylphosphatidylethanolamine (POPE), dioleoyl- phosphatidylethanolamine 4-(N-maleimidomethyl)-cyclohexane-l-carboxylate (DOPE-mal), dipalmitoyl phosphatidyl ethanolamine (DPPE), dimyristoylphosphoethanolamine (DMPE), distearoyl-phosphatidyl-ethanolamine (DSPE), 16-O-monomethyl PE, 16-O-dimethyl PE, 18-1 -trans PE, 1 -stearoyl-2-oleoyl-phosphatidyethanolamine (SOPE), cholesterol, or a mixture thereof. The non-cationic lipid can be from about 5 mol % to about 90 mol %, about 10 mol %, or about 58 mol % if cholesterol is included, of the total lipid present in the particle.

The conjugated lipid that inhibits aggregation of particles can be, for example, a polyethyleneglycol (PEG)-lipid including, without limitation, a PEG-diacylglycerol (DAG), a PEG-dialkyloxypropyl (DAA), a PEG-phospholipid, a PEG-ceramide (Cer), or a mixture thereof. The PEG-DAA conjugate can be, for example, a PEG-dilauryloxypropyl (Ci_2), a PEG-dimyristyloxypropyl (Ci_4), a PEG-dipalmityloxypropyl (Ci_6), or a PEG-distearyloxypropyl ($C]_8$). The conjugated lipid that prevents aggregation of particles can be from 0 mol % to about 20 mol % or about 2 mol % of the total lipid present in the particle.

In some embodiments, the nucleic acid-lipid particle further includes cholesterol at, *e.g.*, about 10 mol % to about 60 mol % or about 48 mol % of the total lipid present in the particle.

In one embodiment, the lipidoid ND98·4HCl (MW 1487) (see U.S. Patent Application No. 12/056,230, filed 3/26/2008, which is incorporated herein by reference), Cholesterol (Sigma-Aldrich), and PEG-Ceramide C16 (Avanti Polar Lipids) can be used to prepare lipid-dsRNA nanoparticles (*i.e.,* LNP01 particles). Stock solutions of each in ethanol can be prepared as follows: ND98, 133 mg/ml; Cholesterol, 25 mg/ml, PEG-Ceramide C16, 100 mg/ml. The ND98, Cholesterol, and PEG-Ceramide C16 stock solutions can then be combined in a, *e.g.*, 42:48:10 molar ratio. The combined lipid solution can be mixed with aqueous dsRNA (*e.g.*, in sodium acetate pH 5) such that the final ethanol concentration is about 35-45% and the final sodium acetate concentration is about 100-300 mM. Lipid-dsRNA nanoparticles typically form spontaneously upon mixing. Depending on the desired particle size distribution, the resultant nanoparticle mixture can be extruded through a

polycarbonate membrane (*e.g.*, 100 nm cut-off) using, for example, a thermobarrel extruder, such as Lipex Extruder (Northern Lipids, Inc). In some cases, the extrusion step can be omitted. Ethanol removal and simultaneous buffer exchange can be accomplished by, for example, dialysis or tangential flow filtration. Buffer can be exchanged with, for example, phosphate buffered saline (PBS) at about pH 7, *e.g.*, about pH 6.9, about pH 7.0, about pH 7.1, about pH 7.2, about pH 7.3, or about pH 7.4.



Formula 1

LNP01 formulations are described, *e.g.*, in International Application Publication No. WO 2008/042973, which is hereby incorporated by reference.

Additional exemplary lipid-dsRNA formulations are described in Table A.

Table A.

	Ionizable/Cationic Lipid	**cationic lipid/non-cationic lipid/cholesterol/PEG-lipid conjugate Lipid:siRNA ratio**
LNP-1	l,2-Dilinolenyloxy-N,N-dimethylaminopropane (DLinDMA)	DLinDMA/DPPC/Cholesterol/PEG-cDMA (57.1/7.1/34.4/1.4) lipid:siRNA ~ 7:1
2-XTC	2,2-Dilinoleyl-4-dimethylaminoethyl-[1,3]-dioxolane (XTC)	XTC/DPPC/Cholesterol/PEG-cDMA 57.1/7.1/34.4/1.4 lipid:siRNA ~ 7:1
LNP05	2,2-Dilinoleyl-4-dimethylaminoethyl-[1,3]-dioxolane (XTC)	XTC/DSPC/Cholesterol/PEG-DMG 57.5/7.5/31.5/3.5 lipid:siRNA ~ 6:1
LNP06	2,2-Dilinoleyl-4-dimethylaminoethyl-[1,3]-dioxolane (XTC)	XTC/DSPC/Cholesterol/PEG-DMG 57.5/7.5/31.5/3.5 lipid:siRNA ~ 11:1
LNP07	2,2-Dilinoleyl-4-dimethylaminoethyl-[1,3]-dioxolane (XTC)	XTC/DSPC/Cholesterol/PEG-DMG 60/7.5/31/1.5,

		lipid:siRNA ~ 6:1
LNP08	2,2-Dilinoleyl-4-dimethylaminoethyl-[1,3]-dioxolane (XTC)	XTC/DSPC/Cholesterol/PEG-DMG 60/7.5/31/1.5, lipid:siRNA ~ 11:1
LNP09	2,2-Dilinoleyl-4-dimethylaminoethyl-[1,3]-dioxolane (XTC)	XTC/DSPC/Cholesterol/PEG-DMG 50/10/38.5/1.5 Lipid:siRNA 10:1
LNP10	(3aR,5s,6aS)-N,N-dimethyl-2,2-di((9Z,12Z)-octadeca-9,12-dienyl)tetrahydro-3aH-cyclopenta[d][1,3]dioxol-5-amine (ALN100)	ALN100/DSPC/Cholesterol/PEG-DMG 50/10/38.5/1.5 Lipid:siRNA 10:1
LNP11	(6Z,9Z,28Z,31Z)-heptatriaconta-6,9,28,31-tetraen-19-yl 4-(dimethylamino)butanoate (MC3)	MC-3/DSPC/Cholesterol/PEG-DMG 50/10/38.5/1.5 Lipid:siRNA 10:1
LNP12	1,1'-(2-(4-(2-((2-(bis(2-hydroxydodecyl)amino)ethyl)(2-hydroxydodecyl)amino)ethyl)piperazin-1-yl)ethylazanediyl)didodecan-2-ol (Tech G1)	Tech G1/DSPC/Cholesterol/PEG-DMG 50/10/38.5/1.5 Lipid:siRNA 10:1
LNP13	XTC	XTC/DSPC/Chol/PEG-DMG 50/10/38.5/1.5 Lipid:siRNA: 33:1
LNP14	MC3	MC3/DSPC/Chol/PEG-DMG 40/15/40/5 Lipid:siRNA: 11:1
LNP15	MC3	MC3/DSPC/Chol/PEG-DSG/GalNAc-PEG-DSG 50/10/35/4.5/0.5 Lipid:siRNA: 11:1
LNP16	MC3	MC3/DSPC/Chol/PEG-DMG 50/10/38.5/1.5 Lipid:siRNA: 7:1
LNP17	MC3	MC3/DSPC/Chol/PEG-DSG 50/10/38.5/1.5 Lipid:siRNA: 10:1

LNP18	MC3	MC3/DSPC/Chol/PEG-DMG 50/10/38.5/1.5 Lipid:siRNA: 12:1
LNP19	MC3	MC3/DSPC/Chol/PEG-DMG 50/10/35/5 Lipid:siRNA: 8:1
LNP20	MC3	MC3/DSPC/Chol/PEG-DPG 50/10/38.5/1.5 Lipid:siRNA: 10:1
LNP21	C12-200	C12-200/DSPC/Chol/PEG-DSG 50/10/38.5/1.5 Lipid:siRNA: 7:1
LNP22	XTC	XTC/DSPC/Chol/PEG-DSG 50/10/38.5/1.5 Lipid:siRNA: 10:1

DSPC: distearoylphosphatidylcholine

DPPC: dipalmitoylphosphatidylcholine

PEG-DMG: PEG-didimyristoyl glycerol (C14-PEG, or PEG-C14) (PEG with avg mol wt of 2000)

PEG-DSG: PEG-distyryl glycerol (C18-PEG, or PEG-C18) (PEG with avg mol wt of 2000)

PEG-cDMA: PEG-carbamoyl-1,2-dimyristyloxypropylamine (PEG with avg mol wt of 2000)

LNP (l,2-Dilinolenyloxy-N,N-dimethylaminopropane (DLinDMA)) comprising formulations are described in International Publication No. WO2009/127060, filed April 15, 2009, which is hereby incorporated by reference.

XTC comprising formulations are described, *e.g.*, in U.S. Provisional Serial No. 61/148,366, filed January 29, 2009; U.S. Provisional Serial No. 61/156,851, filed March 2, 2009; U.S. Provisional Serial No. filed June 10, 2009; U.S. Provisional Serial No. 61/228,373, filed July 24, 2009; U.S. Provisional Serial No. 61/239,686, filed September 3, 2009, and International Application No. PCT/US2010/022614, filed January 29, 2010, which are hereby incorporated by reference.

MC3 comprising formulations are described, *e.g.*, in U.S. Publication No. 2010/0324120, filed June 10, 2010, the entire contents of which are hereby incorporated by reference.

ALNY-100 comprising formulations are described, *e.g.*, International patent application number PCT/US09/63933, filed on November 10, 2009, which is hereby incorporated by reference.

C12-200 comprising formulations are described in U.S. Provisional Serial No. 61/175,770, filed May 5, 2009 and International Application No. PCT/US10/33777, filed May 5, 2010, which are hereby incorporated by reference.

Synthesis of ionizable/cationic lipids

Any of the compounds, *e.g.*, cationic lipids and the like, used in the nucleic acid-lipid particles of the invention can be prepared by known organic synthesis techniques, including the methods described in more detail in the Examples. All substituents are as defined below unless indicated otherwise.

"Alkyl" means a straight chain or branched, noncyclic or cyclic, saturated aliphatic hydrocarbon containing from 1 to 24 carbon atoms. Representative saturated straight chain alkyls include methyl, ethyl, n-propyl, n-butyl, n-pentyl, n-hexyl, and the like; while saturated branched alkyls include isopropyl, sec-butyl, isobutyl, tert-butyl, isopentyl, and the like. Representative saturated cyclic alkyls include cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, and the like; while unsaturated cyclic alkyls include cyclopentenyl and cyclohexenyl, and the like.

"Alkenyl" means an alkyl, as defined above, containing at least one double bond between adjacent carbon atoms. Alkenyls include both cis and trans isomers. Representative straight chain and branched alkenyls include ethylenyl, propylenyl, 1-butenyl, 2-butenyl, isobutylenyl, 1-pentenyl, 2-pentenyl, 3-methyl-1-butenyl, 2-methyl-2-butenyl, 2,3-dimethyl-2-butenyl, and the like.

"Alkynyl" means any alkyl or alkenyl, as defined above, which additionally contains at least one triple bond between adjacent carbons. Representative straight chain and branched alkynyls include acetylenyl, propynyl, 1-butynyl, 2-butynyl, 1-pentynyl, 2-pentynyl, 3-methyl-1 butynyl, and the like.

"Acyl" means any alkyl, alkenyl, or alkynyl wherein the carbon at the point of attachment is substituted with an oxo group, as defined below. For example, -C(=O)alkyl, -C(=O)alkenyl, and -C(=O)alkynyl are acyl groups.

"Heterocycle" means a 5- to 7-membered monocyclic, or 7- to 10-membered bicyclic, heterocyclic ring which is either saturated, unsaturated, or aromatic, and which contains from 1 or 2 heteroatoms independently selected from nitrogen, oxygen and sulfur, and wherein the nitrogen and sulfur heteroatoms can be optionally oxidized, and the nitrogen heteroatom can be optionally quaternized, including bicyclic rings in which any of the above heterocycles are fused to a benzene ring. The heterocycle can be attached via any heteroatom or carbon atom. Heterocycles include heteroaryls as defined below. Heterocycles include morpholinyl, pyrrolidinonyl, pyrrolidinyl, piperidinyl, piperizynyl, hydantoinyl, valerolactamyl, oxiranyl,

oxetanyl, tetrahydrofuranyl, tetrahydropyranyl, tetrahydropyridinyl, tetrahydroprimidinyl, tetrahydrothiophenyl, tetrahydrothiopyranyl, tetrahydropyrimidinyl, tetrahydrothiophenyl, tetrahydrothiopyranyl, and the like.

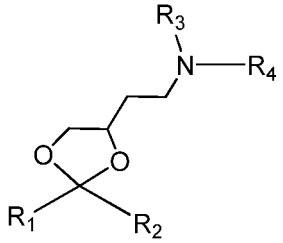
The terms "optionally substituted alkyl", "optionally substituted alkenyl", "optionally substituted alkynyl", "optionally substituted acyl", and "optionally substituted heterocycle" means that, when substituted, at least one hydrogen atom is replaced with a substituent. In the case of an oxo substituent (=O) two hydrogen atoms are replaced. In this regard, substituents include oxo, halogen, heterocycle, -CN, -ORx, -NRxRy, -NRxC(=O)Ry, -NRxSO2Ry, -C(=O)Rx, -C(=O)ORx, -C(=O)NRxRy, –SOnRx and -SOnNRxRy, wherein n is 0, 1 or 2, Rx and Ry are the same or different and independently hydrogen, alkyl or heterocycle, and each of said alkyl and heterocycle substituents can be further substituted with one or more of oxo, halogen, -OH, -CN, alkyl, -ORx, heterocycle, -NRxRy, -NRxC(=O)Ry, -NRxSO2Ry, -C(=O)Rx, -C(=O)ORx, -C(=O)NRxRy, -SOnRx and -SOnNRxRy.

"Halogen" means fluoro, chloro, bromo and iodo.

In some embodiments, the methods of the invention can require the use of protecting groups. Protecting group methodology is well known to those skilled in the art (see, for example, Protective Groups in Organic Synthesis, Green, T.W. *et al.*, Wiley-Interscience, New York City, 1999). Briefly, protecting groups within the context of this invention are any group that reduces or eliminates unwanted reactivity of a functional group. A protecting group can be added to a functional group to mask its reactivity during certain reactions and then removed to reveal the original functional group. In some embodiments an "alcohol protecting group" is used. An "alcohol protecting group" is any group which decreases or eliminates unwanted reactivity of an alcohol functional group. Protecting groups can be added and removed using techniques well known in the art.

Synthesis of Formula A

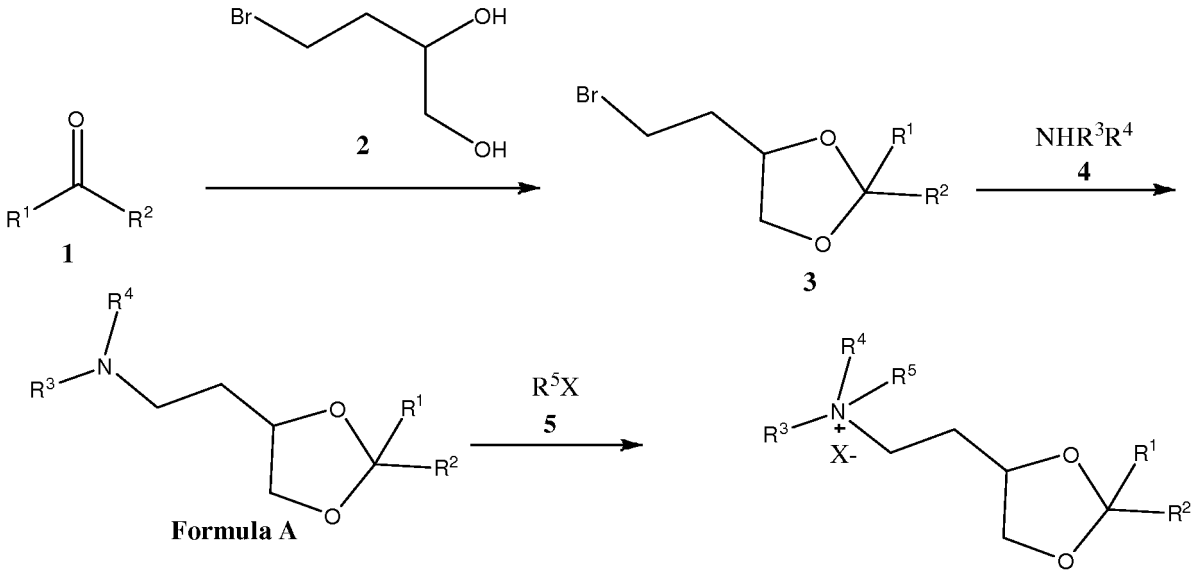
In some embodiments, nucleic acid-lipid particles of the invention are formulated using a cationic lipid of formula A:



where R1 and R2 are independently alkyl, alkenyl or alkynyl, each can be optionally substituted, and R3 and R4 are independently lower alkyl or R3 and R4 can be taken together to form an optionally substituted heterocyclic ring. In some embodiments, the cationic lipid is XTC (2,2-Dilinoleyl-4-dimethylaminoethyl-[1,3]-dioxolane). In general, the lipid of

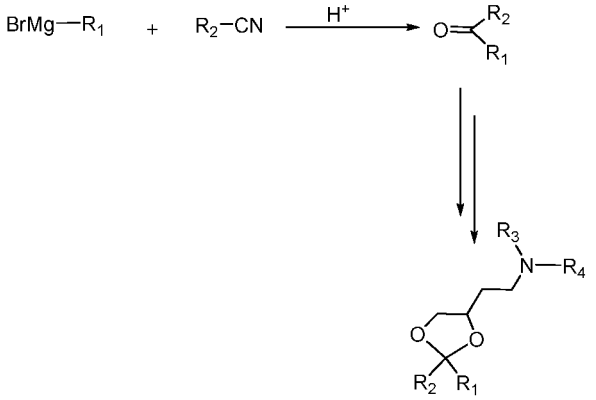
formula A above can be made by the following Reaction Schemes 1 or 2, wherein all substituents are as defined above unless indicated otherwise.

Scheme 1



Lipid A, where R1 and R2 are independently alkyl, alkenyl or alkynyl, each can be optionally substituted, and R3 and R4 are independently lower alkyl or R3 and R4 can be taken together to form an optionally substituted heterocyclic ring, can be prepared according to Scheme 1. Ketone 1 and bromide 2 can be purchased or prepared according to methods known to those of ordinary skill in the art. Reaction of 1 and 2 yields ketal 3. Treatment of ketal 3 with amine 4 yields lipids of formula A. The lipids of formula A can be converted to the corresponding ammonium salt with an organic salt of formula 5, where X is anion counter ion selected from halogen, hydroxide, phosphate, sulfate, or the like.

Scheme 2

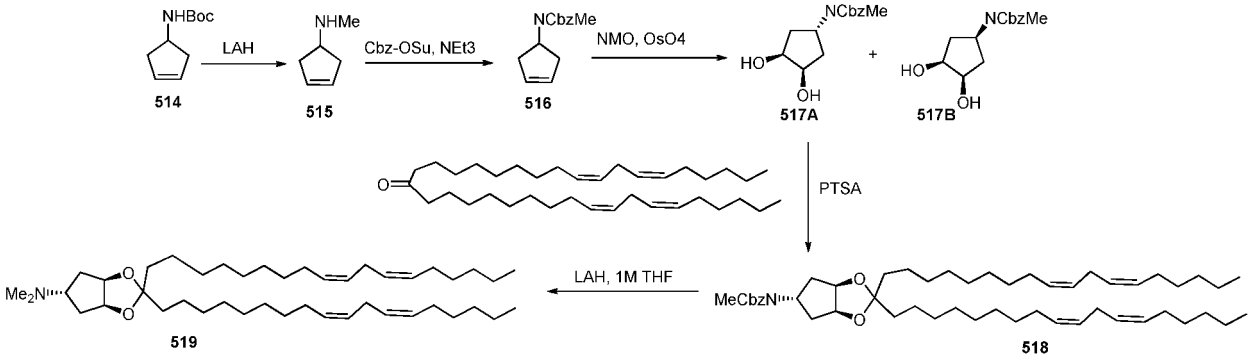


Alternatively, the ketone 1 starting material can be prepared according to Scheme 2. Grignard reagent 6 and cyanide 7 can be purchased or prepared according to methods known to those of ordinary skill in the art. Reaction of 6 and 7 yields ketone 1. Conversion of ketone 1 to the corresponding lipids of formula A is as described in Scheme 1.

Synthesis of MC3

Preparation of DLin-M-C3-DMA (*i.e.*, (6Z,9Z,28Z,31Z)-heptatriaconta-6,9,28,31-tetraen-19-yl 4-(dimethylamino)butanoate) was as follows. A solution of (6Z,9Z,28Z,31Z)-heptatriaconta-6,9,28,31-tetraen-19-ol (0.53 g), 4-N,N-dimethylaminobutyric acid hydrochloride (0.51 g), 4-N,N-dimethylaminopyridine (0.61g) and 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide hydrochloride (0.53 g) in dichloromethane (5 mL) was stirred at room temperature overnight. The solution was washed with dilute hydrochloric acid followed by dilute aqueous sodium bicarbonate. The organic fractions were dried over anhydrous magnesium sulphate, filtered and the solvent removed on a rotovap. The residue was passed down a silica gel column (20 g) using a 1-5% methanol/dichloromethane elution gradient. Fractions containing the purified product were combined and the solvent removed, yielding a colorless oil (0.54 g). *Synthesis of ALNY-100*

Synthesis of ketal 519 [ALNY-100] was performed using the following scheme 3:



Synthesis of 515

To a stirred suspension of LiAlH4 (3.74 g, 0.09852 mol) in 200 ml anhydrous THF in a two neck RBF (1L), was added a solution of 514 (10g, 0.04926mol) in 70 mL of THF slowly at 0 0C under nitrogen atmosphere. After complete addition, reaction mixture was warmed to room temperature and then heated to reflux for 4 h. Progress of the reaction was monitored by TLC. After completion of reaction (by TLC) the mixture was cooled to 0 0C and quenched with careful addition of saturated Na2SO4 solution. Reaction mixture was stirred for 4 h at room temperature and filtered off. Residue was washed well with THF. The filtrate and washings were mixed and diluted with 400 mL dioxane and 26 mL conc. HCl and stirred for 20 minutes at room temperature. The volatilities were stripped off under vacuum to furnish the hydrochloride salt of 515 as a white solid. Yield: 7.12 g 1H-NMR (DMSO, 400MHz): δ= 9.34 (broad, 2H), 5.68 (s, 2H), 3.74 (m, 1H), 2.66-2.60 (m, 2H), 2.50-2.45 (m, 5H).

Synthesis of 516

To a stirred solution of compound 515 in 100 mL dry DCM in a 250 mL two neck RBF, was added NEt3 (37.2 mL, 0.2669 mol) and cooled to 0 0C under nitrogen atmosphere. After a slow addition of N-(benzyloxy-carbonyloxy)-succinimide (20 g, 0.08007 mol) in 50 mL dry DCM, reaction mixture was allowed to warm to room temperature. After completion

of the reaction (2-3 h by TLC) mixture was washed successively with 1N HCl solution (1 x 100 mL) and saturated NaHCO3 solution (1 x 50 mL). The organic layer was then dried over anhyd. Na2SO4 and the solvent was evaporated to give crude material which was purified by silica gel column chromatography to get 516 as sticky mass. Yield: 11g (89%). 1H-NMR (CDCl3, 400MHz): δ = 7.36-7.27(m, 5H), 5.69 (s, 2H), 5.12 (s, 2H), 4.96 (br., 1H) 2.74 (s, 3H), 2.60(m, 2H), 2.30-2.25(m, 2H). LC-MS [M+H] -232.3 (96.94%).

Synthesis of 517A and 517B

The cyclopentene 516 (5 g, 0.02164 mol) was dissolved in a solution of 220 mL acetone and water (10:1) in a single neck 500 mL RBF and to it was added N-methyl morpholine-N-oxide (7.6 g, 0.06492 mol) followed by 4.2 mL of 7.6% solution of OsO4 (0.275 g, 0.00108 mol) in tert-butanol at room temperature. After completion of the reaction (~ 3 h), the mixture was quenched with addition of solid Na2SO3 and resulting mixture was stirred for 1.5 h at room temperature. Reaction mixture was diluted with DCM (300 mL) and washed with water (2 x 100 mL) followed by saturated NaHCO3 (1 x 50 mL) solution, water (1 x 30 mL) and finally with brine (1x 50 mL). Organic phase was dried over an.Na2SO4 and solvent was removed in vacuum. Silica gel column chromatographic purification of the crude material was afforded a mixture of diastereomers, which were separated by prep HPLC. Yield: - 6 g crude

517A - Peak-1 (white solid), 5.13 g (96%). 1H-NMR (DMSO, 400MHz): δ= 7.39-7.31(m, 5H), 5.04(s, 2H), 4.78-4.73 (m, 1H), 4.48-4.47(d, 2H), 3.94-3.93(m, 2H), 2.71(s, 3H), 1.72-1.67(m, 4H). LC-MS - [M+H]-266.3, [M+NH4 +]-283.5 present, HPLC-97.86%. Stereochemistry confirmed by X-ray.

Synthesis of 518

Using a procedure analogous to that described for the synthesis of compound 505, compound 518 (1.2 g, 41%) was obtained as a colorless oil. 1H-NMR (CDCl3, 400MHz): δ= 7.35-7.33(m, 4H), 7.30-7.27(m, 1H), 5.37-5.27(m, 8H), 5.12(s, 2H), 4.75(m,1H), 4.58-4.57(m,2H), 2.78-2.74(m,7H), 2.06-2.00(m,8H), 1.96-1.91(m, 2H), 1.62(m, 4H), 1.48(m, 2H), 1.37-1.25(br m, 36H), 0.87(m, 6H). HPLC-98.65%.

General Procedure for the Synthesis of Compound 519

A solution of compound 518 (1 eq) in hexane (15 mL) was added in a drop-wise fashion to an ice-cold solution of LAH in THF (1 M, 2 eq). After complete addition, the mixture was heated at 40oC over 0.5 h then cooled again on an ice bath. The mixture was carefully hydrolyzed with saturated aqueous Na2SO4 then filtered through celite and reduced to an oil. Column chromatography provided the pure 519 (1.3 g, 68%) which was obtained as a colorless oil. 13C NMR δ = 130.2, 130.1 (x2), 127.9 (x3), 112.3, 79.3, 64.4, 44.7, 38.3, 35.4, 31.5, 29.9 (x2), 29.7, 29.6 (x2), 29.5 (x3), 29.3 (x2), 27.2 (x3), 25.6, 24.5, 23.3, 226, 14.1; Electrospray MS (+ve): Molecular weight for C44H80NO2 (M + H)+ Calc. 654.6, Found 654.6.

Formulations prepared by either the standard or extrusion-free method can be characterized in similar manners. For example, formulations are typically characterized by visual inspection. They should be whitish translucent solutions free from aggregates or sediment. Particle size and particle size distribution of lipid-nanoparticles can be measured by light scattering using, for example, a Malvern Zetasizer Nano ZS (Malvern, USA). Particles should be about 20-300 nm, such as 40-100 nm in size. The particle size distribution should be unimodal. The total dsRNA concentration in the formulation, as well as the entrapped fraction, is estimated using a dye exclusion assay. A sample of the formulated dsRNA can be incubated with an RNA-binding dye, such as Ribogreen (Molecular Probes) in the presence or absence of a formulation disrupting surfactant, *e.g.*, 0.5% Triton-X100. The total dsRNA in the formulation can be determined by the signal from the sample containing the surfactant, relative to a standard curve. The entrapped fraction is determined by subtracting the "free" dsRNA content (as measured by the signal in the absence of surfactant) from the total dsRNA content. Percent entrapped dsRNA is typically >85%. For LNP formulation, the particle size is at least 30 nm, at least 40 nm, at least 50 nm, at least 60 nm, at least 70 nm, at least 80 nm, at least 90 nm, at least 100 nm, at least 110 nm, and at least 120 nm. The suitable range is typically about at least 50 nm to about at least 110 nm, about at least 60 nm to about at least 100 nm, or about at least 80 nm to about at least 90 nm.

Compositions and formulations for oral administration include powders or granules, microparticulates, nanoparticulates, suspensions or solutions in water or non-aqueous media, capsules, gel capsules, sachets, tablets or minitablets. Thickeners, flavoring agents, diluents, emulsifiers, dispersing aids or binders can be desirable. In some embodiments, oral formulations are those in which dsRNAs featured in the invention are administered in conjunction with one or more penetration enhancer surfactants and chelators. Suitable surfactants include fatty acids and/or esters or salts thereof, bile acids and/or salts thereof. Suitable bile acids/salts include chenodeoxycholic acid (CDCA) and ursodeoxychenodeoxycholic acid (UDCA), cholic acid, dehydrocholic acid, deoxycholic acid, glucholic acid, glycholic acid, glycodeoxycholic acid, taurocholic acid, taurodeoxycholic acid, sodium tauro-24,25-dihydro-fusidate and sodium glycodihydrofusidate. Suitable fatty acids include arachidonic acid, undecanoic acid, oleic acid, lauric acid, caprylic acid, capric acid, myristic acid, palmitic acid, stearic acid, linoleic acid, linolenic acid, dicaprate, tricaprate, monoolein, dilaurin, glyceryl 1-monocaprate, 1-dodecylazacycloheptan-2-one, an acylcarnitine, an acylcholine, or a monoglyceride, a diglyceride or a pharmaceutically acceptable salt thereof (*e.g.*, sodium). In some embodiments, combinations of penetration enhancers are used, for example, fatty acids/salts in combination with bile acids/salts. One exemplary combination is the sodium salt of lauric acid, capric acid and UDCA. Further penetration enhancers include polyoxyethylene-9-lauryl

ether, polyoxyethylene-20-cetyl ether. DsRNAs featured in the invention can be delivered orally, in granular form including sprayed dried particles, or complexed to form micro or nanoparticles. DsRNA complexing agents include poly-amino acids; polyimines; polyacrylates; polyalkylacrylates, polyoxethanes, polyalkylcyanoacrylates; cationized gelatins, albumins, starches, acrylates, polyethyleneglycols (PEG) and starches; polyalkylcyanoacrylates; DEAE-derivatized polyimines, pollulans, celluloses and starches. Suitable complexing agents include chitosan, N-trimethylchitosan, poly-L-lysine, polyhistidine, polyornithine, polyspermines, protamine, polyvinylpyridine, polythiodiethylaminomethylethylene P(TDAE), polyaminostyrene (*e.g.,* p-amino), poly(methylcyanoacrylate), poly(ethylcyanoacrylate), poly(butylcyanoacrylate), poly(isobutylcyanoacrylate), poly(isohexylcynaoacrylate), DEAE-methacrylate, DEAE-hexylacrylate, DEAE-acrylamide, DEAE-albumin and DEAE-dextran, polymethylacrylate, polyhexylacrylate, poly(D,L-lactic acid), poly(DL-lactic-co-glycolic acid (PLGA), alginate, and polyethyleneglycol (PEG). Oral formulations for dsRNAs and their preparation are described in detail in U.S. Patent 6,887,906, US Publn. No. 20030027780, and U.S. Patent No. 6,747,014, each of which is incorporated herein by reference.

Compositions and formulations for parenteral, intraparenchymal (into the brain), intrathecal, intraventricular or intrahepatic administration can include sterile aqueous solutions which can also contain buffers, diluents and other suitable additives such as, but not limited to, penetration enhancers, carrier compounds and other pharmaceutically acceptable carriers or excipients.

Pharmaceutical compositions of the present invention include, but are not limited to, solutions, emulsions, and liposome-containing formulations. These compositions can be generated from a variety of components that include, but are not limited to, preformed liquids, self-emulsifying solids and self-emulsifying semisolids. Particularly preferred are formulations that target the liver when treating hepatic disorders such as hepatic carcinoma.

The pharmaceutical formulations of the present invention, which can conveniently be presented in unit dosage form, can be prepared according to conventional techniques well known in the pharmaceutical industry. Such techniques include the step of bringing into association the active ingredients with the pharmaceutical carrier(s) or excipient(s). In general, the formulations are prepared by uniformly and intimately bringing into association the active ingredients with liquid carriers or finely divided solid carriers or both, and then, if necessary, shaping the product.

The compositions of the present invention can be formulated into any of many possible dosage forms such as, but not limited to, tablets, capsules, gel capsules, liquid syrups, soft gels, suppositories, and enemas. The compositions of the present invention can also be formulated as suspensions in aqueous, non-aqueous or mixed media. Aqueous suspensions can further contain substances which increase the viscosity of the suspension

including, for example, sodium carboxymethylcellulose, sorbitol and/or dextran. The suspension can also contain stabilizers.

C. Additional Formulations

i. Emulsions

The compositions of the present invention can be prepared and formulated as emulsions. Emulsions are typically heterogeneous systems of one liquid dispersed in another in the form of droplets usually exceeding 0.1μm in diameter (see *e.g.*, Ansel's Pharmaceutical Dosage Forms and Drug Delivery Systems, Allen, LV., Popovich NG., and Ansel HC., 2004, Lippincott Williams & Wilkins (8th ed.), New York, NY; Idson, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., volume 1, p. 199; Rosoff, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., Volume 1, p. 245; Block in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., volume 2, p. 335; Higuchi *et al.*, in Remington's Pharmaceutical Sciences, Mack Publishing Co., Easton, Pa., 1985, p. 301). Emulsions are often biphasic systems comprising two immiscible liquid phases intimately mixed and dispersed with each other. In general, emulsions can be of either the water-in-oil (w/o) or the oil-in-water (o/w) variety. When an aqueous phase is finely divided into and dispersed as minute droplets into a bulk oily phase, the resulting composition is called a water-in-oil (w/o) emulsion. Alternatively, when an oily phase is finely divided into and dispersed as minute droplets into a bulk aqueous phase, the resulting composition is called an oil-in-water (o/w) emulsion. Emulsions can contain additional components in addition to the dispersed phases, and the active drug which can be present as a solution in either the aqueous phase, oily phase or itself as a separate phase. Pharmaceutical excipients such as emulsifiers, stabilizers, dyes, and anti-oxidants can also be present in emulsions as needed. Pharmaceutical emulsions can also be multiple emulsions that are comprised of more than two phases such as, for example, in the case of oil-in-water-in-oil (o/w/o) and water-in-oil-in-water (w/o/w) emulsions. Such complex formulations often provide certain advantages that simple binary emulsions do not. Multiple emulsions in which individual oil droplets of an o/w emulsion enclose small water droplets constitute a w/o/w emulsion. Likewise a system of oil droplets enclosed in globules of water stabilized in an oily continuous phase provides an o/w/o emulsion.

Emulsions are characterized by little or no thermodynamic stability. Often, the dispersed or discontinuous phase of the emulsion is well dispersed into the external or continuous phase and maintained in this form through the means of emulsifiers or the viscosity of the formulation. Either of the phases of the emulsion can be a semisolid or a solid, as is the case of emulsion-style ointment bases and creams. Other means of stabilizing emulsions entail the use of emulsifiers that can be incorporated into either phase of the emulsion. Emulsifiers can broadly be classified into four categories: synthetic surfactants,

naturally occurring emulsifiers, absorption bases, and finely dispersed solids (see *e.g.*, Ansel's Pharmaceutical Dosage Forms and Drug Delivery Systems, Allen, LV., Popovich NG., and Ansel HC., 2004, Lippincott Williams & Wilkins (8th ed.), New York, NY; Idson, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., volume 1, p. 199).

Synthetic surfactants, also known as surface active agents, have found wide applicability in the formulation of emulsions and have been reviewed in the literature (see *e.g.*, Ansel's Pharmaceutical Dosage Forms and Drug Delivery Systems, Allen, LV., Popovich NG., and Ansel HC., 2004, Lippincott Williams & Wilkins (8th ed.), New York, NY; Rieger, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., volume 1, p. 285; Idson, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), Marcel Dekker, Inc., New York, N.Y., 1988, volume 1, p. 199). Surfactants are typically amphiphilic and comprise a hydrophilic and a hydrophobic portion. The ratio of the hydrophilic to the hydrophobic nature of the surfactant has been termed the hydrophile/lipophile balance (HLB) and is a valuable tool in categorizing and selecting surfactants in the preparation of formulations. Surfactants can be classified into different classes based on the nature of the hydrophilic group: nonionic, anionic, cationic and amphoteric (see *e.g.*, Ansel's Pharmaceutical Dosage Forms and Drug Delivery Systems, Allen, LV., Popovich NG., and Ansel HC., 2004, Lippincott Williams & Wilkins (8th ed.), New York, NY Rieger, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., volume 1, p. 285).

Naturally occurring emulsifiers used in emulsion formulations include lanolin, beeswax, phosphatides, lecithin and acacia. Absorption bases possess hydrophilic properties such that they can soak up water to form w/o emulsions yet retain their semisolid consistencies, such as anhydrous lanolin and hydrophilic petrolatum. Finely divided solids have also been used as good emulsifiers especially in combination with surfactants and in viscous preparations. These include polar inorganic solids, such as heavy metal hydroxides, nonswelling clays such as bentonite, attapulgite, hectorite, kaolin, montmorillonite, colloidal aluminum silicate and colloidal magnesium aluminum silicate, pigments and nonpolar solids such as carbon or glyceryl tristearate.

A large variety of non-emulsifying materials are also included in emulsion formulations and contribute to the properties of emulsions. These include fats, oils, waxes, fatty acids, fatty alcohols, fatty esters, humectants, hydrophilic colloids, preservatives and antioxidants (Block, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., volume 1, p. 335; Idson, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., volume 1, p. 199).

Hydrophilic colloids or hydrocolloids include naturally occurring gums and synthetic polymers such as polysaccharides (for example, acacia, agar, alginic acid, carrageenan, guar gum, karaya gum, and tragacanth), cellulose derivatives (for example, carboxymethylcellulose and carboxypropylcellulose), and synthetic polymers (for example, carbomers, cellulose ethers, and carboxyvinyl polymers). These disperse or swell in water to form colloidal solutions that stabilize emulsions by forming strong interfacial films around the dispersed-phase droplets and by increasing the viscosity of the external phase.

Since emulsions often contain a number of ingredients such as carbohydrates, proteins, sterols and phosphatides that can readily support the growth of microbes, these formulations often incorporate preservatives. Commonly used preservatives included in emulsion formulations include methyl paraben, propyl paraben, quaternary ammonium salts, benzalkonium chloride, esters of p-hydroxybenzoic acid, and boric acid. Antioxidants are also commonly added to emulsion formulations to prevent deterioration of the formulation. Antioxidants used can be free radical scavengers such as tocopherols, alkyl gallates, butylated hydroxyanisole, butylated hydroxytoluene, or reducing agents such as ascorbic acid and sodium metabisulfite, and antioxidant synergists such as citric acid, tartaric acid, and lecithin.

The application of emulsion formulations via dermatological, oral and parenteral routes and methods for their manufacture have been reviewed in the literature (see *e.g.*, Ansel's Pharmaceutical Dosage Forms and Drug Delivery Systems, Allen, LV., Popovich NG., and Ansel HC., 2004, Lippincott Williams & Wilkins (8th ed.), New York, NY; Idson, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., volume 1, p. 199). Emulsion formulations for oral delivery have been very widely used because of ease of formulation, as well as efficacy from an absorption and bioavailability standpoint (see *e.g.*, Ansel's Pharmaceutical Dosage Forms and Drug Delivery Systems, Allen, LV., Popovich NG., and Ansel HC., 2004, Lippincott Williams & Wilkins (8th ed.), New York, NY; Rosoff, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., volume 1, p. 245; Idson, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., volume 1, p. 199). Mineral-oil base laxatives, oil-soluble vitamins and high fat nutritive preparations are among the materials that have commonly been administered orally as o/w emulsions.

ii. Microemulsions

In one embodiment of the present invention, the compositions of iRNAs and nucleic acids are formulated as microemulsions. A microemulsion can be defined as a system of water, oil and amphiphile which is a single optically isotropic and thermodynamically stable liquid solution (see *e.g.*, Ansel's Pharmaceutical Dosage Forms and Drug Delivery Systems, Allen, LV., Popovich NG., and Ansel HC., 2004, Lippincott Williams & Wilkins (8th ed.), New York, NY; Rosoff, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker

(Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., volume 1, p. 245). Typically microemulsions are systems that are prepared by first dispersing an oil in an aqueous surfactant solution and then adding a sufficient amount of a fourth component, generally an intermediate chain-length alcohol to form a transparent system. Therefore, microemulsions have also been described as thermodynamically stable, isotropically clear dispersions of two immiscible liquids that are stabilized by interfacial films of surface-active molecules (Leung and Shah, in: Controlled Release of Drugs: Polymers and Aggregate Systems, Rosoff, M., Ed., 1989, VCH Publishers, New York, pages 185-215). Microemulsions commonly are prepared via a combination of three to five components that include oil, water, surfactant, cosurfactant and electrolyte. Whether the microemulsion is of the water-in-oil (w/o) or an oil-in-water (o/w) type is dependent on the properties of the oil and surfactant used and on the structure and geometric packing of the polar heads and hydrocarbon tails of the surfactant molecules (Schott, in Remington's Pharmaceutical Sciences, Mack Publishing Co., Easton, Pa., 1985, p. 271).

The phenomenological approach utilizing phase diagrams has been extensively studied and has yielded a comprehensive knowledge, to one skilled in the art, of how to formulate microemulsions (see *e.g.*, Ansel's Pharmaceutical Dosage Forms and Drug Delivery Systems, Allen, LV., Popovich NG., and Ansel HC., 2004, Lippincott Williams & Wilkins (8th ed.), New York, NY; Rosoff, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., volume 1, p. 245; Block, in Pharmaceutical Dosage Forms, Lieberman, Rieger and Banker (Eds.), 1988, Marcel Dekker, Inc., New York, N.Y., volume 1, p. 335). Compared to conventional emulsions, microemulsions offer the advantage of solubilizing water-insoluble drugs in a formulation of thermodynamically stable droplets that are formed spontaneously.

Surfactants used in the preparation of microemulsions include, but are not limited to, ionic surfactants, non-ionic surfactants, Brij 96, polyoxyethylene oleyl ethers, polyglycerol fatty acid esters, tetraglycerol monolaurate (ML310), tetraglycerol monooleate (MO310), hexaglycerol monooleate (PO310), hexaglycerol pentaoleate (PO500), decaglycerol monocaprate (MCA750), decaglycerol monooleate (MO750), decaglycerol sequioleate (SO750), decaglycerol decaoleate (DAO750), alone or in combination with cosurfactants. The cosurfactant, usually a short-chain alcohol such as ethanol, 1-propanol, and 1-butanol, serves to increase the interfacial fluidity by penetrating into the surfactant film and consequently creating a disordered film because of the void space generated among surfactant molecules. Microemulsions can, however, be prepared without the use of cosurfactants and alcohol-free self-emulsifying microemulsion systems are known in the art. The aqueous phase can typically be, but is not limited to, water, an aqueous solution of the drug, glycerol, PEG300, PEG400, polyglycerols, propylene glycols, and derivatives of ethylene glycol. The oil phase can include, but is not limited to, materials such as Captex 300, Captex 355,

Capmul MCM, fatty acid esters, medium chain (C8-C12) mono, di, and tri-glycerides, polyoxyethylated glyceryl fatty acid esters, fatty alcohols, polyglycolized glycerides, saturated polyglycolized C8-C10 glycerides, vegetable oils and silicone oil.

Microemulsions are particularly of interest from the standpoint of drug solubilization and the enhanced absorption of drugs. Lipid based microemulsions (both o/w and w/o) have been proposed to enhance the oral bioavailability of drugs, including peptides (see *e.g.*, U.S. Patent Nos. 6,191,105; 7,063,860; 7,070,802; 7,157,099; Constantinides *et al.*, *Pharmaceutical Research*, 1994, 11, 1385-1390; Ritschel, *Meth. Find. Exp. Clin. Pharmacol.*, 1993, 13, 205). Microemulsions afford advantages of improved drug solubilization, protection of drug from enzymatic hydrolysis, possible enhancement of drug absorption due to surfactant-induced alterations in membrane fluidity and permeability, ease of preparation, ease of oral administration over solid dosage forms, improved clinical potency, and decreased toxicity (see *e.g.*, U.S. Patent Nos. 6,191,105; 7,063,860; 7,070,802; 7,157,099; Constantinides *et al.*, *Pharmaceutical Research*, 1994, 11, 1385; Ho *et al.*, *J. Pharm. Sci.,* 1996, 85, 138-143). Often microemulsions can form spontaneously when their components are brought together at ambient temperature. This can be particularly advantageous when formulating thermolabile drugs, peptides or iRNAs. Microemulsions have also been effective in the transdermal delivery of active components in both cosmetic and pharmaceutical applications. It is expected that the microemulsion compositions and formulations of the present invention will facilitate the increased systemic absorption of iRNAs and nucleic acids from the gastrointestinal tract, as well as improve the local cellular uptake of iRNAs and nucleic acids.

Microemulsions of the present invention can also contain additional components and additives such as sorbitan monostearate (Grill 3), Labrasol, and penetration enhancers to improve the properties of the formulation and to enhance the absorption of the iRNAs and nucleic acids of the present invention. Penetration enhancers used in the microemulsions of the present invention can be classified as belonging to one of five broad categories--surfactants, fatty acids, bile salts, chelating agents, and non-chelating non-surfactants (Lee *et al.*, *Critical Reviews in Therapeutic Drug Carrier Systems*, 1991, p. 92). Each of these classes has been discussed above.

iii. Microparticles

An RNAi agent of the invention may be incorporated into a particle, *e.g.*, a microparticle. Microparticles can be produced by spray-drying, but may also be produced by other methods including lyophilization, evaporation, fluid bed drying, vacuum drying, or a combination of these techniques.

iv. Penetration Enhancers

In one embodiment, the present invention employs various penetration enhancers to effect the efficient delivery of nucleic acids, particularly iRNAs, to the skin of animals. Most

drugs are present in solution in both ionized and nonionized forms. However, usually only lipid soluble or lipophilic drugs readily cross cell membranes. It has been discovered that even non-lipophilic drugs can cross cell membranes if the membrane to be crossed is treated with a penetration enhancer. In addition to aiding the diffusion of non-lipophilic drugs across cell membranes, penetration enhancers also enhance the permeability of lipophilic drugs.

Penetration enhancers can be classified as belonging to one of five broad categories, *i.e.*, surfactants, fatty acids, bile salts, chelating agents, and non-chelating non-surfactants (see *e.g.*, Malmsten, M. Surfactants and polymers in drug delivery, Informa Health Care, New York, NY, 2002; Lee *et al.*, Critical Reviews in Therapeutic Drug Carrier Systems, 1991, p.92). Each of the above mentioned classes of penetration enhancers are described below in greater detail.

Surfactants (or "surface-active agents") are chemical entities which, when dissolved in an aqueous solution, reduce the surface tension of the solution or the interfacial tension between the aqueous solution and another liquid, with the result that absorption of iRNAs through the mucosa is enhanced. In addition to bile salts and fatty acids, these penetration enhancers include, for example, sodium lauryl sulfate, polyoxyethylene-9-lauryl ether and polyoxyethylene-20-cetyl ether) (see *e.g.*, Malmsten, M. Surfactants and polymers in drug delivery, Informa Health Care, New York, NY, 2002; Lee *et al.*, Critical Reviews in Therapeutic Drug Carrier Systems, 1991, p.92); and perfluorochemical emulsions, such as FC-43. Takahashi *et al.*, *J. Pharm. Pharmacol.*, 1988, 40, 252).

Various fatty acids and their derivatives which act as penetration enhancers include, for example, oleic acid, lauric acid, capric acid (n-decanoic acid), myristic acid, palmitic acid, stearic acid, linoleic acid, linolenic acid, dicaprate, tricaprate, monoolein (1-monooleoyl-rac-glycerol), dilaurin, caprylic acid, arachidonic acid, glycerol 1-monocaprate, 1-dodecylazacycloheptan-2-one, acylcarnitines, acylcholines, C_{1-20} alkyl esters thereof (*e.g.*, methyl, isopropyl and t-butyl), and mono- and di-glycerides thereof (*i.e.*, oleate, laurate, caprate, myristate, palmitate, stearate, linoleate, *etc.*) (see *e.g.*, Touitou, E., *et al.* Enhancement in Drug Delivery, CRC Press, Danvers, MA, 2006; Lee *et al.*, Critical Reviews in Therapeutic Drug Carrier Systems, 1991, p.92; Muranishi, Critical Reviews in Therapeutic Drug Carrier Systems, 1990, 7, 1-33; El Hariri *et al.*, *J. Pharm. Pharmacol.*, 1992, 44, 651-654).

The physiological role of bile includes the facilitation of dispersion and absorption of lipids and fat-soluble vitamins (see *e.g.*, Malmsten, M. Surfactants and polymers in drug delivery, Informa Health Care, New York, NY, 2002; Brunton, Chapter 38 in: Goodman & Gilman's The Pharmacological Basis of Therapeutics, 9th Ed., Hardman *et al.* Eds., McGraw-Hill, New York, 1996, pp. 934-935). Various natural bile salts, and their synthetic derivatives, act as penetration enhancers. Thus the term "bile salts" includes any of the naturally occurring components of bile as well as any of their synthetic derivatives. Suitable

bile salts include, for example, cholic acid (or its pharmaceutically acceptable sodium salt, sodium cholate), dehydrocholic acid (sodium dehydrocholate), deoxycholic acid (sodium deoxycholate), glucholic acid (sodium glucholate), glycholic acid (sodium glycocholate), glycodeoxycholic acid (sodium glycodeoxycholate), taurocholic acid (sodium taurocholate), taurodeoxycholic acid (sodium taurodeoxycholate), chenodeoxycholic acid (sodium chenodeoxycholate), ursodeoxycholic acid (UDCA), sodium tauro-24,25-dihydro-fusidate (STDHF), sodium glycodihydrofusidate and polyoxyethylene-9-lauryl ether (POE) (see *e.g.*, Malmsten, M. Surfactants and polymers in drug delivery, Informa Health Care, New York, NY, 2002; Lee *et al.*, Critical Reviews in Therapeutic Drug Carrier Systems, 1991, page 92; Swinyard, Chapter 39 In: Remington's Pharmaceutical Sciences, 18th Ed., Gennaro, ed., Mack Publishing Co., Easton, Pa., 1990, pages 782-783; Muranishi, Critical Reviews in Therapeutic Drug Carrier Systems, 1990, 7, 1-33; Yamamoto *et al.*, *J. Pharm. Exp. Ther.*, 1992, 263, 25; Yamashita *et al.*, *J. Pharm. Sci.*, 1990, 79, 579-583).

Chelating agents, as used in connection with the present invention, can be defined as compounds that remove metallic ions from solution by forming complexes therewith, with the result that absorption of iRNAs through the mucosa is enhanced. With regards to their use as penetration enhancers in the present invention, chelating agents have the added advantage of also serving as DNase inhibitors, as most characterized DNA nucleases require a divalent metal ion for catalysis and are thus inhibited by chelating agents (Jarrett, *J. Chromatogr.*, 1993, 618, 315-339). Suitable chelating agents include but are not limited to disodium ethylenediaminetetraacetate (EDTA), citric acid, salicylates (*e.g.*, sodium salicylate, 5-methoxysalicylate and homovanilate), N-acyl derivatives of collagen, laureth-9 and N-amino acyl derivatives of beta-diketones (enamines)(see *e.g.*, Katdare, A. *et al.*, Excipient development for pharmaceutical, biotechnology, and drug delivery, CRC Press, Danvers, MA, 2006; Lee *et al.*, Critical Reviews in Therapeutic Drug Carrier Systems, 1991, page 92; Muranishi, Critical Reviews in Therapeutic Drug Carrier Systems, 1990, 7, 1-33; Buur *et al.*, *J. Control Rel.*, 1990, 14, 43-51).

As used herein, non-chelating non-surfactant penetration enhancing compounds can be defined as compounds that demonstrate insignificant activity as chelating agents or as surfactants but that nonetheless enhance absorption of iRNAs through the alimentary mucosa (see *e.g.*, Muranishi, Critical Reviews in Therapeutic Drug Carrier Systems, 1990, 7, 1-33). This class of penetration enhancers includes, for example, unsaturated cyclic ureas, 1-alkyl- and 1-alkenylazacyclo-alkanone derivatives (Lee *et al.*, Critical Reviews in Therapeutic Drug Carrier Systems, 1991, page 92); and non-steroidal anti-inflammatory agents such as diclofenac sodium, indomethacin and phenylbutazone (Yamashita *et al.*, *J. Pharm. Pharmacol.*, 1987, 39, 621-626).

Agents that enhance uptake of iRNAs at the cellular level can also be added to the pharmaceutical and other compositions of the present invention. For example, cationic lipids,

such as lipofectin (Junichi *et al*, U.S. Pat. No. 5,705,188), cationic glycerol derivatives, and polycationic molecules, such as polylysine (Lollo *et al*., PCT Application WO 97/30731), are also known to enhance the cellular uptake of dsRNAs. Examples of commercially available transfection reagents include, for example Lipofectamine™ (Invitrogen; Carlsbad, CA), Lipofectamine 2000™ (Invitrogen; Carlsbad, CA), 293fectin™ (Invitrogen; Carlsbad, CA), Cellfectin™ (Invitrogen; Carlsbad, CA), DMRIE-C™ (Invitrogen; Carlsbad, CA), FreeStyle™ MAX (Invitrogen; Carlsbad, CA), Lipofectamine™ 2000 CD (Invitrogen; Carlsbad, CA), Lipofectamine™ (Invitrogen; Carlsbad, CA), RNAiMAX (Invitrogen; Carlsbad, CA), Oligofectamine™ (Invitrogen; Carlsbad, CA), Optifect™ (Invitrogen; Carlsbad, CA), X-tremeGENE Q2 Transfection Reagent (Roche; Grenzacherstrasse, Switzerland), DOTAP Liposomal Transfection Reagent (Grenzacherstrasse, Switzerland), DOSPER Liposomal Transfection Reagent (Grenzacherstrasse, Switzerland), or Fugene (Grenzacherstrasse, Switzerland), Transfectam® Reagent (Promega; Madison, WI), TransFast™ Transfection Reagent (Promega; Madison, WI), Tfx™-20 Reagent (Promega; Madison, WI), Tfx™-50 Reagent (Promega; Madison, WI), DreamFect™ (OZ Biosciences; Marseille, France), EcoTransfect (OZ Biosciences; Marseille, France), TransPass^a D1 Transfection Reagent (New England Biolabs; Ipswich, MA, USA), LyoVec™/LipoGen™ (Invitrogen; San Diego, CA, USA), PerFectin Transfection Reagent (Genlantis; San Diego, CA, USA), NeuroPORTER Transfection Reagent (Genlantis; San Diego, CA, USA), GenePORTER Transfection reagent (Genlantis; San Diego, CA, USA), GenePORTER 2 Transfection reagent (Genlantis; San Diego, CA, USA), Cytofectin Transfection Reagent (Genlantis; San Diego, CA, USA), BaculoPORTER Transfection Reagent (Genlantis; San Diego, CA, USA), TroganPORTER™ transfection Reagent (Genlantis; San Diego, CA, USA), RiboFect (Bioline; Taunton, MA, USA), PlasFect (Bioline; Taunton, MA, USA), UniFECTOR (B-Bridge International; Mountain View, CA, USA), SureFECTOR (B-Bridge International; Mountain View, CA, USA), or HiFect™ (B-Bridge International, Mountain View, CA, USA), among others.

Other agents can be utilized to enhance the penetration of the administered nucleic acids, including glycols such as ethylene glycol and propylene glycol, pyrrols such as 2-pyrrol, azones, and terpenes such as limonene and menthone.

v. Carriers

Certain compositions of the present invention also incorporate carrier compounds in the formulation. As used herein, "carrier compound" or "carrier" can refer to a nucleic acid, or analog thereof, which is inert (*i.e*., does not possess biological activity *per se*) but is recognized as a nucleic acid by *in vivo* processes that reduce the bioavailability of a nucleic acid having biological activity by, for example, degrading the biologically active nucleic acid or promoting its removal from circulation. The coadministration of a nucleic acid and a carrier compound, typically with an excess of the latter substance, can result in a substantial

reduction of the amount of nucleic acid recovered in the liver, kidney or other extracirculatory reservoirs, presumably due to competition between the carrier compound and the nucleic acid for a common receptor. For example, the recovery of a partially phosphorothioate dsRNA in hepatic tissue can be reduced when it is coadministered with polyinosinic acid, dextran sulfate, polycytidic acid or 4-acetamido-4'isothiocyano-stilbene-2,2'-disulfonic acid (Miyao *et al.*, DsRNA Res. Dev., 1995, 5, 115-121; Takakura *et al.*, DsRNA & Nucl. Acid Drug Dev., 1996, 6, 177-183.

vi. Excipients

In contrast to a carrier compound, a "pharmaceutical carrier" or "excipient" is a pharmaceutically acceptable solvent, suspending agent or any other pharmacologically inert vehicle for delivering one or more nucleic acids to an animal. The excipient can be liquid or solid and is selected, with the planned manner of administration in mind, so as to provide for the desired bulk, consistency, *etc.*, when combined with a nucleic acid and the other components of a given pharmaceutical composition. Typical pharmaceutical carriers include, but are not limited to, binding agents (*e.g.*, pregelatinized maize starch, polyvinylpyrrolidone or hydroxypropyl methylcellulose, *etc.*); fillers (*e.g.*, lactose and other sugars, microcrystalline cellulose, pectin, gelatin, calcium sulfate, ethyl cellulose, polyacrylates or calcium hydrogen phosphate, *etc.*); lubricants (*e.g.*, magnesium stearate, talc, silica, colloidal silicon dioxide, stearic acid, metallic stearates, hydrogenated vegetable oils, corn starch, polyethylene glycols, sodium benzoate, sodium acetate, *etc.*); disintegrants (*e.g.*, starch, sodium starch glycolate, *etc.*); and wetting agents (*e.g.*, sodium lauryl sulphate, *etc*).

Pharmaceutically acceptable organic or inorganic excipients suitable for non-parenteral administration which do not deleteriously react with nucleic acids can also be used to formulate the compositions of the present invention. Suitable pharmaceutically acceptable carriers include, but are not limited to, water, salt solutions, alcohols, polyethylene glycols, gelatin, lactose, amylose, magnesium stearate, talc, silicic acid, viscous paraffin, hydroxymethylcellulose, polyvinylpyrrolidone and the like.

Formulations for topical administration of nucleic acids can include sterile and non-sterile aqueous solutions, non-aqueous solutions in common solvents such as alcohols, or solutions of the nucleic acids in liquid or solid oil bases. The solutions can also contain buffers, diluents and other suitable additives. Pharmaceutically acceptable organic or inorganic excipients suitable for non-parenteral administration which do not deleteriously react with nucleic acids can be used.

Suitable pharmaceutically acceptable excipients include, but are not limited to, water, salt solutions, alcohol, polyethylene glycols, gelatin, lactose, amylose, magnesium stearate, talc, silicic acid, viscous paraffin, hydroxymethylcellulose, polyvinylpyrrolidone and the like.

vii. Other Components

The compositions of the present invention can additionally contain other adjunct components conventionally found in pharmaceutical compositions, at their art-established usage levels. Thus, for example, the compositions can contain additional, compatible, pharmaceutically-active materials such as, for example, antipruritics, astringents, local anesthetics or anti-inflammatory agents, or can contain additional materials useful in physically formulating various dosage forms of the compositions of the present invention, such as dyes, flavoring agents, preservatives, antioxidants, opacifiers, thickening agents and stabilizers. However, such materials, when added, should not unduly interfere with the biological activities of the components of the compositions of the present invention. The formulations can be sterilized and, if desired, mixed with auxiliary agents, *e.g.*, lubricants, preservatives, stabilizers, wetting agents, emulsifiers, salts for influencing osmotic pressure, buffers, colorings, flavorings and/or aromatic substances and the like which do not deleteriously interact with the nucleic acid(s) of the formulation.

Aqueous suspensions can contain substances which increase the viscosity of the suspension including, for example, sodium carboxymethylcellulose, sorbitol and/or dextran. The suspension can also contain stabilizers.

In some embodiments, pharmaceutical compositions featured in the invention include (a) one or more iRNA compounds and (b) one or more agents which function by a non-RNAi mechanism and which are useful in treating a bleeding disorder. Examples of such agents include, but are not lmited to an anti-inflammatory agent, anti-steatosis agent, anti-viral, and/or anti-fibrosis agent. In addition, other substances commonly used to protect the liver, such as silymarin, can also be used in conjunction with the *iRNAs described herein.* Other agents useful for treating liver diseases include telbivudine, entecavir, and protease inhibitors such as telaprevir and other disclosed, for example, in Tung *et al.*, U.S. Application Publication Nos. 2005/0148548, 2004/0167116, and 2003/0144217; and in Hale *et al.*, U.S. Application Publication No. 2004/0127488.

Toxicity and therapeutic efficacy of such compounds can be determined by standard pharmaceutical procedures in cell cultures or experimental animals, *e.g.*, for determining the LD50 (the dose lethal to 50% of the population) and the ED50 (the dose therapeutically effective in 50% of the population). The dose ratio between toxic and therapeutic effects is the therapeutic index and it can be expressed as the ratio LD50/ED50. Compounds that exhibit high therapeutic indices are preferred.

The data obtained from cell culture assays and animal studies can be used in formulating a range of dosage for use in humans. The dosage of compositions featured herein in the invention lies generally within a range of circulating concentrations that include the ED50 with little or no toxicity. The dosage can vary within this range depending upon the dosage form employed and the route of administration utilized. For any compound used in the methods featured in the invention, the therapeutically effective dose can be estimated

initially from cell culture assays. A dose can be formulated in animal models to achieve a circulating plasma concentration range of the compound or, when appropriate, of the polypeptide product of a target sequence (*e.g.*, achieving a decreased concentration of the polypeptide) that includes the IC_{50} (*i.e.*, the concentration of the test compound which achieves a half-maximal inhibition of symptoms) as determined in cell culture. Such information can be used to more accurately determine useful doses in humans. Levels in plasma can be measured, for example, by high performance liquid chromatography.

In addition to their administration, as discussed above, the iRNAs featured in the invention can be administered in combination with other known agents effective in treatment of pathological processes that are mediated by iron overload and that can be treated by inhibiting TMPRSS6 expression. In any event, the administering physician can adjust the amount and timing of iRNA administration on the basis of results observed using standard measures of efficacy known in the art or described herein.

V. Methods For Inhibiting TMPRSS6 Expression

The present invention provides methods of inhibiting expression of TMPRSS6 (matriptase-2) in a cell. The methods include contacting a cell with an RNAi agent, *e.g.*, a double stranded RNAi agent, in an amount effective to inhibit expression of the TMPRSS6 in the cell, thereby inhibiting expression of the TMPRSS6 in the cell.

Contacting of a cell with a double stranded RNAi agent may be done *in vitro* or *in vivo*. Contacting a cell *in vivo* with the RNAi agent includes contacting a cell or group of cells within a subject, *e.g.*, a human subject, with the RNAi agent. Combinations of *in vitro* and *in vivo* methods of contacting are also possible. Contacting may be direct or indirect, as discussed above. Furthermore, contacting a cell may be accomplished via a targeting ligand, including any ligand described herein or known in the art. In preferred embodiments, the targeting ligand is a carbohydrate moiety, *e.g.*, a $GalNAc_3$ ligand, or any other ligand that directs the RNAi agent to a site of interest, *e.g.*, the liver of a subject.

The term "inhibiting," as used herein, is used interchangeably with "reducing," "silencing," "downregulating" and other similar terms, and includes any level of inhibition.

The phrase "inhibiting expression of a TMPRSS6" is intended to refer to inhibition of expression of any TMPRSS6 gene (such as, *e.g.*, a mouse TMPRSS6 gene, a rat TMPRSS6 gene, a monkey TMPRSS6 gene, or a human TMPRSS6 gene) as well as variants or mutants of a TMPRSS6 gene. Thus, the TMPRSS6 gene may be a wild-type TMPRSS6 gene, a mutant TMPRSS6 gene, or a transgenic TMPRSS6 gene in the context of a genetically manipulated cell, group of cells, or organism.

"Inhibiting expression of a TMPRSS6 gene" includes any level of inhibition of a TMPRSS6 gene, *e.g.*, at least partial suppression of the expression of a TMPRSS6 gene. The expression of the TMPRSS6 gene may be assessed based on the level, or the change in the

level, of any variable associated with TMPRSS6 gene expression, *e.g.*, TMPRSS6 mRNA level, TMPRSS6 protein level, or lipid levels. This level may be assessed in an individual cell or in a group of cells, including, for example, a sample derived from a subject.

Inhibition may be assessed by a decrease in an absolute or relative level of one or more variables that are associated with TMPRSS6 expression compared with a control level. The control level may be any type of control level that is utilized in the art, *e.g.*, a pre-dose baseline level, or a level determined from a similar subject, cell, or sample that is untreated or treated with a control (such as, *e.g.*, buffer only control or inactive agent control).

In some embodiments of the methods of the invention, expression of a TMPRSS6 gene is inhibited by at least about 5%, at least about 10%, at least about 15%, at least about 20%, at least about 25%, at least about 30%, at least about 35%, at least about 40%, at least about 45%, at least about 50%, at least about 55%, at least about 60%, at least about 65%, at least about 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 91%, at least about 92%, at least about 93%, at least about 94%. at least about 95%, at least about 96%, at least about 97%, at least about 98%, or at least about 99%.

Inhibition of the expression of a TMPRSS6 gene may be manifested by a reduction of the amount of mRNA expressed by a first cell or group of cells (such cells may be present, for example, in a sample derived from a subject) in which a TMPRSS6 gene is transcribed and which has or have been treated (*e.g.*, by contacting the cell or cells with an RNAi agent of the invention, or by administering an RNAi agent of the invention to a subject in which the cells are or were present) such that the expression of a TMPRSS6 gene is inhibited, as compared to a second cell or group of cells substantially identical to the first cell or group of cells but which has not or have not been so treated (control cell(s)). In preferred embodiments, the inhibition is assessed by expressing the level of mRNA in treated cells as a percentage of the level of mRNA in control cells, using the following formula:

$$\frac{(\text{mRNA in control cells}) - (\text{mRNA in treated cells})}{(\text{mRNA in control cells})} \bullet 100\%$$

Alternatively, inhibition of the expression of a TMPRSS6 gene may be assessed in terms of a reduction of a parameter that is functionally linked to TMPRSS6 gene expression, *e.g.*, TMPRSS6 protein expression, hepcidin gene or protein expression, or iron levels in tissues or serum. TMPRSS6 gene silencing may be determined in any cell expressing TMPRSS6, either constitutively or by genomic engineering, and by any assay known in the art. The liver is the major site of TMPRSS6 expression. Other significant sites of expression include the kidneys and the uterus.

Inhibition of the expression of a TMPRSS6 protein may be manifested by a reduction in the level of the TMPRSS6 protein that is expressed by a cell or group of cells (*e.g.*, the level of protein expressed in a sample derived from a subject). As explained above for the assessment of mRNA suppression, the inhibiton of protein expression levels in a treated cell

or group of cells may similarly be expressed as a percentage of the level of protein in a control cell or group of cells.

A control cell or group of cells that may be used to assess the inhibition of the expression of a TMPRSS6 gene includes a cell or group of cells that has not yet been contacted with an RNAi agent of the invention. For example, the control cell or group of cells may be derived from an individual subject (*e.g.*, a human or animal subject) prior to treatment of the subject with an RNAi agent.

The level of TMPRSS6 mRNA that is expressed by a cell or group of cells may be determined using any method known in the art for assessing mRNA expression. In one embodiment, the level of expression of TMPRSS6 in a sample is determined by detecting a transcribed polynucleotide, or portion thereof, *e.g.,* mRNA of the TMPRSS6 gene. RNA may be extracted from cells using RNA extraction techniques including, for example, using acid phenol/guanidine isothiocyanate extraction (RNAzol B; Biogenesis), RNeasy RNA preparation kits (Qiagen) or PAXgene (PreAnalytix, Switzerland). Typical assay formats utilizing ribonucleic acid hybridization include nuclear run-on assays, RT-PCR, RNase protection assays (Melton *et al.*, *Nuc. Acids Res.* 12:7035), Northern blotting, *in situ* hybridization, and microarray analysis.

In one embodiment, the level of expression of TMPRSS6 is determined using a nucleic acid probe. The term "probe", as used herein, refers to any molecule that is capable of selectively binding to a specific TMPRSS6. Probes can be synthesized by one of skill in the art, or derived from appropriate biological preparations. Probes may be specifically designed to be labeled. Examples of molecules that can be utilized as probes include, but are not limited to, RNA, DNA, proteins, antibodies, and organic molecules.

Isolated mRNA can be used in hybridization or amplification assays that include, but are not limited to, Southern or Northern analyses, polymerase chain reaction (PCR) analyses and probe arrays. One method for the determination of mRNA levels involves contacting the isolated mRNA with a nucleic acid molecule (probe) that can hybridize to TMPRSS6 mRNA. In one embodiment, the mRNA is immobilized on a solid surface and contacted with a probe, for example by running the isolated mRNA on an agarose gel and transferring the mRNA from the gel to a membrane, such as nitrocellulose. In an alternative embodiment, the probe(s) are immobilized on a solid surface and the mRNA is contacted with the probe(s), for example, in an Affymetrix gene chip array. A skilled artisan can readily adapt known mRNA detection methods for use in determining the level of TMPRSS6 mRNA.

An alternative method for determining the level of expression of TMPRSS6 in a sample involves the process of nucleic acid amplification and/or reverse transcriptase (to prepare cDNA) of for example mRNA in the sample, *e.g.*, by RT-PCR (the experimental embodiment set forth in Mullis, 1987, U.S. Pat. No. 4,683,202), ligase chain reaction (Barany (1991) *Proc. Natl. Acad. Sci. USA* 88:189-193), self sustained sequence replication (Guatelli

et al. (1990) *Proc. Natl. Acad. Sci. USA* 87:1874-1878), transcriptional amplification system (Kwoh *et al.* (1989) *Proc. Natl. Acad. Sci. USA* 86:1173-1177), Q-Beta Replicase (Lizardi *et al.* (1988) *Bio/Technology* 6:1197), rolling circle replication (Lizardi et al., U.S. Pat. No. 5,854,033) or any other nucleic acid amplification method, followed by the detection of the amplified molecules using techniques well known to those of skill in the art. These detection schemes are especially useful for the detection of nucleic acid molecules if such molecules are present in very low numbers. In particular aspects of the invention, the level of expression of TMPRSS6 is determined by quantitative fluorogenic RT-PCR (*i.e.*, the TaqMan™ System).

The expression levels of TMPRSS6 mRNA may be monitored using a membrane blot (such as used in hybridization analysis such as Northern, Southern, dot, and the like), or microwells, sample tubes, gels, beads or fibers (or any solid support comprising bound nucleic acids). See U.S. Pat. Nos. 5,770,722, 5,874,219, 5,744,305, 5,677,195 and 5,445,934, which are incorporated herein by reference. The determination of TMPRSS6 expression level may also comprise using nucleic acid probes in solution.

In preferred embodiments, the level of mRNA expression is assessed using branched DNA (bDNA) assays or real time PCR (qPCR). The use of these methods is described and exemplified in the Examples presented herein.

The level of TMPRSS6 protein expression may be determined using any method known in the art for the measurement of protein levels. Such methods include, for example, electrophoresis, capillary electrophoresis, high performance liquid chromatography (HPLC), thin layer chromatography (TLC), hyperdiffusion chromatography, fluid or gel precipitin reactions, absorption spectroscopy, a colorimetric assays, spectrophotometric assays, flow cytometry, immunodiffusion (single or double), immunoelectrophoresis, Western blotting, radioimmunoassay (RIA), enzyme-linked immunosorbent assays (ELISAs), immunofluorescent assays, electrochemiluminescence assays, and the like.

The term "sample" as used herein refers to a collection of similar fluids, cells, or tissues isolated from a subject, as well as fluids, cells, or tissues present within a subject. Examples of biological fluids include blood, serum and serosal fluids, plasma, lymph, urine, cerebrospinal fluid, saliva, ocular fluids, and the like. Tissue samples may include samples from tissues, organs or localized regions. For example, samples may be derived from particular organs, parts of organs, or fluids or cells within those organs. In certain embodiments, samples may be derived from the liver (*e.g.*, whole liver or certain segments of liver or certain types of cells in the liver, such as, *e.g.*, hepatocytes). In preferred embodiments, a "sample derived from a subject" refers to blood or plasma drawn from the subject. In further embodiments, a "sample derived from a subject" refers to liver tissue derived from the subject.

In some embodiments of the methods of the invention, the RNAi agent is administered to a subject such that the RNAi agent is delivered to a specific site within the subject. The inhibition of expression of TMPRSS6 may be assessed using measurements of the level or change in the level of TMPRSS6 mRNA or TMPRSS6 protein in a sample derived from fluid or tissue from the specific site within the subject. In preferred embodiments, the site is the liver. The site may also be a subsection or subgroup of cells from any one of the aforementioned sites. The site may also include cells that express a particular type of receptor.

VI. Methods for Treating or Preventing a TMPRSS6 Associated Disorder

The present invention also provides methods for treating or preventing diseases and conditions that can be modulated by TMPRSS6 gene expression. For example, the compositions described herein can be used to treat any disorder associated with iron overload, *e.g.*, a thalassemia (*e.g.*, β-thalassemia or α-thalassemia), primary hemochromatosis, secondary hemochromatosis, severe juvenile hemochromatosis, erythropoietic porphyria, sideroblastic anemia, hemolytic anemia, dyserythropoietic anemia, or sickle-cell anemia. In one embodiment, a TMPRSS6 iRNA is used to treat a hemoglobinopathy. The TMPRSS6 iRNAs of the invention can also be used to treat elevated levels of iron due to other conditions, such as chronic alcoholism.

In thalassemias, the bone marrow synthesizes insufficient amounts of a hemoglobin chain; this in turn reduces the production of red blood cells and causes anemia. Either the α or the β chain may be affected, but β thalassemias are more common. Newborn babies are healthy because their bodies still produce HbF, which does not have β chains; during the first few months of life, the bone marrow switches to producing HbA, and symptoms start to appear.

β-thalassemias result from mutation with either non-expressing (β°) or low expressing (β+) alleles of the HBB gene, β-thalassemias vary in severity depending on the genotype, and include minor/trait β-thalassemia (β/ β° or β/ β+), intermedia β-thalassemia (β°/β+), and major β-thalassemia (β° /β° or β"7 β+).

Thalassemia intermedia (TI) typically presents with little hemolysis, while major β-thalassemia (TM) is typically accompanied by abundant hemolysis which causes, e.g., anemia and splenomegaly; and highly ineffective erythropoiesis, which causes bone marrow drive (skeletal changes, oteopenia), increased erythropoietin synthesis, hepato-splenomegaly, consumption of haematinics (megablastic anemia), and high uric acid in blood. The iRNAs of the invention, *e.g.*, TMPRSS6 iRNAs, are better suited for treating the iron overload that typically accompanies thalassemia's that are more TI like (*e.g.*, for treating individuals having a β°/β+, β/ β° or β/ β+ genotype).

Symptoms of β-thalassemias also include, *e.g.*, complication due to therapy, *e.g.*, iron overload, which causes endocrinopathy, liver fibrosis and cardiac fibrosis. Administration of an iRNA agent that targets TMPRSS6 can be effective to treat one or more of these symptoms.

α-thalassemias result from mutation with either non-expressing (a°) or low expressing (a+) alleles of the HBA1 or HBA2 genes, orthalassemias vary in severity depending on the genotype, and include trait thalassemia (-α/αα), Hb Bart and Hydrops fetalis (a° /a°), a-Thalaseemia minor (— /αα), (-α/-α), and HbH disease (-/-a). Lower a-globin chains are produced, resulting in an excess of β chains in adults and excess γ chains in newborns. The excess β chains form unstable tetramers (called Hemoglobin H or HbH of 4 beta chains), which have abnormal oxygen dissociation curves. Administration of an iRNA agent that targets TMPRSS6 can be effective to treat iron overload in a subject who has an a-thalassemias.

Symptoms of hemochromatosis include, *e.g.*, abdominal pain, joint pain, fatigue, lack of energy, weakness, darkening of the skin (often referred to as "bronzing"), and loss of body hair. Administration of an iRNA agent that targets TMPRSS6 can be effective to treat one or more of these symptoms.

Other symptoms associated with iron overload include increased risk for liver disease (cirrhosis, cancer), heart attack or heart failure, diabetes mellitus, osteoarthritis, osteoporosis, metabolic syndrome, hypothyroidism, hypogonadism, and in some cases premature death. Iron mismanagement resulting in overload can also accelerate such neurodegenerative diseases as Alzheimer's, early-onset Parkinson's, Huntington's, epilepsy and multiple sclerosis. Administration of an iRNA agent that targets TMPRSS6, *e.g.*, an iRNA described in Tables 1 or 2 can treat one or more of these symptoms, or prevent the development or progression of a disease or disorder that is aggrevated by increased iron levels.

The methods of the invention further relate to the use of an iRNA agent or a pharmaceutical composition thereof, *e.g.*, for treating a disorder associated with iron overload, in combination with other pharmaceuticals and/or other therapeutic methods, *e.g.*, with known pharmaceuticals and/or known therapeutic methods, such as, for example, those which are currently employed for treating these disorders. For example, in certain embodiments, an iRNA agent targeting TMPRSS6 is administered in combination with, *e.g.*, iron chelators (*e.g.*, desferoxamine), folic acid, a blood transfusion, a phlebotomy, agents to manage ulcers, agents to increase fetal hemoglobin levels (*e.g.*, hydroxyurea), agents to control infection (*e.g.*, antibiotics and antivirals), agents to treat thrombotic state, or a stem cell or bone marrow transplant. A stem cell transplant can utilize stem cells from an umbilical cord, such as from a relative, *e.g.*, a sibling. Exemplary iron chelators include desferoxamine, Deferasirox (Exjade), deferiprone, vitamin E, wheat germ oil, tocophersolan, and indicaxanthin.

The iRNA agent and an additional therapeutic agent can be administered in the same composition, *e.g.*, parenterally, or the additional therapeutic agent can be administered as part of a separate composition or by another method described herein. Administration of the iRNA agent and the additional therapeutic agent can be at the same time, or at different times and, in any order.

Administration of the iRNA agent of the invention can lower iron levels, lower ferritin levels, and/or lower transferrin saturation levels. For example, administration of the dsRNA can lower serum iron levels and/or lower serum ferritin levels. Transferrin saturation levels can be lowered by 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, or more. In another embodiment, the transferrin saturation levels remain lower for 7 days, 10 days, 20 days, 30 days, or more following administration.

Transferrin saturation levels can be lowered to below 50%, below 45%, below 40%, below 35%, below 35%, below 30%, below 25%, below 20%, below 15%, or lower. In another embodiment, the lower transferrin saturation levels are maintained for 7 days, 10 days, 20 days, 30 days, or more following administration. Transferrin saturation is a measure of the amount of iron bound to serum transferrin, and corresponds to the ratio of serum iron and total iron-binding capacity.

Serum iron levels can be lowered by 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, or more. In another embodiment, the serum iron levels remain lower for 7 days, 10 days, 20 days, 30 days, or more following administration.

Administration of the iRNA agent of the invention preferably results in lowered iron levels in the blood, and more particularly in the serum, or in one or more tissues of the mammal. In some embodiments, iron levels are decreased by at least 10%, 15%, 20%, 25%, 30%, 40%, 50%, 60%, 70%, 80%, 90% or more, as compared to pretreatment levels.

By "lower" in this context is meant a statistically significant decrease in such level. The decrease can be, for example, at least 10%, at least 20%, at least 30%, at least 40% or more, and is preferably down to a level accepted as within the range of normal for an individual without such disorder.

Administration of the iRNA agent of the invention can increase serum hepcidin levels, and/or increase hepcidin gene expression. For example, administration of the dsRNA can increase serum hepcidin by at least about 10%, 25%, 50%, 100%, 150%, 200%, 250%, 300%, or more. In a further example, administration of the dsRNA can increase hepcidin mRNA levels by at least about 1.5-fold, 2-fold, 3-fold, 4-fold, 5-fold, or greater.

Efficacy of treatment or prevention of disease can be assessed, for example by measuring disease progression, disease remission, symptom severity, reduction in pain, quality of life, dose of a medication required to sustain a treatment effect, level of a disease marker or any other measurable parameter appropriate for a given disease being treated or targeted for prevention. It is well within the ability of one skilled in the art to monitor

efficacy of treatment or prevention by measuring any one of such parameters, or any combination of parameters. For example, the levels of transferrin saturation or serum ferritin can be monitored for efficacy of a given treatment regime.

Iron level tests are typically performed on a sample of a pateint's blood. An iron level test measure the amount of iron in the blood serum that is being carried by the proteins transferrin. A TIBC (Total iron-binding capacity) test measures the amount of iron that the blood would carry if the transferrin were fully saturated. Since transferrin is produced by the liver, the TIBC can be used to monitor liver function and nutrition. The transferrin test is a direct measure of transferrin (also called siderophilin) levels in the blood. The saturation level of transferrin can be calculated by dividing the serum iron level by the TIBC. The ferritin test measures the level of a protein in the blood that stores iron for later use by the body.

The iRNA treatments described herein can be used to treat individuals afflicted with a TMPRSS6 associated disorder, *e.g.*, elevated iron levels, as may be indicated by iron levels in serum *e.g.*, iron levels measuring greater than 350 μg/dL, greater than 500 μg/dL, greater than 1000 μg/dL, or more. In an embodiment, elevated levels of iron in serum, e.g., greater than 15, 20, 25, or 30 mg/g dry weight.

The iRNA treatments described herein can also be used to treat individuals having elevated iron levels, as may be indicated by elevated ferritin levels in serum, *e.g.*, ferritin levels measuring greater than 300 μg/L, greater than 500 μg/L, greater than 1000 μg/L, greater than 1500 μg/L, greater than 2000 μg/L, greater than 2500 μg/L, or 3000 μg/L, or more.

The iRNA treatments described herein can further be used to treat individuals having elevated iron levels, as may be indicated by elevated transferrin levels in serum, *e.g.*, transferrin levels measuring greater than 400 mg/dL, greater than 500 mg/L, greater than 1000 mg/dL, or more.

The iRNA treatments described herein can also be used to treat individuals having moderately elevated iron levels, as may be indicated by moderately elevated transferrin saturation levels, *e.g.*, saturation levels of 40%, 45%, or 50% or more. In addition, the treatment described herein may also be used to prevent elevated iron levels in individuals with only minor elevations in transferrin saturation. One of skill in the art can easily monitor the transferrin saturation levels in subjects receiving treatment with iRNA as described herein and assay for a reduction in transferrin saturation levels of at least 5% or 10%.

The iRNA treatments described herein can be used to treat individuals having elevated iron levels, as may be indicated by a TIBC value greater than 400 μg/dL, greater than 500 μg/dL, or greater than 1000 μg/dL, or more.

In some embodiments, individuals in need of treatment with an iRNA agent of the invention have decreased hematocrit levels, decreased hemoglobin levels, increased red blood

cell distribution width, increased number of reticulocytes, decreased number of mature red blood cells, increased unsaturated iron binding capacity, decreased ineffective erythropoiesis, decreased extradedullary hematopoiesis, and/or decreased HAMP1 expression levels.

A patient can be further monitored by assay of blood sugar (glucose) level or a fetoprotein level, by echocardiogram (*e.g.*, to examine the heart's function), electrocardiogram (ECG) (e.g., to look at the electrical activity of the heart), imaging tests (such as CT scans, MRI and ultrasound), and liver function tests. Excess iron staining or iron concentrations can be measured on liver biopsy samples, or to confirm the extent of liver damage, *e.g.*, the stage of liver disease.

A treatment or preventive effect is evident when there is a statistically significant improvement in one or more parameters of disease status, or by a failure to worsen or to develop symptoms where they would otherwise be anticipated. As an example, a favorable change of at least 10% in a measurable parameter of disease, and preferably at least 20%, 30%, 40%, 50% or more can be indicative of effective treatment. Efficacy for a given iRNA drug or formulation of that drug can also be judged using an experimental animal model for the given disease as known in the art. When using an experimental animal model, efficacy of treatment is evidenced when a statistically significant reduction in a marker or symptom is observed.

Alternatively, the efficacy can be measured by a reduction in the severity of disease as determined by one skilled in the art of diagnosis based on a clinically accepted disease severity grading scale.

As used herein, a "subject" includes a human or non-human animal, preferably a vertebrate, and more preferably a mammal. A subject may include a transgenic organism. Most preferably, the subject is a human, such as a human suffering from or predisposed to developing a TMPRSS6 associated disorder.

In some embodiments of the methods of the invention, TMPRSS6 expression is decreased for an extended duration, *e.g.*, at least one week, two weeks, three weeks, or four weeks or longer. For example, in certain instances, expression of the TMPRSS6 gene is suppressed by at least about 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 98%, or 100% by administration of an iRNA agent described herein. In some embodiments, the TMPRSS6 gene is suppressed by at least about 60%, 70%, or 80% by administration of the iRNA agent. In some embodiments, the TMPRSS6 gene is suppressed by at least about 85%, 90%, or 95% by administration of the double-stranded oligonucleotide. In another embodiment, the TMPRSS6 gene remains suppressed for 7 days, 10 days, 20 days, 30 days, or more following administration.

The RNAi agents of the invention may be administered to a subject using any mode of administration known in the art, including, but not limited to subcutaneous, intravenous, intramuscular, intraocular, intrabronchial, intrapleural, intraperitoneal, intraarterial,

lymphatic, cerebrospinal, and any combinations thereof. In preferred embodiments, the agents are administered subcutaneously.

In some embodiments, the administration is via a depot injection. A depot injection may release the RNAi agent in a consistent way over a prolonged time period. Thus, a depot injection may reduce the frequency of dosing needed to obtain a desired effect, *e.g.*, a desired inhibition of TMPRSS6, or a therapeutic or prophylactic effect. A depot injection may also provide more consistent serum concentrations. Depot injections may include subcutaneous injections or intramuscular injections. In preferred embodiments, the depot injection is a subcutaneous injection.

In some embodiments, the administration is via a pump. The pump may be an external pump or a surgically implanted pump. In certain embodiments, the pump is a subcutaneously implanted osmotic pump. In other embodiments, the pump is an infusion pump. An infusion pump may be used for intravenous, subcutaneous, arterial, or epidural infusions. In preferred embodiments, the infusion pump is a subcutaneous infusion pump. In other embodiments, the pump is a surgically implanted pump that delivers the RNAi agent to the liver.

Other modes of administration include epidural, intracerebral, intracerebroventricular, nasal administration, intraarterial, intracardiac, intraosseous infusion, intrathecal, and intravitreal, and pulmonary. The mode of administration may be chosen based upon whether local or systemic treatment is desired and based upon the area to be treated. The route and site of administration may be chosen to enhance targeting.

The method includes administering an iRNA agent, *e.g.*, a dose sufficient to depress levels of TMPRSS6 mRNA for at least 5, more preferably 7, 10, 14, 21, 25, 30 or 40 days; and optionally, administering a second single dose of dsRNA, wherein the second single dose is administered at least 5, more preferably 7, 10, 14, 21, 25, 30 or 40 days after the first single dose is administered, thereby inhibiting the expression of the TMPRSS6 gene in a subject.

In one embodiment, doses of iRNA agent of the invention are administered not more than once every four weeks, not more than once every three weeks, not more than once every two weeks, or not more than once every week. In another embodiment, the administrations can be maintained for one, two, three, or six months, or one year or longer. In another embodiment, doses of iRNA agent of the invention are administered once a week for three weeks.

In general, the iRNA agent does not activate the immune system, *e.g.*, it does not increase cytokine levels, such as TNF-alpha or IFN-alpha levels. For example, when measured by an assay, such as an in vitro PBMC assay, such as described herein, the increase in levels of TNF-alpha or IFN-alpha, is less than 30%, 20%, or 10% of control cells treated with a control dsRNA, such as a dsRNA that does not target TMPRSS6.

For example, a subject can be administered a therapeutic amount of an iRNA agent, such as 0.3 mg/kg, 0.5 mg/kg, 1.0 mg/kg, 1.5 mg/kg, 2.0 mg/kg, 2.5 mg/kg, or 3 mg/kg of dsRNA. The iRNA agent can be administered by intravenous infusion over a period of time, such as over a 5 minute, 10 minute, 15 minute, 20 minute, or 25 minute period. The administration is repeated, for example, on a regular basis, such as biweekly (*i.e.*, every two weeks) for one month, two months, three months, four months or longer. After an initial treatment regimen, the treatments can be administered on a less frequent basis. For example, after administration biweekly for three months, administration can be repeated once per month, for six months or a year or longer. Administration of the iRNA agent can reduce TMPRSS6 levels, *e.g.*, in a cell, tissue, blood, urine or other compartment of the patient by at least 10%, at least 15%, at least 20%, at least 25%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80 % or at least 90% or more.

Before administration of a full dose of the iRNA agent, patients can be administered a smaller dose, such as a dose resulting in less than 5% infusion reaction, and monitored for adverse effects, such as an allergic reaction, or for elevated lipid levels or blood pressure. In another example, the patient can be monitored for unwanted immunostimulatory effects, such as increased cytokine (*e.g.*, TNF-alpha or INF-alpha) levels.

Many disorders associated with elevated iron levels are hereditary. Therefore, a patient in need of a TMPRSS6 iRNA may be identified by taking a family history. A healthcare provider, such as a doctor, nurse, or family member, can take a family history before prescribing or administering a TMPRSS6 dsRNA. A DNA test may also be performed on the patient to identify a mutation in the TMPRSS6 gene, before a TMPRSS6 dsRNA is administered to the patient. For example, diagnosis of hereditary hemochromatosis can be confirmed by identifying the two HFE (Hemochromatosis) gene mutations C282Y and H63D, according to GenBank Accession No. CAB07442.1 (GI: 1890180, record dated October 23, 2008).

A treatment or preventive effect is evident when there is a statistically significant improvement in one or more parameters of disease status, or by a failure to worsen or to develop symptoms where they would otherwise be anticipated. As an example, a favorable change of at least 10% in a measurable parameter of disease, and preferably at least 20%, 30%, 40%, 50% or more can be indicative of effective treatment. Efficacy for a given iRNA agent of the invention or formulation of that iRNA agent can also be judged using an experimental animal model for the given disease as known in the art. When using an experimental animal model, efficacy of treatment is evidenced when a statistically significant reduction in a marker or symptom is observed.

In one embodiment, the RNAi agent is administered at a dose of between about 0.25 mg/kg to about 50 mg/kg, *e.g.*, between about 0.25 mg/kg to about 0.5 mg/kg, between about 0.25 mg/kg to about 1 mg/kg, between about 0.25 mg/kg to about 5 mg/kg, between about

0.25 mg/kg to about 10 mg/kg, between about 1 mg/kg to about 10 mg/kg, between about 5 mg/kg to about 15 mg/kg, between about 10 mg/kg to about 20 mg/kg, between about 15 mg/kg to about 25 mg/kg, between about 20 mg/kg to about 30 mg/kg, between about 25 mg/kg to about 35 mg/kg, or between about 40 mg/kg to about 50 mg/kg.

In some embodiments, the RNAi agent is administered at a dose of about 0.25 mg/kg, about 0.5 mg/kg, about 1 mg/kg, about 2 mg/kg, about 3 mg/kg, about 4 mg/kg, about 5 mg/kg, about 6 mg/kg, about 7 mg/kg, about 8 mg/kg, about 9 mg/kg, about 10 mg/kg, about 11 mg/kg, about 12 mg/kg, about 13 mg/kg, about 14 mg/kg, about 15 mg/kg, about 16 mg/kg, about 17 mg/kg, about 18 mg/kg, about 19 mg/kg, about 20 mg/kg, about 21 mg/kg, about 22 mg/kg, about 23 mg/kg, about 24 mg/kg, about 25 mg/kg, about 26 mg/kg, about 27 mg/kg, about 28 mg/kg, about 29 mg/kg, 30 mg/kg, about 31 mg/kg, about 32 mg/kg, about 33 mg/kg, about 34 mg/kg, about 35 mg/kg, about 36 mg/kg, about 37 mg/kg, about 38 mg/kg, about 39 mg/kg, about 40 mg/kg, about 41 mg/kg, about 42 mg/kg, about 43 mg/kg, about 44 mg/kg, about 45 mg/kg, about 46 mg/kg, about 47 mg/kg, about 48 mg/kg, about 49 mg/kg or about 50 mg/kg.

In certain embodiments, for example, when a composition of the invention comprises a dsRNA as described herein and a lipid, subjects can be administered a therapeutic amount of iRNA, such as about 0.01 mg/kg to about 5 mg/kg, about 0.01 mg/kg to about 10 mg/kg, about 0.05 mg/kg to about 5 mg/kg, about 0.05 mg/kg to about 10 mg/kg, about 0.1 mg/kg to about 5 mg/kg, about 0.1 mg/kg to about 10 mg/kg, about 0.2 mg/kg to about 5 mg/kg, about 0.2 mg/kg to about 10 mg/kg, about 0.3 mg/kg to about 5 mg/kg, about 0.3 mg/kg to about 10 mg/kg, about 0.4 mg/kg to about 5 mg/kg, about 0.4 mg/kg to about 10 mg/kg, about 0.5 mg/kg to about 5 mg/kg, about 0.5 mg/kg to about 10 mg/kg, about 1 mg/kg to about 5 mg/kg, about 1 mg/kg to about 10 mg/kg, about 1.5 mg/kg to about 5 mg/kg, about 1.5 mg/kg to about 10 mg/kg, about 2 mg/kg to about about 2.5 mg/kg, about 2 mg/kg to about 10 mg/kg, about 3 mg/kg to about 5 mg/kg, about 3 mg/kg to about 10 mg/kg, about 3.5 mg/kg to about 5 mg/kg, about 4 mg/kg to about 5 mg/kg, about 4.5 mg/kg to about 5 mg/kg, about 4 mg/kg to about 10 mg/kg, about 4.5 mg/kg to about 10 mg/kg, about 5 mg/kg to about 10 mg/kg, about 5.5 mg/kg to about 10 mg/kg, about 6 mg/kg to about 10 mg/kg, about 6.5 mg/kg to about 10 mg/kg, about 7 mg/kg to about 10 mg/kg, about 7.5 mg/kg to about 10 mg/kg, about 8 mg/kg to about 10 mg/kg, about 8.5 mg/kg to about 10 mg/kg, about 9 mg/kg to about 10 mg/kg, or about 9.5 mg/kg to about 10 mg/kg. Values and ranges intermediate to the recited values are also intended to be part of this invention.

For example, the dsRNA may be administered at a dose of about 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6, 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 7, 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 8, 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 9, 9.1, 9.2, 9.3, 9.4,

9.5, 9.6, 9.7, 9.8, 9.9, or about 10 mg/kg. Values and ranges intermediate to the recited values are also intended to be part of this invention.

In certain embodiments of the invention, for example, when a double-stranded RNAi agent includes one or more modifications (*e.g.,* motifs of three identical modifications on three consecutive nucleotides, including one such motif at or near the cleavage site of the agent), six phosphorothioate linkages, and a ligand, such an agent is administered at a dose of about 0.01 to about 0.5 mg/kg, about 0.01 to about 0.4 mg/kg, about 0.01 to about 0.3 mg/kg, about 0.01 to about 0.2 mg/kg, about 0.01 to about 0.1 mg/kg, about 0.01 mg/kg to about 0.09 mg/kg, about 0.01 mg/kg to about 0.08 mg/kg, about 0.01 mg/kg to about 0.07 mg/kg, about 0.01 mg/kg to about 0.06 mg/kg, about 0.01 mg/kg to about 0.05 mg/kg, about 0.02 to about 0.5 mg/kg, about 0.02 to about 0.4 mg/kg, about 0.02 to about 0.3 mg/kg, about 0.02 to about 0.2 mg/kg, about 0.02 to about 0.1 mg/kg, about 0.02 mg/kg to about 0.09 mg/kg, about 0.02 mg/kg to about 0.08 mg/kg, about 0.02 mg/kg to about 0.07 mg/kg, about 0.02 mg/kg to about 0.06 mg/kg, about 0.02 mg/kg to about 0.05 mg/kg, about 0.03 to about 0.5 mg/kg, about 0.03 to about 0.4 mg/kg, about 0.03 to about 0.3 mg/kg, about 0.03 to about 0.2 mg/kg, about 0.03 to about 0.1 mg/kg, about 0.03 mg/kg to about 0.09 mg/kg, about 0.03 mg/kg to about 0.08 mg/kg, about 0.03 mg/kg to about 0.07 mg/kg, about 0.03 mg/kg to about 0.06 mg/kg, about 0.03 mg/kg to about 0.05 mg/kg, about 0.04 to about 0.5 mg/kg, about 0.04 to about 0.4 mg/kg, about 0.04 to about 0.3 mg/kg, about 0.04 to about 0.2 mg/kg, about 0.04 to about 0.1 mg/kg, about 0.04 mg/kg to about 0.09 mg/kg, about 0.04 mg/kg to about 0.08 mg/kg, about 0.04 mg/kg to about 0.07 mg/kg, about 0.04 mg/kg to about 0.06 mg/kg, about 0.05 to about 0.5 mg/kg, about 0.05 to about 0.4 mg/kg, about 0.05 to about 0.3 mg/kg, about 0.05 to about 0.2 mg/kg, about 0.05 to about 0.1 mg/kg, about 0.05 mg/kg to about 0.09 mg/kg, about 0.05 mg/kg to about 0.08 mg/kg, or about 0.05 mg/kg to about 0.07 mg/kg. Values and ranges intermediate to the foregoing recited values are also intended to be part of this invention, *e.g.,*, the RNAi agent may be administered to the subject at a dose of about 0.015 mg/kg to about 0.45 mg/mg.

For example, the RNAi agent, *e.g.*, RNAi agent in a pharmaceutical composition, may be administered at a dose of about 0.01 mg/kg, 0.0125 mg/kg, 0.015 mg/kg, 0.0175 mg/kg, 0.02 mg/kg, 0.0225 mg/kg, 0.025 mg/kg, 0.0275 mg/kg, 0.03 mg/kg, 0.0325 mg/kg, 0.035 mg/kg, 0.0375 mg/kg, 0.04 mg/kg, 0.0425 mg/kg, 0.045 mg/kg, 0.0475 mg/kg, 0.05 mg/kg, 0.0525 mg/kg, 0.055 mg/kg, 0.0575 mg/kg, 0.06 mg/kg, 0.0625 mg/kg, 0.065 mg/kg, 0.0675 mg/kg, 0.07 mg/kg, 0.0725 mg/kg, 0.075 mg/kg, 0.0775 mg/kg, 0.08 mg/kg, 0.0825 mg/kg, 0.085 mg/kg, 0.0875 mg/kg, 0.09 mg/kg, 0.0925 mg/kg, 0.095 mg/kg, 0.0975 mg/kg, 0.1 mg/kg, 0.125 mg/kg, 0.15 mg/kg, 0.175 mg/kg, 0.2 mg/kg, 0.225 mg/kg, 0.25 mg/kg, 0.275 mg/kg, 0.3 mg/kg, 0.325 mg/kg, 0.35 mg/kg, 0.375 mg/kg, 0.4 mg/kg, 0.425 mg/kg, 0.45 mg/kg, 0.475 mg/kg, or about 0.5 mg/kg. Values intermediate to the foregoing recited values are also intended to be part of this invention.

The dose of an RNAi agent that is administered to a subject may be tailored to balance the risks and benefits of a particular dose, for example, to achieve a desired level of TMPRSS6 gene suppression (as assessed, *e.g.*, based on TMPRSS6 mRNA suppression, TMPRSS6 protein expression, or a reduction in lipid levels) or a desired therapeutic or prophylactic effect, while at the same time avoiding undesirable side effects.

In some embodiments, the RNAi agent is administered in two or more doses. If desired to facilitate repeated or frequent infusions, implantation of a delivery device, *e.g.*, a pump, semi-permanent stent (*e.g.*, intravenous, intraperitoneal, intracisternal or intracapsular), or reservoir may be advisable. In some embodiments, the number or amount of subsequent doses is dependent on the achievement of a desired effect, *e.g.*, the suppression of a TMPRSS6 gene, or the achievement of a therapeutic or prophylactic effect, *e.g.*, reducing iron overload. In some embodiments, the RNAi agent is administered according to a schedule. For example, the RNAi agent may be administered once per week, twice per week, three times per week, four times per week, or five times per week. In some embodiments, the schedule involves regularly spaced administrations, *e.g.*, hourly, every four hours, every six hours, every eight hours, every twelve hours, daily, every 2 days, every 3 days, every 4 days, every 5 days, weekly, biweekly, or monthly. In other embodiments, the schedule involves closely spaced administrations followed by a longer period of time during which the agent is not administered. For example, the schedule may involve an initial set of doses that are administered in a relatively short period of time (*e.g.*, about every 6 hours, about every 12 hours, about every 24 hours, about every 48 hours, or about every 72 hours) followed by a longer time period (*e.g.*, about 1 week, about 2 weeks, about 3 weeks, about 4 weeks, about 5 weeks, about 6 weeks, about 7 weeks, or about 8 weeks) during which the RNAi agent is not administered. In one embodiment, the RNAi agent is initially administered hourly and is later administered at a longer interval (*e.g.*, daily, weekly, biweekly, or monthly). In another embodiment, the RNAi agent is initially administered daily and is later administered at a longer interval (*e.g.*, weekly, biweekly, or monthly). In certain embodiments, the longer interval increases over time or is determined based on the achievement of a desired effect. In a specific embodiment, the RNAi agent is administered once daily during a first week, followed by weekly dosing starting on the eighth day of administration. In another specific embodiment, the RNAi agent is administered every other day during a first week followed by weekly dosing starting on the eighth day of administration.

In some embodiments, the RNAi agent is administered in a dosing regimen that includes a "loading phase" of closely spaced administrations that may be followed by a "maintenance phase", in which the RNAi agent is administred at longer spaced intervals. In one embodiment, the loading phase comprises five daily administrations of the RNAi agent during the first week. In another embodiment, the maintenance phase comprises one or two

weekly administrations of the RNAi agent. In a further embodiment, the maintenance phase lasts for 5 weeks.

Any of these schedules may optionally be repeated for one or more iterations. The number of iterations may depend on the achievement of a desired effect, *e.g.*, the suppression of a TMPRSS6 gene, and/or the achievement of a therapeutic or prophylactic effect, *e.g.*, reducing iron levels or reducing a symptom of thalassemia, *e.g.*, β-thalassemia, or hemotochromatosis.

In another aspect, the invention features, a method of instructing an end user, *e.g.*, a caregiver or a subject, on how to administer an iRNA agent described herein. The method includes, optionally, providing the end user with one or more doses of the iRNA agent, and instructing the end user to administer the iRNA agent on a regimen described herein, thereby instructing the end user.

VII. Kits

The present invention also provides kits for using any of the iRNA agents and/or performing any of the methods of the invention. Such kits include one or more RNAi agent(s) and instructions for use, *e.g.*, instructions for inhibiting expression of a TMPRSS6 in a cell by contacting the cell with the RNAi agent(s) in an amount effective to inhibit expression of the TMPRSS6. The kits may optionally further comprise means for contacting the cell with the RNAi agent (*e.g.*, an injection device), or means for measuring the inhibition of TMPRSS6 (*e.g.*, means for measuring the inhibition of TMPRSS6 mRNA or TTR protein). Such means for measuring the inhibition of TMPRSS6 may comprise a means for obtaining a sample from a subject, such as, *e.g.*, a plasma sample. The kits of the invention may optionally further comprise means for administering the RNAi agent(s) to a subject or means for determining the therapeutically effective or prophylactically effective amount.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the iRNAs and methods featured in the invention, suitable methods and materials are described below. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

EXAMPLES

Materials and Methods

The following materials and methods were used in the Examples.

cDNA synthesis using ABI High capacity cDNA reverse transcription kit (Applied Biosystems, Foster City, CA, Cat #4368813)

A master mix of 2µl 10X Buffer, 0.8µl 25X dNTPs, 2µl Random primers, 1µl Reverse Transcriptase, 1µl RNase inhibitor and 3.2µl of H_2O per reaction was added into 10µl total RNA. cDNA was generated using a Bio-Rad C-1000 or S-1000 thermal cycler (Hercules, CA) through the following steps: 25°C 10 min, 37°C 120 min, 85°C 5 sec, 4°C hold.

Cell culture and transfections

Hep3B cells (ATCC, Manassas, VA) were grown to near confluence at 37 °C in an atmosphere of 5% CO2 in EMEM (ATCC) supplemented with 10% FBS, streptomycin, and glutamine (ATCC) before being released from the plate by trypsinization. Transfection was carried out by adding 14.8µl of Opti-MEM plus 0.2µl of Lipofectamine RNAiMax per well (Invitrogen, Carlsbad CA. cat # 13778-150) to 5µl of siRNA duplexes per well into a 96-well plate and incubated at room temperature for 15 minutes. Subsequently, 80µl of complete growth media without antibiotic containing ~2 x10^4 Hep3B cells were then added to the siRNA mixture. Cells were incubated for 24 hours prior to RNA purification. Single dose experiments were performed at 10nM and 0.1nM final duplex concentration.

Total RNA isolation using DYNABEADS mRNA Isolation Kit (Invitrogen, part #: 610-12)

Cells were harvested and lysed in 150µl of Lysis/Binding Buffer then mixed for 5 minute at 850 rpm using a platform shaker (the mixing speed was the same throughout the process). Ten microliters of magnetic beads and 80µl Lysis/Binding Buffer mixture were added to a round bottom plate and mixed for 1 minute. Magnetic beads were captured using magnetic stand and the supernatant was removed without disturbing the beads. After the supernatant was removed, the lysed cells were added to the remaining beads and mixed for 5 minutes. After the supernatant was removed, magnetic beads were washed 2 times with 150µl Wash Buffer A and mixed for 1 minute. Beads were capture again and supernatant removed. Beads were then washed with 150µl Wash Buffer B, captured and supernatant was removed. Beads were next washed with 150µl Elution Buffer, captured and supernatant removed. Beads were allowed to dry for 2 minutes. After drying, 50µl of Elution Buffer was added and mixed for 5 minutes at 75°C. Beads were captured on magnet for 5 minutes, and 50µl of supernatant containing the purified RNA was removed and added to a new 96 well plate.

Real time PCR

Two µl of cDNA was added to a master mix containing 0.5µl human GAPDH TaqMan Probe (Applied Biosystems Cat #4326317E), 0.5µl human TMPRSS6 TaqMan probe (Applied Biosystems cat # Hs00542184_m1) and 5µl Lightcycler 480 probe master mix (Roche Cat #04887301001) per well in a 384 well plate (Roche cat # 04887301001). Real time PCR was performed in a Roche LC480 Real Time PCR system (Roche) using the ΔΔCt(RQ) assay. Each duplex was tested in two independent transfections and each transfection was assayed in duplicate, unless otherwise noted.

To calculate relative fold change, real time data were analyzed using the ΔΔCt method and normalized to assays performed with cells transfected with 10nM AD-1955, or mock transfected cells.

The sense and antisense sequences of AD-1955 are: SENSE: 5'-cuuAcGcuGAGuAcuucGAdTsdT-3' (SEQ ID NO: 15); and ANTISENSE: 5'-UCGAAGuACUcAGCGuAAGdTsdT-3' (SEQ ID NO: 16).

Table B**:** Abbreviations of nucleotide monomers used in nucleic acid sequence representation.

Abbreviation	**Nucleotide(s)**
A	Adenosine-3'-phosphate
Ab	beta-L-adenosine-3`-phosphate
Af	2'-fluoroadenosine-3'-phosphate
Afs	2'-fluoroadenosine-3'-phosphorothioate
As	adenosine-3'-phosphorothioate
C	cytidine-3'-phosphate
Cb	beta-L-cytidine-3'-phosphate
Cf	2'-fluorocytidine-3'-phosphate
Cfs	2'-fluorocytidine-3'-phosphorothioate
Cs	cytidine-3'-phosphorothioate
G	guanosine-3'-phosphate
Gb	beta-L-guanosine-3`-phosphate
Gbs	beta-L-guanosine-3`-phosphorothioate
Gf	2'-fluoroguanosine-3'-phosphate
Gfs	2'-fluoroguanosine-3'-phosphorothioate
Gs	guanosine-3'-phosphorothioate
T	5'-methyluridine-3'-phosphate
Tf	2'-fluoro-5-methyluridine-3'-phosphate
Tfs	2'-fluoro-5-methyluridine-3'-phosphorothioate
Ts	5-methyluridine-3'-phosphorothioate

Abbreviation	Nucleotide(s)
U	Uridine-3'-phosphate
Uf	2'-fluorouridine-3'-phosphate
Ufs	2'-fluorouridine -3'-phosphorothioate
Us	uridine -3'-phosphorothioate
N	any nucleotide (G, A, C, T or U)
a	2'-O-methyladenosine-3'-phosphate
as	2'-O-methyladenosine-3'- phosphorothioate
c	2'-O-methylcytidine-3'-phosphate
cs	2'-O-methylcytidine-3'- phosphorothioate
g	2'-O-methylguanosine-3'-phosphate
gs	2'-O-methylguanosine-3'- phosphorothioate
t	2'-O-methyl-5-methyluridine-3'-phosphate
ts	2'-O-methyl-5-methyluridine-3'-phosphorothioate
u	2'-O-methyluridine-3'-phosphate
us	2'-O-methyluridine-3'-phosphorothioate
dT	2'-deoxythymidine
dTs	2`-deoxythymidine-3`-phosphorothioate
dU	2`-deoxyuridine
s	phosphorothioate linkage
L96	N-[tris(GalNAc-alkyl)-amidodecanoyl)]-4-hydroxyprolinol Hyp-(GalNAc-alkyl)3
(Aeo)	2'-O-methoxyethyladenosine-3'-phosphate
(Aeos)	2'-O-methoxyethyladenosine-3'-phosphorothioate
(Geo)	2'-O-methoxyethylguanosine-3'-phosphate
(Geos)	2'-O-methoxyethylguanosine-3'- phosphorothioate
(Teo)	2'-O-methoxyethyl-5-methyluridine-3'-phosphate
(Teos)	2'-O-methoxyethyl-5-methyluridine-3'- phosphorothioate
(m5Ceo)	2'-O-methoxyethyl-5-methylcytidine-3'-phosphate
(m5Ceos)	2'-O-methoxyethyl-5-methylcytidine-3'- phosphorothioate
(A3m)	3`-O-methyladenosine-2`-phosphate
(A3mx)	3'-O-methyl-xylofuranosyladenosine-2'-phosphate
(G3m)	3`-O-methylguanosine-2`-phosphate
(G3mx)	3'-O-methyl-xylofuranosylguanosine-2'-phosphate
(C3m)	3`-O-methylcytidine-2`-phosphate
(C3mx)	3'-O-methyl-xylofuranosylcytidine-2'-phosphate
(U3m)	3`-O-methyluridine-2`-phosphate

Abbreviation	Nucleotide(s)
(U3mx)	3'-O-methylxylouridine-2'-phosphate
(Chd)	2'-O-hexadecyl-cytidine-3'-phosphate
(pshe)	Hydroxyethylphosphorothioate
(Uhd)	2'-O-hexadecyl-uridine-3'-phosphate
(Tgn)	Thymidine-glycol nucleic acid (GNA) S-Isomer
(Cgn)	Cytidine-glycol nucleic acid (GNA)
(Chd)	2'-O-hexadecyl-cytidine-3'-phosphate
(Ggn)	2'-O-hexadecyl-cytidine-3'-phosphate
(Agn)	Adenosine-glycol nucleic acid (GNA)
P	5'-phosphate
(m5Cam)	2`-O-(N-methylacetamide)-5-methylcytidine-3`-phosphate
(m5Cams)	2`-O-(N-methylacetamide)-5-methylcytidine-3`-phosphorothioate
(Tam)	2`-O-(N-methylacetamide)thymidine-3`-phosphate
(Tams)	2`-O-(N-methylacetamide)thymidine-3`-phosphorothioate
(Aam)	2`-O-(N-methylacetamide)adenosine-3`-phosphate
(Aams)	2`-O-(N-methylacetamide)adenosine-3`-phosphorothioate
(Gam)	2`-O-(N-methylacetamide)guanosine-3`-phosphate
(Gams)	2`-O-(N-methylacetamide)guanosine-3`-phosphorothioate
Y44	2-hydroxymethyl-tetrahydrofurane-5-phosphate

Example 1. Design, Specificity and Efficacy Prediction of Oligonucleotides

Transcripts

siRNA design was carried out to identify siRNAs targeting human, rhesus (Macaca mulatta), mouse, and rat TMPRSS6 transcripts annotated in the NCBI Gene database (http://www.ncbi.nlm.nih.gov/gene/). Design used the following transcripts from the NCBI RefSeq collection: Human -NM_153609.2; Rhesus - XM_001085203.2 and XM_001085319.1; Mouse - NM_027902.2; Rat -NM_001130556.1. Due to high primate/rodent sequence divergence, siRNA duplexes were designed in several separate batches, including but not limited to batches containing duplexes matching human and rhesus transcripts only; human, rhesus, and mouse transcripts only; human, rhesus, mouse, and rat transcripts only; and mouse and rat transcripts only. All siRNA duplexes were designed that shared 100% identity with the listed human transcript and other species transcripts considered in each design batch (above).

The specificity of all possible 19mers was predicted from each sequence. Candidate 19mers that lacked repeats longer than 7 nucleotides were then selected. These 1259 candidate human/rhesus, 91 human/rhesus/mouse, 37 human/rhesus/mouse/rat, and 810

mouse/rat siRNAs were used in comprehensive searches against the appropriate transcriptomes (defined as the set of NM_ and XM_ records within the human, rhesus, mouse, or rat NCBI Refseq sets) using an exhaustive "brute-force" algorithm implemented in the python script 'BruteForce.py'. The script next parsed the transcript-oligo alignments to generate a score based on the position and number of mismatches between the siRNA and any potential 'off-target' transcript. The off-target score is weighted to emphasize differences in the 'seed' region of siRNAs, in positions 2-9 from the 5' end of the molecule. Each oligo-transcript pair from the brute-force search was given a mismatch score by summing the individual mismatch scores; mismatches in the position 2-9 were counted as 2.8, mismatches in the cleavage site positions 10-11 were counted as 1.2, and mismatches in region 12-19 counted as 1.0. An additional off-target prediction was carried out by comparing the frequency of heptamers and octomers derived from 3 distinct, seed-derived hexamers of each oligo. The hexamers from positions 2-7 relative to the 5' start were used to create 2 heptamers and one octomer. Heptamer1 was created by adding a 3' A to the hexamer; heptamer2 was created by adding a 5' A to the hexamer; the octomer was created by adding an A to both 5' and 3' ends of the hexamer. The frequency of octomers and heptamers in the human, rhesus, mouse, or rat 3'UTRome (defined as the subsequence of the transcriptome from NCBI's Refseq database where the end of the coding region, the 'CDS', is clearly defined) was pre-calculated. The octomer frequency was normalized to the heptamer frequency using the median value from the range of octomer frequencies. A 'mirSeedScore' was then calculated by calculating the sum of ((3 X normalized octomer count) + (2 X heptamer2 count) + (1 X heptamer1 count)).

Both siRNA strands were assigned to a category of specificity according to the calculated scores: a score above 3 qualified as highly specific, equal to 3 as specific and between 2.2 and 2.8 qualified as moderately specific. The siRNAs were sorted by the specificity of the antisense strand. Duplexes from the human/rhesus and mouse/rat sets whose antisense oligos lacked GC at the first position, lacked G at both positions 13 and 14, and had 3 or more Us or As in the seed region (characteristics of duplexes with high predicted efficacy) were then selected. Similarly, duplexes from the human/rhesus/mouse and human/rhesus/mouse/rat sets that had had 3 or more Us or As in the seed region were selected.

Candidate GalNAc-conjugated duplexes, 21 and 23 nucleotides long on the sense and antisense strands respectively, were designed by extending antisense 19mers 4 additional nucleotides in the 3' direction (preserving perfect complementarity with the target transcript). The sense strand was specified as the reverse complement of the first 21 nucleotides of the antisense 23mer. Duplexes were selected that maintained perfect matches to all selected species transcripts across all 23 nucleotides.

siRNA sequence selection

A total of 39 sense and 39 antisense derived human/rhesus, 6 sense and 6 antisense derived human/rhesus/mouse, 3 sense and 3 antisense derived human/rhesus/mouse/rat, and 16 sense and 16 antisense derived mouse/rat siRNA 21/23mer oligos were synthesized and formed into GalNAc-conjugated duplexes.

The sequences of the sense and antisense strands of the modified duplexes are shown in Table 1, and the sequences of the sense and antisense strands of the unmodified duplexes are shown in Table 2.

Table 1. TMPRSS6 modified sequences

Duplex ID	Sense sequence ID	Sense sequence	SEQ ID NO:	Antisense sequence	Antisense sequence	SEQ ID NO:
AD-58686.1	A-119159.1	UfsgsGfcCfuGfgAfGfAfgGfuGfuCfcUfuCfL96	17	A-119160.1	usUfsgAfaGfgAfcAfccuCfuCfcAfgGfcsCfsa	65
AD-58687.1	A-119175.1	GfsgsGfgUfgCfuAfCfUfcUfgGfuAfuUfuCfL96	18	A-119176.1	asGfsgAfaAfuAfcCfagaGfuAfgCfaCfcsCfsc	66
AD-58688.1	A-119191.1	CfsasAfcGfgCfcUfGfGfaUfgAfgAfgAfaAfL96	19	A-119192.1	asGfsuUfuCfuCfuCfaucCfaGfgCfcGfusUfsg	67
AD-58689.1	A-119207.1	AfsusCfgCfcAfcUfUfCfuCfcCfaGfgAfuCfL96	20	A-119208.1	asAfsgAfuCfcUfgGfgagAfaGfuGfgCfgsAfsu	68
AD-58690.1	A-119223.1	GfsgsUfgGfcAfgGfAfGfgUfgGfcAfuCfuUfL96	21	A-119224.1	asCfsaAfgAfuGfcCfaccUfcCfuGfcCfasCfsc	69
AD-58692.1	A-119161.1	GfsasCfcGfaCfuGfGfCfcAfuGfuAfuGfaCfL96	22	A-119162.1	asCfsgUfcAfuAfcAfuggCfcAfgUfcGfgsUfsc	70
AD-58693.1	A-119177.1	GfsgsUfgUfgCfgGfGfUfgCfaCfuAfuGfgCfL96	23	A-119178.1	asAfsgCfcAfuAfgUfgcaCfcCfgCfaCfasCfsc	71
AD-58694.1	A-119193.1	GfsgsCfcUfgGfaUfGfAfgAfgAfaAfcUfgCfL96	24	A-119194.1	asCfsgCfaGfuUfuCfucuCfaUfcCfaGfgsCfsc	72
AD-58695.1	A-119209.1	CfsusCfuGfgUfaUfUfUfcCfuAfgGfgUfaCfL96	25	A-119210.1	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsAfsg	73
AD-58696.1	A-119225.1	GfscsCfcCfuGfgUfCfUfaAfcUfuGfgGfaUfL96	26	A-119226.1	asGfsaUfcCfcAfaGfuuaGfaCfcAfgGfgsGfsc	74

Duplex ID	Sense sequence ID	Sense sequence	SEQ ID NO:	Antisense sequence	Antisense sequence	SEQ ID NO:
AD-58698.1	A-119163.1	GfsasGfgCfaGfaAfGfUfaUfgAfuUfuGfcCfL96	27	A-119164.1	asCfsgGfcAfaAfuCfauaCfuUfcUfgCfcsUfsc	75
AD-58699.1	A-119179.1	AfsasGfcCfaGfuGfUfGfaAfaGfaCfaUfaGfL96	28	A-119180.1	asGfscUfaUfgUfcUfuucAfcAfcUfgGfcsUfsu	76
AD-58700.1	A-119195.1	GfscsCfgGfgAfcCfGfAfcUfgGfcCfaUfgUfL96	29	A-119196.1	asUfsaCfaUfgGfcCfaguCfgGfuCfcCfgsGfsc	77
AD-58701.1	A-119211.1	CfsusCfcAfgGfuUfCfGfgGfgUfcGfaCfaCfL96	30	A-119212.1	asUfsgUfgUfcGfaCfcccGfaAfcCfuGfgsAfsg	78
AD-58702.1	A-119227.1	AfsgsCfcCfcUfgGfUfCfuAfaCfuUfgGfgAfL96	31	A-119228.1	gsAfsuCfcCfaAfgUfuagAfcCfaGfgGfgsCfsu	79
AD-58704.1	A-119165.1	UfscsGfcCfaCfuUfCfUfcCfcAfgGfaUfcUfL96	32	A-119166.1	usAfsaGfaUfcCfuGfggaGfaAfgUfgGfcsGfsa	80
AD-58705.1	A-119181.1	AfscsUfcUfgGfuAfUfUfuCfcUfaGfgGfuAfL96	33	A-119182.1	usGfsuAfcCfcUfaGfgaaAfuAfcCfaGfasGfsu	81
AD-58706.1	A-119197.1	UfscsGfcUfgAfcCfGfCfuGfgGfuGfaUfaAfL96	34	A-119198.1	usGfsuUfaUfcAfcCfcagCfgGfuCfaGfcsGfsa	82
AD-58707.1	A-119213.1	GfscsCfcCfaAfcGfGfCfcUfgGfaUfgAfgAfL96	35	A-119214.1	usCfsuCfuCfaUfcCfaggCfcGfuUfgGfgsGfsc	83
AD-58708.1	A-119229.1	GfscsCfaAfgCfaGfGfGfgGfaCfaAfgUfaUfL96	36	A-119230.1	gsAfsaUfaCfuUfgUfcccCfcUfgCfuUfgsGfsc	84
AD-	A-119167.1	UfscsCfcCfuAfcAfGfGfgCfcGfaGfuAfcGfL96	37	A-119168.1	usUfscGfuAfcUfcGfgccCfuGfuAfgGfgsGfsa	85

Duplex ID	Sense sequence ID	Sense sequence	SEQ ID NO:	Antisense sequence	Antisense sequence	SEQ ID NO:
58710.1						
AD-58711.1	A-119183.1	CfsusGfgGfuUfgUfUfAfcCfgCfuAfcAfgCfL96	38	A-119184.1	usAfsgCfuGfuAfgCfgguAfaCfaAfcCfcsAfsg	86
AD-58712.1	A-119199.1	CfsusGfgCfcUfgGfAfGfaGfgUfgUfcCfuUfL96	39	A-119200.1	usGfsaAfgGfaCfaCfcucUfcCfaGfgCfcsAfsg	87
AD-58713.1	A-119215.1	GfsusGfcGfgGfuGfCfAfcUfaUfgGfcUfuGfL96	40	A-119216.1	usAfscAfaGfcCfaUfaguGfcAfcCfcGfcsAfsc	88
AD-58714.1	A-119231.1	UfsgsGfcAfgGfaGfGfUfgGfcAfuCfuUfgUfL96	41	A-119232.1	asGfsaCfaAfgAfuGfccaCfcUfcCfuGfcsCfsa	89
AD-58716.1	A-119169.1	CfscsCfuAfcAfgGfGfCfcGfaGfuAfcGfaAfL96	42	A-119170.1	asCfsuUfcGfuAfcUfcggCfcCfuGfuAfgsGfsg	90
AD-58717.1	A-119185.1	AfscsCfuGfcUfuCfUfUfcUfgGfuUfcAfuUfL96	43	A-119186.1	asGfsaAfuGfaAfcCfagaAfgAfaGfcAfgsGfsu	91
AD-58718.1	A-119201.1	UfsgsCfcUfgUfgAfUfGfgGfgUfcAfaGfgAfL96	44	A-119202.1	asGfsuCfcUfuGfaCfcccAfuCfaCfaGfgsCfsa	92
AD-58719.1	A-119217.1	CfsasGfcUfuCfgGfAfAfgCfcCfcUfgGfuCfL96	45	A-119218.1	usAfsgAfcCfaGfgGfgcuUfcCfgAfaGfcsUfsg	93
AD-58720.1	A-119233.1	CfscsCfcUfgGfuCfUfAfaCfuUfgGfgAfuCfL96	46	A-119234.1	csAfsgAfuCfcCfaAfguuAfgAfcCfaGfgsGfsg	94
AD-58721.1	A-119171.1	UfsgsCfuUfcUfuCfUfGfgUfuCfaUfuCfuCfL96	47	A-119172.1	usGfsgAfgAfaUfgAfaccAfgAfaGfaAfgsCfsa	95

Duplex ID	Sense sequence ID	Sense sequence	SEQ ID NO:	Antisense sequence	Antisense sequence	SEQ ID NO:
AD-58722.1	A-119187.1	CfscsCfaAfcGfgCfCfUfgGfaUfgAfgAfgAfL96	48	A-119188.1	usUfsuCfuCfuCfaUfccaGfgCfcGfuUfgsGfsg	96
AD-58723.1	A-119203.1	AfsasGfgGfcCfuGfCfAfcAfgCfuAfcUfaCfL96	49	A-119204.1	usCfsgUfaGfuAfgCfuguGfcAfgGfcCfcsUfsu	97
AD-58724.1	A-119219.1	GfsusCfuAfaCfuUfGfGfgAfuCfuGfgGfaAfL96	50	A-119220.1	csAfsuUfcCfcAfgAfuccCfaAfgUfuAfgsAfsc	98
AD-58725.1	A-119235.1	AfsgsCfuUfcGfgAfAfGfcCfcCfuGfgUfcUfL96	51	A-119236.1	usUfsaGfaCfcAfgGfggcUfuCfcGfaAfgsCfsu	99
AD-58726.1	A-119173.1	CfscsAfgUfgUfgAfAfAfgAfcAfuAfgCfuGfL96	52	A-119174.1	usGfscAfgCfuAfuGfucuUfuCfaCfaCfusGfsg	100
AD-58727.1	A-119189.1	CfscsAfgGfuUfcGfGfGfgUfcGfaCfaCfaUfL96	53	A-119190.1	asGfsaUfgUfgUfcGfaccCfcGfaAfcCfusGfsg	101
AD-58728.1	A-119205.1	UfscsCfaCfgCfuGfGfGfuUfgUfuAfcCfgCfL96	54	A-119206.1	usAfsgCfgGfuAfaCfaacCfcAfgCfgUfgsGfsa	102
AD-58729.1	A-119221.1	UfsgsCfcAfaGfcAfGfGfgGfgAfcAfaGfuAfL96	55	A-119222.1	asAfsuAfcUfuGfuCfcccCfuGfcUfuGfgsCfsa	103
AD-58697.1	A-119241.1	AfsusCfcAfgAfaCfAfGfgAfgGfcUfgUfgUfL96	56	A-119242.1	csCfsaCfaCfaGfcCfuccUfgUfuCfuGfgsAfsu	104
AD-58703.1	A-119243.1	UfsusCfaCfcUfcCfCfAfgAfuCfuCfcCfuCfL96	57	A-119244.1	gsUfsgAfgGfgAfgAfucuGfgGfaGfgUfgsAfsa	105
AD-	A-119245.1	CfscsUfcCfgAfgGfGfUfgAfgUfgGfcCfaUfL96	58	A-119246.1	csCfsaUfgGfcCfaCfucaCfcCfuCfgGfasGfsg	106

Duplex ID	Sense sequence ID	Sense sequence	SEQ ID NO:	Antisense sequence	Antisense sequence	SEQ ID NO:
58709.1						
AD-58715.1	A-119247.1	UfscsCfaGfaAfcAfGfGfaGfgCfuGfuGfuGfL96	59	A-119248.1	gsCfscAfcAfcAfgCfcucCfuGfuUfcUfgsGfsa	107
AD-58730.1	A-119237.1	GfsusGfuCfcUfcCfGfAfgGfgUfgAfgUfgGfL96	60	A-119238.1	gsGfscCfaCfuCfaCfccuCfgGfaGfgAfcsAfsc	108
AD-58731.1	A-119249.1	UfsusCfgGfgGfuCfGfAfcAfcAfuCfuGfuGfL96	61	A-119250.1	csCfscAfcAfgAfuGfuguCfgAfcCfcCfgsAfsa	109
AD-58734.1	A-119251.1	UfscsGfgGfgUfcGfAfCfaCfaUfcUfgUfgGfL96	62	A-119252.1	csCfscCfaCfaGfaUfgugUfcGfaCfcCfcsGfsa	110
AD-58737.1	A-119253.1	UfsgsCfuUfcCfaGfGfAfgGfaCfaGfcAfuGfL96	63	A-119254.1	gsCfscAfuGfcUfgUfccuCfcUfgGfaAfgsCfsa	111
AD-59743.1	A-120243.1	UfscsUfgGfuAfuUfUfCfcUfaGfgGfuAfcAfL96	64	A-120244.1	usGfsuAfcCfcUfaGfgaaAfuAfcCfaGfasgsu	112

Table 2. TMPRSS6 unmodified sequences

Duplex ID	Sense sequence ID	Sense sequence	SEQ ID NO:	Position in NM_153609.2	Antisense sequence	Antisense sequence	SEQ ID NO:	Position in NM_153609.2
AD-58686.1	A-119159.1	UGGCCUGGAGAGGUGUCCUUC	113	2041-2063	A-119160.1	UUGAAGGACACCUCUCCAGGCCA	161	2041-2063

Duplex ID	Sense sequence ID	Sense sequence	SEQ ID NO:	Position in NM_153609.2	Antisense sequence	Antisense sequence	SEQ ID NO:	Position in NM_153609.2
AD-58687.1	A-119175.1	GGGGUGCUACUCUGGUAUUUC	114	319-341	A-119176.1	AGGAAAUACCAGAGUAGCACCCC	162	319-341
AD-58688.1	A-119191.1	CAACGGCCUGGAUGAGAGAAA	115	1557-1579	A-119192.1	AGUUUCUCUCAUCCAGGCCGUUG	163	1557-1579
AD-58689.1	A-119207.1	AUCGCCACUUCUCCCAGGAUC	116	401-423	A-119208.1	AAGAUCCUGGGAGAAGUGGCGAU	164	401-423
AD-58690.1	A-119223.1	GGUGGCAGGAGGUGGCAUCUU	117	2665-2688	A-119224.1	ACAAGAUGCCACCUCCUGCCACC	165	2665-2688
AD-58692.1	A-119161.1	GACCGACUGGCCAUGUAUGAC	118	922-944	A-119162.1	ACGUCAUACAUGGCCAGUCGGUC	166	922-944
AD-58693.1	A-119177.1	GGUGUGCGGGUGCACUAUGGC	119	1444-1466	A-119178.1	AAGCCAUAGUGCACCCGCACACC	167	1444-1466
AD-58694.1	A-119193.1	GGCCUGGAUGAGAGAAACUGC	120	1561-1583	A-119194.1	ACGCAGUUUCUCUCAUCCAGGCC	168	1561-1583
AD-58695.1	A-119209.1	CUCUGGUAUUUCCUAGGGUAC	121	328-350	A-119210.1	UUGUACCCUAGGAAAUACCAGAG	169	328-350
AD-58696.1	A-119225.1	GCCCCUGGUCUAACUUGGGAU	122	2966-2989	A-119226.1	AGAUCCCAAGUUAGACCAGGGGC	170	2966-2989
AD-58698.1	A-119163.1	GAGGCAGAAGUAUGAUUUGCC	123	1281-1303	A-119164.1	ACGGCAAAUCAUACUUCUGCCUC	171	1281-1303
AD-	A-	AAGCCAGUGUGAAAGACAUAG	124	731-753	A-	AGCUAUGUCUUUCACACUGGCUU	172	731-753

Duplex ID	Sense sequence ID	Sense sequence	SEQ ID NO:	Position in NM_153609.2	Antisense sequence	Antisense sequence	SEQ ID NO:	Position in NM_153609.2
58699.1	119179.1				119180.1			
AD-58700.1	A-119195.1	GCCGGGACCGACUGGCCAUGU	125	917-939	A-119196.1	AUACAUGGCCAGUCGGUCCCGGC	173	917-939
AD-58701.1	A-119211.1	CUCCAGGUUCGGGGUCGACAC	126	1894-1916	A-119212.1	AUGUGUCGACCCCGAACCUGGAG	174	1894-1916
AD-58702.1	A-119227.1	AGCCCCUGGUCUAACUUGGGA	127	2965-2988	A-119228.1	GAUCCCAAGUUAGACCAGGGGCU	175	2965-2988
AD-58704.1	A-119165.1	UCGCCACUUCUCCCAGGAUCU	128	402-424	A-119166.1	UAAGAUCCUGGGAGAAGUGGCGA	176	402-424
AD-58705.1	A-119181.1	ACUCUGGUAUUUCCUAGGGUA	129	327-349	A-119182.1	UGUACCCUAGGAAAUACCAGAGU	177	327-349
AD-58706.1	A-119197.1	UCGCUGACCGCUGGGUGAUAA	130	1934-1956	A-119198.1	UGUUAUCACCCAGCGGUCAGCGA	178	1934-1956
AD-58707.1	A-119213.1	GCCCCAACGGCCUGGAUGAGA	131	1553-1575	A-119214.1	UCUCUCAUCCAGGCCGUUGGGGC	179	1553-1575
AD-58708.1	A-119229.1	GCCAAGCAGGGGGACAAGUAU	132	2610-2633	A-119230.1	GAAUACUUGUCCCCCUGCUUGGC	180	2610-2633
AD-58710.1	A-119167.1	UCCCCUACAGGGCCGAGUACG	133	680-702	A-119168.1	UUCGUACUCGGCCCUGUAGGGGA	181	680-702
AD-58711.1	A-119183.1	CUGGGUUGUUACCGCUACAGC	134	769-791	A-119184.1	UAGCUGUAGCGGUAACAACCCAG	182	769-791

Duplex ID	Sense sequence ID	Sense sequence	SEQ ID NO:	Position in NM_153609.2	Antisense sequence	Antisense sequence	SEQ ID NO:	Position in NM_153609.2
AD-58712.1	A-119199.1	CUGGCCUGGAGAGGUGUCCUU	135	2040-2062	A-119200.1	UGAAGGACACCUCUCCAGGCCAG	183	2040-2062
AD-58713.1	A-119215.1	GUGCGGGUGCACUAUGGCUUG	136	1447-1469	A-119216.1	UACAAGCCAUAGUGCACCCGCAC	184	1447-1469
AD-58714.1	A-119231.1	UGGCAGGAGGUGGCAUCUUGU	137	2667-2690	A-119232.1	AGACAAGAUGCCACCUCCUGCCA	185	2667-2690
AD-58716.1	A-119169.1	CCCUACAGGGCCGAGUACGAA	138	682-704	A-119170.1	ACUUCGUACUCGGCCCUGUAGGG	186	682-704
AD-58717.1	A-119185.1	ACCUGCUUCUUCUGGUUCAUU	139	559-581	A-119186.1	AGAAUGAACCAGAAGAAGCAGGU	187	559-581
AD-58718.1	A-119201.1	UGCCUGUGAUGGGGUCAAGGA	140	1530-1552	A-119202.1	AGUCCUUGACCCCAUCACAGGCA	188	1530-1552
AD-58719.1	A-119217.1	CAGCUUCGGAAGCCCCUGGUC	141	2955-2978	A-119218.1	UAGACCAGGGGCUUCCGAAGCUG	189	2955-2978
AD-58720.1	A-119233.1	CCCCUGGUCUAACUUGGGAUC	142	2967-2990	A-119234.1	CAGAUCCCAAGUUAGACCAGGGG	190	2967-2990
AD-58721.1	A-119171.1	UGCUUCUUCUGGUUCAUUCUC	143	562-584	A-119172.1	UGGAGAAUGAACCAGAAGAAGCA	191	562-584
AD-58722.1	A-119187.1	CCCAACGGCCUGGAUGAGAGA	144	1555-1577	A-119188.1	UUUCUCUCAUCCAGGCCGUUGGG	192	1555-1577
AD-	A-	AAGGGCCUGCACAGCUACUAC	145	1054-1076	A-	UCGUAGUAGCUGUGCAGGCCCUU	193	1054-1076

Duplex ID	Sense sequence ID	Sense sequence	SEQ ID NO:	Position in NM_153609.2	Antisense sequence	Antisense sequence	SEQ ID NO:	Position in NM_153609.2
58723.1	119203.1				119204.1			
AD-58724.1	A-119219.1	GUCUAACUUGGGAUCUGGGAA	146	2973-2996	A-119220.1	CAUUCCCAGAUCCCAAGUUAGAC	194	2973-2996
AD-58725.1	A-119235.1	AGCUUCGGAAGCCCCUGGUCU	147	2956-2979	A-119236.1	UUAGACCAGGGGCUUCCGAAGCU	195	2956-2979
AD-58726.1	A-119173.1	CCAGUGUGAAAGACAUAGCUG	148	734-756	A-119174.1	UGCAGCUAUGUCUUUCACACUGG	196	734-756
AD-58727.1	A-119189.1	CCAGGUUCGGGGUCGACACAU	149	1896-1918	A-119190.1	AGAUGUGUCGACCCCGAACCUGG	197	1896-1918
AD-58728.1	A-119205.1	UCCACGCUGGGUUGUUACCGC	150	763-785	A-119206.1	UAGCGGUAACAACCCAGCGUGGA	198	763-785
AD-58729.1	A-119221.1	UGCCAAGCAGGGGGACAAGUA	151	2609-2632	A-119222.1	AAUACUUGUCCCCCUGCUUGGCA	199	2609-2632
AD-58697.1	A-119241.1	AUCCAGAACAGGAGGCUGUGU	152	1324-1346	A-119242.1	CCACACAGCCUCCUGUUCUGGAU	200	1324-1346
AD-58703.1	A-119243.1	UUCACCUCCCAGAUCUCCCUC	153	1414-1436	A-119244.1	GUGAGGGAGAUCUGGGAGGUGAA	201	1414-1436
AD-58709.1	A-119245.1	CCUCCGAGGGUGAGUGGCCAU	154	1862-1884	A-119246.1	CCAUGGCCACUCACCCUCGGAGG	202	1862-1884
AD-58715.1	A-119247.1	UCCAGAACAGGAGGCUGUGUG	155	1325-1347	A-119248.1	GCCACACAGCCUCCUGUUCUGGA	203	1325-1347

Duplex ID	Sense sequence ID	Sense sequence	SEQ ID NO:	Position in NM_153609.2	Antisense sequence	Antisense sequence	SEQ ID NO:	Position in NM_153609.2
AD-58730.1	A-119237.1	GUGUCCUCCGAGGGUGAGUGG	156	1858-1880	A-119238.1	GGCCACUCACCCUCGGAGGACAC	204	1858-1880
AD-58731.1	A-119249.1	UUCGGGGUCGACACAUCUGUG	157	1901-1923	A-119250.1	CCCACAGAUGUGUCGACCCCGAA	205	1901-1923
AD-58734.1	A-119251.1	UCGGGGUCGACACAUCUGUGG	158	1902-1924	A-119252.1	CCCCACAGAUGUGUCGACCCCGA	206	1902-1924
AD-58737.1	A-119253.1	UGCUUCCAGGAGGACAGCAUG	159	1966-1988	A-119254.1	GCCAUGCUGUCCUCCUGGAAGCA	207	1966-1988
AD-59743.1	A-120243.1	UCUGGUAUUUCCUAGGGUACA	160		A-120244.1	UGUACCCUAGGAAAUACCAGAGU	208	

Example 2. ***In vitro*** **single dose screen.**

The modified and conjugated TMPRSS6 siRNA duplexes were also evaluated for efficacy by transfection assays in human cell line Hep3B. TMPRSS6 siRNAs were transfected at two doses, 10nM and 0.1nM. The results of these assays are shown in Table 3 and the data are expressed as a fraction of the message remaining in cells transfected with siRNAs targeting TMPRSS6, relative to cells transfected with a negative control siRNA, AD-1955 ± the standard deviation (SD).

Table 3. TMPRSS6 single dose screen.

Duplex ID	Avg 10nM	SD 10nM	Avg 0.1nM	SD 0.1nM
AD-58686.1	71.58	18.94	103.29	32.00
AD-58687.1	89.33	13.14	104.94	20.06
AD-58688.1	34.16	11.36	87.18	8.43
AD-58689.1	79.82	7.28	110.37	6.08
AD-58690.1	69.10	9.83	99.92	24.84
AD-58692.1	79.21	5.67	136.49	0.84
AD-58693.1	77.29	12.12	106.01	17.97
AD-58694.1	50.51	10.36	89.47	3.84
AD-58695.1	54.37	5.75	87.66	13.59
AD-58696.1	93.26	0.06	84.79	3.84
AD-58697.1	72.95	23.41	98.98	10.29
AD-58698.1	42.61	7.81	109.98	16.78
AD-58699.1	24.93	8.58	79.71	12.55
AD-58700.1	74.10	15.37	89.75	7.80
AD-58701.1	79.18	8.18	89.70	9.98
AD-58702.1	96.43	18.38	113.05	10.65
AD-58703.1	79.15	28.50	97.30	6.79
AD-58704.1	67.92	0.87	92.26	1.24
AD-58705.1	59.50	20.47	99.25	3.28
AD-58706.1	71.67	0.75	102.38	14.88
AD-58707.1	77.89	22.26	97.52	1.31
AD-58708.1	73.87	9.61	98.38	1.81
AD-58709.1	94.62	4.69	100.73	16.10
AD-58710.1	59.19	10.57	95.23	11.99
AD-58711.1	63.62	16.83	103.11	3.66
AD-58712.1	65.79	6.96	81.58	1.50
AD-58713.1	84.14	26.41	101.56	5.60

Duplex ID	Avg 10nM	SD 10nM	Avg 0.1nM	SD 0.1nM
AD-58714.1	64.73	6.06	102.37	1.63
AD-58715.1	91.05	18.67	101.08	11.00
AD-58716.1	70.07	13.02	97.20	2.98
AD-58717.1	11.27	6.91	66.56	4.32
AD-58718.1	62.10	18.62	89.01	15.30
AD-58719.1	72.94	18.26	91.58	9.97
AD-58720.1	60.51	14.43	90.92	5.68
AD-58721.1	17.72	7.70	56.72	2.57
AD-58722.1	51.65	11.33	81.44	0.50
AD-58723.1	53.27	21.60	94.25	16.20
AD-58724.1	58.03	49.89	77.11	4.63
AD-58725.1	54.58	40.10	76.12	1.59
AD-58726.1	10.33	9.88	42.75	7.97
AD-58727.1	62.80	26.45	83.23	13.10
AD-58728.1	49.36	36.27	83.30	1.74
AD-58729.1	43.83	61.99	73.54	19.33
AD-58730.1	59.60	41.85	76.12	1.03
AD-58731.1	85.29	24.78	128.06	32.14
AD-58734.1	85.71	10.74	101.75	6.11
AD-58737.1	79.87	10.59	114.89	7.46

Example 3. *In vivo* single dose screen using AD-59743

The ability of AD-59743 to suppress expression of TMPRSS6 protein was assessed by measuring levels of TMPRSS6 and hepcidin mRNA in the liver of wild-type C57BL/6 mice following administration of AD-59743. A single dose of 1, 3 or 10 mg/kg of AD-59743 was administered subcutaneously, and the mice were sacrified on day 3 or day 7. Levels of TMPRSS6 and hepcidin mRNA in the liver were measured by qPCR using the methods described above. A control group received injections with PBS.

The levels of TMPRSS6 mRNA following administration of AD-59743 are shown in Figure 1, and the levels of hepcidin mRNA following administration of AD-59743 are shown in Figure 2. The results demonstrate a dose-dependent decrease in the levels of TMPRSS6 transcripts that is sustained through day 7.

Example 4. *In vivo* effect of TMPRSS6 iRNA agents in combination with an iron chelator

The purpose of this study was to test the effect of co-administered TMPRSS6 specific siRNA and iron chelators on iron levels. In the study, 6-week old wild-type C57BL/6 and thalassemic Th3/+ mice (Douet *et al.*, *Am. J. Pathol.* (2011), 178(2):774-83) were fed low-iron diets containing 3-5 ppm iron. The mice were administered intravevously the formulation AF-011-46273 containing deferiprone, an iron chelator at a dose of 250 mg/kg/day and an iRNA agent with the following structure: oligoSeq-sense – uGGuAuuuccuAGGGuAcAdTsdT (SEQ ID NO: 209); oligoSeq-antisense – UGuACCCuAGGAAAuACcAdTsdT (SEQ ID NO: 210). The formulation also contained MC-3/DSPC/Cholesterol/PEG-DMG 50/10/38.5/1.5. Liver and spleen tissues were collected and tissue nonheme iron concentrations were determined as described previously (see, *e.g.*, Schmidt *et al.* (2013) *Blood* 121(7):1200-8; Cook, JD, *et al.*. *Tissue iron stores*. In: Cook JD , editor. *Methods in Hematology*. Vol 1. New York, NY: Churchill Livingstone Press; 1980. p. 104-109).

The results of these experiments demonstrate an additive effect of AD-46273 and deferiprone in Th3/+ mice, with the decreased iron levels relative to the negative controls.

Example 5. Design, Specificity and Efficacy Prediction of Oligonucleotides

Transcripts

siRNA design was carried out to identify siRNAs targeting human, cynomolgus monkey (*Macaca fascicularis*; henceforth "cyno"), mouse, and rat TMPRSS6 transcripts annotated in the NCBI Gene database (http://www.ncbi.nlm.nih.gov/gene/). Design used the following transcripts from the NCBI RefSeq collection: Human -NM_153609.2; Mouse -NM_027902.2; Rat -NM_001130556.1. For cyno, a transcript sequence was obtained via alignment with human TMPRSS6 of sequence assembled from two accessions: "ENSP00000384964 [mRNA] locus=chr10:82446450:82485403:-" and FR874253.1, available from the *M. fascicularis* genome project and NCBI Nucleotide databases, respectively (http://macaque.genomics.org.cn/page/species/download.jsp and http://www.ncbi.nlm.nih.gov/nucleotide/). Due to high primate/rodent sequence divergence, siRNA duplexes were designed in several separate batches, including but not limited to batches containing duplexes matching human and cyno transcripts only; human, cyno, and mouse transcripts only; and human, cyno, mouse, and rat transcripts only. Most siRNA duplexes were designed that shared 100% identity in the designated region with the listed human transcript and other species transcripts considered in each design batch (above). In some instances, mismatches between duplex and mRNA target were allowed at the first antisense (last sense) position when the antisense strand:target mRNA complementary

basepair was a GC or CG pair. In these cases, duplexes were designed with UA or AU pairs at the first antisense:last sense pair. Thus the duplexes maintained complementarity but were mismatched with respect to target (U:C, U:G, A:C, or A:G).

The specificity of all possible 19mers was predicted from each sequence. Candidate 19mers that lacked repeats longer than 7 nucleotides were then selected. These 1128 candidate human/cyno, 69 human/cyno/mouse, and 23 human/cyno/mouse/rat siRNAs were used in comprehensive searches against the appropriate transcriptomes (defined as the set of NM_ and XM_ records within the human, mouse, or rat NCBI Refseq sets, and the cyno transcriptome set in NCBI nucleotide) using an exhaustive "brute-force" algorithm implemented in the python script 'BruteForce.py'. The script next parsed the transcript-oligo alignments to generate a score based on the position and number of mismatches between the siRNA and any potential 'off-target' transcript. The off-target score is weighted to emphasize differences in the 'seed' region of siRNAs, in positions 2-9 from the 5' end of the molecule. Each oligo-transcript pair from the brute-force search was given a mismatch score by summing the individual mismatch scores; mismatches in the position 2-9 were counted as 2.8, mismatches in the cleavage site positions 10-11 were counted as 1.2, and mismatches in region 12-19 counted as 1.0. An additional off-target prediction was carried out by comparing the frequency of heptamers and octomers derived from 3 distinct, seed-derived hexamers of each oligo. The hexamers from positions 2-7 relative to the 5' start were used to create 2 heptamers and one octomer. Heptamer1 was created by adding a 3' A to the hexamer; heptamer2 was created by adding a 5' A to the hexamer; the octomer was created by adding an A to both 5' and 3' ends of the hexamer. The frequency of octomers and heptamers in the human, cyno, mouse, or rat 3'UTRome (defined as the subsequence of the transcriptome from NCBI's Refseq database where the end of the coding region, the 'CDS', is clearly defined) was pre-calculated. The octomer frequency was normalized to the heptamer frequency using the median value from the range of octomer frequencies. A 'mirSeedScore' was then calculated by calculating the sum of ((3 X normalized octomer count) + (2 X heptamer2 count) + (1 X heptamer1 count)).

Both siRNAs strands were assigned to a category of specificity according to the calculated scores: a score above 3 qualifies as highly specific, equal to 3 as specific and between 2 and 2.8 as moderately specific. We sorted by the specificity of the antisense strand. We then selected moderately (or higher) specific duplexes whose antisense oligos possessed characteristics of duplexes with high predicted efficacy, including maximal UA content in the seed region and low overall GC content.

For GalNaC-conjugated duplexes, sense 21mer and antisense 23mer oligos were designed by extending antisense 19mers (described above) to 23 nucleotides of target-complementary sequence. All species transcripts included in the design batch were checked

for complementarity. For each duplex, the sense 21mer was specified as the reverse complement of the first 21 nucleotides of the antisense strand.

siRNA sequence selection

A total of 5 sense and 5 antisense human, 32 sense and 32 antisense derived human/cyno, 4 sense and 4 antisense derived human/cyno/mouse, 8 sense and 8 antisense derived human/cyno/mouse/rat, 19 sense and 19 antisense derived human/cyno/rat, 2 sense and 2 antisense derived human/mouse, and 1 sense and 1 antisense derived human/mouse/rat siRNA 21/23mer oligos were synthesized and formed into GalNAc-conjugated duplexes.

The sequences of the sense and antisense strands of the unmodified duplexes are shown in Table 4, and the sequences of the sense and antisense strands of the modified duplexes are shown in Table 5.

Table 4. TMPRSS6- unmodified seqeunces

Duplex ID	Sense sequence ID	Sense sequence	SEQ ID NO:	Antisense sequence ID	Antisense sequence	SEQ ID NO:	Position in NM_153609.2
AD-60944.1	A-122732.1	GGUGCUACUCUGGUAUUUCCU	211	A-122733.1	AGGAAAUACCAGAGUAGCACCCC	280	318
AD-59743.1	A-120243.1	UCUGGUAUUUCCUAGGGUACA	212	A-120244.1	UGUACCCUAGGAAAUACCAGAGU	281	326
AD-60940.1	A-122745.1	CUGGUAUUUCCUAGGGUACAA	213	A-122746.1	UUGUACCCUAGGAAAUACCAGAG	282	327
AD-61002.2	A-122838.1	UGGUAUUUCCUAGGGUACAAA	214	A-122839.1	UUUGUACCCUAGGAAAUACCAGA	283	328
AD-61000.1	A-122852.1	GGUAUUUCCUAGGGUACAAGA	215	A-122853.1	UCUUGUACCCUAGGAAAUACCAG	284	329
AD-46273.1	A-96908.1	UGGUAUUUCCUAGGGUACA	216	A-96909.1	UGUACCCUAGGAAAUACCA	285	330
AD-61003.1	A-122854.1	GUAUUUCCUAGGGUACAAGGA	217	A-122855.1	UCCUUGUACCCUAGGAAAUACCA	286	330
AD-60994.1	A-122848.1	AUUUCCUAGGGUACAAGGCGA	218	A-122849.1	UCGCCUUGUACCCUAGGAAAUAC	287	332
AD-60990.1	A-122830.1	UUUCCUAGGGUACAAGGCGGA	219	A-122831.1	UCCGCCUUGUACCCUAGGAAAUA	288	333
AD-60956.1	A-122736.1	CGCCACUUCUCCCAGGAUCUU	220	A-122737.1	AAGAUCCUGGGAGAAGUGGCGAU	289	400
AD-60981.1	A-122757.1	GCCACUUCUCCCAGGAUCUUA	221	A-122758.1	UAAGAUCCUGGGAGAAGUGGCGA	290	401
AD-60953.1	A-122775.1	CUGCUUCUUCUGGUUCAUUCU	222	A-122776.1	AGAAUGAACCAGAAGAAGCAGGU	291	558
AD-60977.1	A-122783.1	CUUCUUCUGGUUCAUUCUCCA	223	A-122784.1	UGGAGAAUGAACCAGAAGAAGCA	292	561
AD-60964.1	A-119169.2	CCCUACAGGGCCGAGUACGAA	224	A-122764.1	UUCGUACUCGGCCCUGUAGGGGA	293	679
AD-60947.1	A-122773.1	CUACAGGGCCGAGUACGAAGU	225	A-122774.1	ACUUCGUACUCGGCCCUGUAGGG	294	681
AD-60957.1	A-122751.1	GCCAGUGUGAAAGACAUAGCU	226	A-122752.1	AGCUAUGUCUUUCACACUGGCUU	295	730
AD-60960.1	A-122792.1	AGUGUGAAAGACAUAGCUGCA	227	A-122793.1	UGCAGCUAUGUCUUUCACACUGG	296	733
AD-60972.1	A-122796.1	CACGCUGGGUUGUUACCGCUA	228	A-122797.1	UAGCGGUAACAACCCAGCGUGGA	297	762
AD-60970.1	A-122765.1	GGGUUGUUACCGCUACAGCUA	229	A-122766.1	UAGCUGUAGCGGUAACAACCCAG	298	768
AD-60963.1	A-122753.1	CGGGACCGACUGGCCAUGUAU	230	A-122754.1	AUACAUGGCCAGUCGGUCCCGGC	299	916
AD-60968.1	A-122739.1	CCGACUGGCCAUGUAUGACGU	231	A-122740.1	ACGUCAUACAUGGCCAGUCGGUC	300	921
AD-60942.1	A-122786.1	GGGCCUGCACAGCUACUACGA	232	A-122787.1	UCGUAGUAGCUGUGCAGGCCCUU	301	1053
AD-60951.1	A-122749.1	GGCAGAAGUAUGAUUUGCCGU	233	A-122750.1	ACGGCAAAUCAUACUUCUGCCUC	302	1280
AD-60984.1	A-122800.1	CCAGAACAGGAGGCUGUGUGG	234	A-122801.1	CCACACAGCCUCCUGUUCUGGAU	303	1323

AD-60955.1	A-122806.1	CAGAACAGGAGGCUGUGUGGC	235	A-122807.1	GCCACACAGCCUCCUGUUCUGGA	304	1324
AD-60943.1	A-122802.1	CACCUCCCAGAUCUCCCUCAC	236	A-122803.1	GUGAGGGAGAUCUGGGAGGUGAA	305	1413
AD-61001.1	A-122823.1	CACCUCCCAGAUCUCCCUCAA	237	A-122824.1	UUGAGGGAGAUCUGGGAGGUGAA	306	1413
AD-60974.1	A-122741.1	UGUGCGGGUGCACUAUGGCUU	238	A-122742.1	AAGCCAUAGUGCACCCGCACACC	307	1443
AD-60982.1	A-122769.1	GCGGGUGCACUAUGGCUUGUA	239	A-122770.1	UACAAGCCAUAGUGCACCCGCAC	308	1446
AD-60996.1	A-122834.1	CCCCUGCCCUGGAGAGUUCCU	240	A-122835.1	AGGAACUCUCCAGGGCAGGGGUC	309	1479
AD-60997.1	A-122850.1	CCCUGCCCUGGAGAGUUCCUA	241	A-122851.1	UAGGAACUCUCCAGGGCAGGGGU	310	1480
AD-61006.1	A-122856.1	CCUGCCCUGGAGAGUUCCUCU	242	A-122857.1	AGAGGAACUCUCCAGGGCAGGGG	311	1481
AD-60988.1	A-122844.1	CUGCCCUGGAGAGUUCCUCUA	243	A-122845.1	UAGAGGAACUCUCCAGGGCAGGG	312	1482
AD-60959.1	A-122777.1	CCUGUGAUGGGGUCAAGGACU	244	A-122778.1	AGUCCUUGACCCCAUCACAGGCA	313	1529
AD-60999.1	A-122836.1	GGACUGCCCCAACGGCCUGGA	245	A-122837.1	UCCAGGCCGUUGGGGCAGUCCUU	314	1545
AD-60991.1	A-122846.1	ACUGCCCCAACGGCCUGGAUA	246	A-122847.1	UAUCCAGGCCGUUGGGGCAGUCC	315	1547
AD-60993.1	A-122832.1	CUGCCCCAACGGCCUGGAUGA	247	A-122833.1	UCAUCCAGGCCGUUGGGGCAGUC	316	1548
AD-61005.1	A-122840.1	UGCCCCAACGGCCUGGAUGAA	248	A-122841.1	UUCAUCCAGGCCGUUGGGGCAGU	317	1549
AD-60987.1	A-119213.2	GCCCCAACGGCCUGGAUGAGA	249	A-122829.1	UCUCAUCCAGGCCGUUGGGGCAG	318	1550
AD-60986.1	A-122842.1	CCCCAACGGCCUGGAUGAGAA	250	A-122843.1	UUCUCAUCCAGGCCGUUGGGGCA	319	1551
AD-60952.1	A-119187.2	CCCAACGGCCUGGAUGAGAGA	251	A-122761.1	UCUCUCAUCCAGGCCGUUGGGGC	320	1552
AD-60983.1	A-119191.2	CAACGGCCUGGAUGAGAGAAA	252	A-122785.1	UUUCUCUCAUCCAGGCCGUUGGG	321	1554
AD-60950.1	A-122734.1	ACGGCCUGGAUGAGAGAAACU	253	A-122735.1	AGUUUCUCUCAUCCAGGCCGUUG	322	1556
AD-60980.1	A-122743.1	CCUGGAUGAGAGAAACUGCGU	254	A-122744.1	ACGCAGUUUCUCUCAUCCAGGCC	323	1560
AD-60998.1	A-122821.1	CACUGUGACUGUGGCCUCCAA	255	A-122822.1	UUGGAGGCCACAGUCACAGUGCU	324	1804
AD-60961.1	A-122808.1	GUCCUCCGAGGGUGAGUGGCC	256	A-122809.1	GGCCACUCACCCUCGGAGGACAC	325	1857
AD-61004.1	A-122825.1	CUCCGAGGGUGAGUGGCCAUA	257	A-122826.1	UAUGGCCACUCACCCUCGGAGGA	326	1860
AD-60949.1	A-122804.1	UCCGAGGGUGAGUGGCCAUGG	258	A-122805.1	CCAUGGCCACUCACCCUCGGAGG	327	1861
AD-60969.1	A-119189.2	CCAGGUUCGGGGUCGACACAU	259	A-122755.1	AUGUGUCGACCCCGAACCUGGAG	328	1893
AD-60966.1	A-122794.1	AGGUUCGGGGUCGACACAUCU	260	A-122795.1	AGAUGUGUCGACCCCGAACCUGG	329	1895
AD-60967.1	A-122810.1	CGGGGUCGACACAUCUGUGGG	261	A-122811.1	CCCACAGAUGUGUCGACCCCGAA	330	1900
AD-60989.1	A-122816.1	CGGGGUCGACACAUCUGUGGA	262	A-122817.1	UCCACAGAUGUGUCGACCCCGAA	331	1900

AD-60973.1	A-122812.1	GGGGUCGACACAUCUGUGGGG	263	A-122813.1	CCCCACAGAUGUGUCGACCCCGA	332	1901
AD-60992.1	A-122818.1	GGGGUCGACACAUCUGUGGGA	264	A-122819.1	UCCCACAGAUGUGUCGACCCCGA	333	1901
AD-60985.1	A-122827.1	GGGUCGACACAUCUGUGGGGA	265	A-122828.1	UCCCCACAGAUGUGUCGACCCCG	334	1902
AD-60946.1	A-122759.1	GCUGACCGCUGGGUGAUAACA	266	A-122760.1	UGUUAUCACCCAGCGGUCAGCGA	335	1933
AD-60979.1	A-122814.1	CUUCCAGGAGGACAGCAUGGC	267	A-122815.1	GCCAUGCUGUCCUCCUGGAAGCA	336	1965
AD-60976.1	A-122767.1	GGCCUGGAGAGGUGUCCUUCA	268	A-122768.1	UGAAGGACACCUCUCCAGGCCAG	337	2039
AD-60939.1	A-122730.1	GCCUGGAGAGGUGUCCUUCAA	269	A-122731.1	UUGAAGGACACCUCUCCAGGCCA	338	2040
AD-60978.1	A-122798.1	CCAAGCAGGGGGACAAGUAUU	270	A-122799.1	AAUACUUGUCCCCCUGCUUGGCA	339	2608
AD-60958.1	A-122762.1	CAAGCAGGGGGACAAGUAUUC	271	A-122763.1	GAAUACUUGUCCCCCUGCUUGGC	340	2609
AD-60962.1	A-119231.2	UGGCAGGAGGUGGCAUCUUGU	272	A-122738.1	ACAAGAUGCCACCUCCUGCCACC	341	2664
AD-60941.1	A-122771.1	GCAGGAGGUGGCAUCUUGUCU	273	A-122772.1	AGACAAGAUGCCACCUCCUGCCA	342	2666
AD-60965.1	A-122779.1	GCUUCGGAAGCCCCUGGUCUA	274	A-122780.1	UAGACCAGGGGCUUCCGAAGCUG	343	2954
AD-60954.1	A-122790.1	CUUCGGAAGCCCCUGGUCUAA	275	A-122791.1	UUAGACCAGGGGCUUCCGAAGCU	344	2955
AD-60975.1	A-119233.2	CCCCUGGUCUAACUUGGGAUC	276	A-122756.1	GAUCCCAAGUUAGACCAGGGGCU	345	2964
AD-60945.1	A-122747.1	CCCUGGUCUAACUUGGGAUCU	277	A-122748.1	AGAUCCCAAGUUAGACCAGGGGC	346	2965
AD-60971.1	A-122781.1	CCUGGUCUAACUUGGGAUCUG	278	A-122782.1	CAGAUCCCAAGUUAGACCAGGGG	347	2966
AD-60948.1	A-122788.1	CUAACUUGGGAUCUGGGAAUG	279	A-122789.1	CAUUCCCAGAUCCCAAGUUAGAC	348	2972

Table 5. TMPRSS6 modified sequences

Duplex ID	Sense sequence ID	Sense sequence	SEQ ID NO:	Antisense sequence ID	Antisense sequence	SEQ ID NO:
AD-46273.1	A-96908.1	uGGuAuuuccuAGGGuAcAdTsdT	349	A-96909.1	UGuACCCuAGGAAAuACcAdTsdT	418
AD-59743.1	A-120243.1	UfscsUfgGfuAfuUfUfCfcUfaGfgGfuAfcAfL96	350	A-120244.1	usGfsuAfcCfcUfaGfgaaAfuAfcCfaGfasgsu	419
AD-60939.1	A-122730.1	GfscsCfuGfgAfgAfGfGfuGfuCfcUfuCfaAfL96	351	A-122731.1	usUfsgAfaGfgAfcAfccuCfuCfcAfgGfcscsa	420
AD-60940.1	A-122745.1	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	352	A-122746.1	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	421
AD-60941.1	A-122771.1	GfscsAfgGfaGfgUfGfGfcAfuCfuUfgUfcUfL96	353	A-122772.1	asGfsaCfaAfgAfuGfccaCfcUfcCfuGfcscsa	422
AD-60942.1	A-122786.1	GfsgsGfcCfuGfcAfCfAfgCfuAfcUfaCfgAfL96	354	A-122787.1	usCfsgUfaGfuAfgCfuguGfcAfgGfcCfcsusu	423

AD-60943.1	A-122802.1	CfsasCfcUfcCfcAfGfAfuCfuCfcCfuCfaCfL96	355	A-122803.1	gsUfsgAfgGfgAfgAfucuGfgGfaGfgUfgsasa	424
AD-60944.1	A-122732.1	GfsgsUfgCfuAfcUfCfUfgGfuAfuUfuCfcUfL96	356	A-122733.1	asGfsgAfaAfuAfcCfagaGfuAfgCfaCfcscsc	425
AD-60945.1	A-122747.1	CfscsCfuGfgUfcUfAfAfcUfuGfgGfaUfcUfL96	357	A-122748.1	asGfsaUfcCfcAfaGfuuaGfaCfcAfgGfgsgsc	426
AD-60946.1	A-122759.1	GfscsUfgAfcCfgCfUfGfgGfuGfaUfaAfcAfL96	358	A-122760.1	usGfsuUfaUfcAfcCfcagCfgGfuCfaGfcsgsa	427
AD-60947.1	A-122773.1	CfsusAfcAfgGfgCfCfGfaGfuAfcGfaAfgUfL96	359	A-122774.1	asCfsuUfcGfuAfcUfcggCfcCfuGfuAfgsgsg	428
AD-60948.1	A-122788.1	CfsusAfaCfuUfgGfGfAfuCfuGfgGfaAfuGfL96	360	A-122789.1	csAfsuUfcCfcAfgAfuccCfaAfgUfuAfgsasc	429
AD-60949.1	A-122804.1	UfscsCfgAfgGfgUfGfAfgUfgGfcCfaUfgGfL96	361	A-122805.1	csCfsaUfgGfcCfaCfucaCfcCfuCfgGfasgsg	430
AD-60950.1	A-122734.1	AfscsGfgCfcUfgGfAfUfgAfgAfgAfaAfcUfL96	362	A-122735.1	asGfsuUfuCfuCfuCfaucCfaGfgCfcGfususg	431
AD-60951.1	A-122749.1	GfsgsCfaGfaAfgUfAfUfgAfuUfuGfcCfgUfL96	363	A-122750.1	asCfsgGfcAfaAfuCfauaCfuUfcUfgCfcsusc	432
AD-60952.1	A-119187.2	CfscsCfaAfcGfgCfCfUfgGfaUfgAfgAfgAfL96	364	A-122761.1	usCfsuCfuCfaUfcCfaggCfcGfuUfgGfgsgsc	433
AD-60953.1	A-122775.1	CfsusGfcUfuCfuUfCfUfgGfuUfcAfuUfcUfL96	365	A-122776.1	asGfsaAfuGfaAfcCfagaAfgAfaGfcAfgsgsu	434
AD-60954.1	A-122790.1	CfsusUfcGfgAfaGfCfCfcCfuGfgUfcUfaAfL96	366	A-122791.1	usUfsaGfaCfcAfgGfggcUfuCfcGfaAfgscsu	435
AD-60955.1	A-122806.1	CfsasGfaAfcAfgGfAfGfgCfuGfuGfuGfgCfL96	367	A-122807.1	gsCfscAfcAfcAfgCfcucCfuGfuUfcUfgsgsa	436
AD-60956.1	A-122736.1	CfsgsCfcAfcUfuCfUfCfcCfaGfgAfuCfuUfL96	368	A-122737.1	asAfsgAfuCfcUfgGfgagAfaGfuGfgCfgsasu	437
AD-60957.1	A-122751.1	GfscsCfaGfuGfuGfAfAfaGfaCfaUfaGfcUfL96	369	A-122752.1	asGfscUfaUfgUfcUfuucAfcAfcUfgGfcsusu	438
AD-60958.1	A-122762.1	CfsasAfgCfaGfgGfGfGfaCfaAfgUfaUfuCfL96	370	A-122763.1	gsAfsaUfaCfuUfgUfcccCfcUfgCfuUfgsgsc	439
AD-60959.1	A-122777.1	CfscsUfgUfgAfuGfGfGfgUfcAfaGfgAfcUfL96	371	A-122778.1	asGfsuCfcUfuGfaCfcccAfuCfaCfaGfgscsa	440
AD-60960.1	A-122792.1	AfsgsUfgUfgAfaAfGfAfcAfuAfgCfuGfcAfL96	372	A-122793.1	usGfscAfgCfuAfuGfucuUfuCfaCfaCfusgsg	441
AD-60961.1	A-122808.1	GfsusCfcUfcCfgAfGfGfgUfgAfgUfgGfcCfL96	373	A-122809.1	gsGfscCfaCfuCfaCfccuCfgGfaGfgAfcsasc	442
AD-60962.1	A-119231.2	UfsgsGfcAfgGfaGfGfUfgGfcAfuCfuUfgUfL96	374	A-122738.1	asCfsaAfgAfuGfcCfaccUfcCfuGfcCfascsc	443
AD-60963.1	A-122753.1	CfsgsGfgAfcCfgAfCfUfgGfcCfaUfgUfaUfL96	375	A-122754.1	asUfsaCfaUfgGfcCfaguCfgGfuCfcCfgsgsc	444
AD-60964.1	A-119169.2	CfscsCfuAfcAfgGfGfCfcGfaGfuAfcGfaAfL96	376	A-122764.1	usUfscGfuAfcUfcGfgccCfuGfuAfgGfgsgsa	445
AD-60965.1	A-122779.1	GfscsUfuCfgGfaAfGfCfcCfcUfgGfuCfuAfL96	377	A-122780.1	usAfsgAfcCfaGfgGfgcuUfcCfgAfaGfcsusg	446
AD-60966.1	A-122794.1	AfsgsGfuUfcGfgGfGfUfcGfaCfaCfaUfcUfL96	378	A-122795.1	asGfsaUfgUfgUfcGfaccCfcGfaAfcCfusgsg	447
AD-60967.1	A-122810.1	CfsgsGfgGfuCfgAfCfAfcAfuCfuGfuGfgGfL96	379	A-122811.1	csCfscAfcAfgAfuGfuguCfgAfcCfcCfgsasa	448
AD-60968.1	A-122739.1	CfscsGfaCfuGfgCfCfAfuGfuAfuGfaCfgUfL96	380	A-122740.1	asCfsgUfcAfuAfcAfuggCfcAfgUfcGfgsusc	449
AD-60969.1	A-119189.2	CfscsAfgGfuUfcGfGfGfgUfcGfaCfaCfaUfL96	381	A-122755.1	asUfsgUfgUfcGfaCfcccGfaAfcCfuGfgsasg	450
AD-60970.1	A-122765.1	GfsgsGfuUfgUfuAfCfCfgCfuAfcAfgCfuAfL96	382	A-122766.1	usAfsgCfuGfuAfgCfgguAfaCfaAfcCfcsasg	451

AD-60971.1	A-122781.1	CfscsUfgGfuCfuAfAfCfuUfgGfgAfuCfuGfL96	383	A-122782.1	csAfsgAfuCfcCfaAfguuAfgAfcCfaGfgsgsg	452
AD-60972.1	A-122796.1	CfsasCfgCfuGfgGfUfUfgUfuAfcCfgCfuAfL96	384	A-122797.1	usAfsgCfgGfuAfaCfaacCfcAfgCfgUfgsgsa	453
AD-60973.1	A-122812.1	GfsgsGfgUfcGfaCfAfCfaUfcUfgUfgGfgGfL96	385	A-122813.1	csCfscCfaCfaGfaUfgugUfcGfaCfcCfcsgsa	454
AD-60974.1	A-122741.1	UfsgsUfgCfgGfgUfGfCfaCfuAfuGfgCfuUfL96	386	A-122742.1	asAfsgCfcAfuAfgUfgcaCfcCfgCfaCfascsc	455
AD-60975.1	A-119233.2	CfscsCfcUfgGfuCfUfAfaCfuUfgGfgAfuCfL96	387	A-122756.1	gsAfsuCfcCfaAfgUfuagAfcCfaGfgGfgscsu	456
AD-60976.1	A-122767.1	GfsgsCfcUfgGfaGfAfGfgUfgUfcCfuUfcAfL96	388	A-122768.1	usGfsaAfgGfaCfaCfcucUfcCfaGfgCfcsasg	457
AD-60977.1	A-122783.1	CfsusUfcUfuCfuGfGfUfuCfaUfuCfuCfcAfL96	389	A-122784.1	usGfsgAfgAfaUfgAfaccAfgAfaGfaAfgscsa	458
AD-60978.1	A-122798.1	CfscsAfaGfcAfgGfGfGfgAfcAfaGfuAfuUfL96	390	A-122799.1	asAfsuAfcUfuGfuCfcccCfuGfcUfuGfgscsa	459
AD-60979.1	A-122814.1	CfsusUfcCfaGfgAfGfGfaCfaGfcAfuGfgCfL96	391	A-122815.1	gsCfscAfuGfcUfgUfccuCfcUfgGfaAfgscsa	460
AD-60980.1	A-122743.1	CfscsUfgGfaUfgAfGfAfgAfaAfcUfgCfgUfL96	392	A-122744.1	asCfsgCfaGfuUfuCfucuCfaUfcCfaGfgscsc	461
AD-60981.1	A-122757.1	GfscsCfaCfuUfcUfCfCfcAfgGfaUfcUfuAfL96	393	A-122758.1	usAfsaGfaUfcCfuGfggaGfaAfgUfgGfcsgsa	462
AD-60982.1	A-122769.1	GfscsGfgGfuGfcAfCfUfaUfgGfcUfuGfuAfL96	394	A-122770.1	usAfscAfaGfcCfaUfaguGfcAfcCfcGfcsasc	463
AD-60983.1	A-119191.2	CfsasAfcGfgCfcUfGfGfaUfgAfgAfgAfaAfL96	395	A-122785.1	usUfsuCfuCfuCfaUfccaGfgCfcGfuUfgsgsg	464
AD-60984.1	A-122800.1	CfscsAfgAfaCfaGfGfAfgGfcUfgUfgUfgGfL96	396	A-122801.1	csCfsaCfaCfaGfcCfuccUfgUfuCfuGfgsasu	465
AD-60985.1	A-122827.1	GfsgsGfuCfgAfcAfCfAfuCfuGfuGfgGfgAfL96	397	A-122828.1	usCfscCfcAfcAfgAfuguGfuCfgAfcCfcscsg	466
AD-60986.1	A-122842.1	CfscsCfcAfaCfgGfCfCfuGfgAfuGfaGfaAfL96	398	A-122843.1	usUfscUfcAfuCfcAfggcCfgUfuGfgGfgscsa	467
AD-60987.1	A-119213.2	GfscsCfcCfaAfcGfGfCfcUfgGfaUfgAfgAfL96	399	A-122829.1	usCfsuCfaUfcCfaGfgccGfuUfgGfgGfcsasg	468
AD-60988.1	A-122844.1	CfsusGfcCfcUfgGfAfGfaGfuUfcCfuCfuAfL96	400	A-122845.1	usAfsgAfgGfaAfcUfcucCfaGfgGfcAfgsgsg	469
AD-60989.1	A-122816.1	CfsgsGfgGfuCfgAfCfAfcAfuCfuGfuGfgAfL96	401	A-122817.1	usCfscAfcAfgAfuGfuguCfgAfcCfcCfgsasa	470
AD-60990.1	A-122830.1	UfsusUfcCfuAfgGfGfUfaCfaAfgGfcGfgAfL96	402	A-122831.1	usCfscGfcCfuUfgUfaccCfuAfgGfaAfasusa	471
AD-60991.1	A-122846.1	AfscsUfgCfcCfcAfAfCfgGfcCfuGfgAfuAfL96	403	A-122847.1	usAfsuCfcAfgGfcCfguuGfgGfgCfaGfuscsc	472
AD-60992.1	A-122818.1	GfsgsGfgUfcGfaCfAfCfaUfcUfgUfgGfgAfL96	404	A-122819.1	usCfscCfaCfaGfaUfgugUfcGfaCfcCfcsgsa	473
AD-60993.1	A-122832.1	CfsusGfcCfcCfaAfCfGfgCfcUfgGfaUfgAfL96	405	A-122833.1	usCfsaUfcCfaGfgCfcguUfgGfgGfcAfgsusc	474
AD-60994.1	A-122848.1	AfsusUfuCfcUfaGfGfGfuAfcAfaGfgCfgAfL96	406	A-122849.1	usCfsgCfcUfuGfuAfcccUfaGfgAfaAfusasc	475
AD-60996.1	A-122834.1	CfscsCfcUfgCfcCfUfGfgAfgAfgUfuCfcUfL96	407	A-122835.1	asGfsgAfaCfuCfuCfcagGfgCfaGfgGfgsusc	476
AD-60997.1	A-122850.1	CfscsCfuGfcCfcUfGfGfaGfaGfuUfcCfuAfL96	408	A-122851.1	usAfsgGfaAfcUfcUfccaGfgGfcAfgGfgsgsu	477
AD-60998.1	A-122821.1	CfsasCfuGfuGfaCfUfGfuGfgCfcUfcCfaAfL96	409	A-122822.1	usUfsgGfaGfgCfcAfcagUfcAfcAfgUfgscsu	478
AD-60999.1	A-122836.1	GfsgsAfcUfgCfcCfCfAfaCfgGfcCfuGfgAfL96	410	A-122837.1	usCfscAfgGfcCfgUfuggGfgCfaGfuCfcsusu	479

AD-61000.1	A-122852.1	GfsgsUfaUfuUfcCfUfAfgGfgUfaCfaAfgAfL96	411	A-122853.1	usCfsuUfgUfaCfcCfuagGfaAfaUfaCfcsasg	480
AD-61001.1	A-122823.1	CfsasCfcUfcCfcAfGfAfuCfuCfcCfuCfaAfL96	412	A-122824.1	usUfsgAfgGfgAfgAfucuGfgGfaGfgUfgsasa	481
AD-61002.1	A-122838.1	UfsgsGfuAfuUfuCfCfUfaGfgGfuAfcAfaAfL96	413	A-122839.1	usUfsuGfuAfcCfcUfaggAfaAfuAfcCfasgsa	482
AD-61003.1	A-122854.1	GfsusAfuUfuCfcUfAfGfgGfuAfcAfaGfgAfL96	414	A-122855.1	usCfscUfuGfuAfcCfcuaGfgAfaAfuAfcscsa	483
AD-61004.1	A-122825.1	CfsusCfcGfaGfgGfUfGfaGfuGfgCfcAfuAfL96	415	A-122826.1	usAfsuGfgCfcAfcUfcacCfcUfcGfgAfgsgsa	484
AD-61005.1	A-122840.1	UfsgsCfcCfcAfaCfGfGfcCfuGfgAfuGfaAfL96	416	A-122841.1	usUfscAfuCfcAfgGfccgUfuGfgGfgCfasgsu	485
AD-61006.1	A-122856.1	CfscsUfgCfcCfuGfGfAfgAfgUfuCfcUfcUfL96	417	A-122857.1	asGfsaGfgAfaCfuCfuccAfgGfgCfaGfgsgsg	486

Example 6. *In vitro* single dose screen

Cell culture and transfections for single dose and dose response studies

Hep3B cells (ATCC, Manassas, VA) were grown to near confluence at 37°C in an atmosphere of 5% CO_2 in DMEM (ATCC) supplemented with 10% FBS, streptomycin, and glutamine (ATCC) before being released from the plate by trypsinization. Transfection was carried out by adding 14.8µl of Opti-MEM plus 0.2µl of Lipofectamine RNAiMax per well (Invitrogen, Carlsbad CA. cat # 13778-150) to 5µl of siRNA duplexes per well into a 96-well plate and incubated at room temperature for 15 minutes. 80µl of complete growth media without antibiotic containing ~2 x10^4 Hep3B cells were then added to the siRNA mixture. Cells were incubated for 24 hours prior to RNA purification. Experiments were performed at 10nM and 0.1nM final duplex concentration.

Total RNA isolation using DYNABEADS mRNA Isolation Kit (Invitrogen, part #: 610-12)

Cells were harvested and lysed in 150µl of Lysis/Binding Buffer then mixed for 5 minutes at 850rpm using an Eppendorf Thermomixer (the mixing speed was the same throughout the process). Ten microliters of magnetic beads and 80µl Lysis/Binding Buffer mixture were added to a round bottom plate and mixed for 1 minute. Magnetic beads were captured using magnetic stand and the supernatant was removed without disturbing the beads. After removing supernatant, the lysed cells were added to the remaining beads and mixed for 5 minutes. After removing supernatant, magnetic beads were washed 2 times with 150µl Wash Buffer A and mixed for 1 minute. Beads were capture again and supernatant removed. Beads were then washed with 150µl Wash Buffer B, captured and supernatant was removed. Beads were next washed with 150µl Elution Buffer, captured and supernatant removed. Beads were allowed to dry for 2 minutes. After drying, 50µl of Elution Buffer was added and mixed for 5 minutes at 70°C. Beads were captured on magnet for 5 minutes. 40µl of supernatant was removed and added to another 96 well plate.

cDNA synthesis using ABI High capacity cDNA reverse transcription kit (Applied Biosystems, Foster City, CA, Cat #4368813)

A master mix of 2µl 10X Buffer, 0.8µl 25X dNTPs, 2µl Random primers, 1µl Reverse Transcriptase, 1µl RNase inhibitor and 3.2µl of H2O per reaction were added into 10µl total RNA. cDNA was generated using a Bio-Rad C-1000 or S-1000 thermal cycler (Hercules, CA) through the following steps: 25°C 10 min, 37°C 120 min, 85°C 5 sec, 4°C hold.

Real time PCR

2µl of cDNA were added to a master mix containing 0.5µl GAPDH TaqMan Probe (Applied Biosystems Cat #4326317E), 0.5µl TMPRSS6 TaqMan probe (Applied Biosystems cat # Hs00542184_m1) and 5µl Lightcycler 480 probe master mix (Roche Cat #04887301001) per well in a 384 well 50 plates (Roche cat # 04887301001). Real time PCR was done in an Roche Lightcycler Real Time PCR system (Roche) using the ΔΔCt(RQ) assay. Each duplex was tested in two independent transfections and each transfection was assayed in duplicate, unless otherwise noted in the summary tables.

To calculate relative fold change, real time data were analyzed using the ΔΔCt method and normalized to assays performed with cells transfected with 10nM AD-1955, or mock transfected cells.

Data are expressed as a fraction of TMPRSS6 message remaining in cells transfected with siRNAs targeting TMPRSS6, relative to naïve cells. All siRNAs were transfected at least two times and qPCR reactions were performed in duplicate. Data are show in Table 6.

Table 6. TMPRSS6 single dose screen.

Duplex ID	Avg 10nM	Avg 0.1nM	SD 10nM	SD 0.1nM
AD-46273	76.5	112.1	14.3	18.6
AD-59743	61.4	108.2	8.7	4.4
AD-60939	38.0	85.7	19.3	25.2
AD-60940	24.2	22.6	10.1	9.7
AD-60941	48.5	84.7	11.7	29.7
AD-60942	102.9	111.2	4.3	44.8
AD-60943	86.2	96.5	2.3	28.8
AD-60944	24.6	78.5	1.1	36.5
AD-60945	65.8	140.9	0.5	59.2
AD-60946	50.3	105.9	4.1	31.2
AD-60947	79.1	147.2	12.3	51.2
AD-60948	81.0	113.9	0.6	32.7
AD-60949	111.3	96.2	8.2	28.1
AD-60950	53.8	93.2	7.6	42.3
AD-60951	74.1	121.6	6.4	56.2
AD-60952	47.6	118.3	8.1	52.4
AD-60953	22.0	56.7	8.3	18.0
AD-60954	23.3	55.8	5.3	31.7
AD-60955	110.8	117.5	1.6	38.7
AD-60956	15.8	29.6	1.7	10.2
AD-60957	22.3	58.3	1.5	6.1
AD-60958	106.4	136.0	24.1	61.7
AD-60959	79.6	123.3	0.6	49.9
AD-60960	17.4	49.4	8.6	10.2
AD-60961	107.7	129.0	6.6	50.5
AD-60962	90.2	113.3	8.0	67.2

AD-60963	117.4	138.1	2.6	16.8
AD-60964	80.7	123.2	24.2	18.9
AD-60965	30.1	80.2	9.0	20.8
AD-60966	54.1	133.6	4.6	44.0
AD-60967	122.2	147.4	11.7	42.0
AD-60968	86.9	142.0	39.9	49.7
AD-60969	106.2	116.3	16.6	39.1
AD-60970	54.6	112.6	7.3	11.8
AD-60971	50.5	118.8	6.9	47.0
AD-60972	55.6	94.2	6.5	3.4
AD-60973	126.1	133.6	8.0	36.8
AD-60974	82.6	115.0	8.7	43.7
AD-60975	88.2	114.3	13.6	43.9
AD-60976	46.3	71.0	11.6	30.2
AD-60977	13.5	26.4	3.4	9.2
AD-60978	72.7	92.9	6.4	31.7
AD-60979	103.8	97.0	13.7	29.2
AD-60980	28.4	58.0	12.3	21.1
AD-60981	56.0	80.6	18.3	4.5
AD-60982	102.4	137.4	15.2	16.4
AD-60983	60.8	87.1	10.1	20.3
AD-60984	53.6	116.7	1.2	47.8
AD-60985	72.6	99.2	0.7	21.7
AD-60986	90.1	96.4	6.6	29.5
AD-60987	83.1	90.7	1.6	13.7
AD-60988	69.4	102.3	2.4	55.4
AD-60989	112.4	105.7	0.6	14.7
AD-60990	90.4	93.4	6.2	4.1
AD-60991	97.6	95.6	15.5	23.4
AD-60992	104.0	131.4	6.9	33.7
AD-60993	118.6	129.2	10.5	30.1
AD-60994	25.9	57.2	6.8	0.3
AD-60996	77.3	94.2	7.8	12.6
AD-60997	60.1	80.9	18.8	7.5
AD-60998	32.6	61.4	5.7	24.6
AD-60999	133.6	110.9	39.7	15.4
AD-61000	55.8	117.6	14.2	24.9
AD-61001	57.9	85.2	8.1	42.0
AD-61002	15.4	31.4	1.5	10.1
AD-61003	82.3	98.1	4.0	11.8
AD-61004	106.4	97.7	38.5	18.8
AD-61005	138.0	141.2	65.7	20.0
AD-61006	31.7	70.9	7.8	6.6

Example 7. *In vivo* effect of single dose administration of TMPRSS6 iRNA agent

Female C57BL/6 mice were administered a single subcutaneous injection of AD-60940 at a dose of 0.3 mg/kg, 1.0 mg/kg or 3.0 mg/kg, or PBS alone as a control. Three mice were evaluated per dose for hepatic TMPRSS6 mRNA, hepatic hepcidin mRNA, serum hepcidin, total serum iron, and percent transferrin saturation at various time points. Mice receiving 1.0 mg/kg or 3.0 mg/kg of AD-60940 or PBS were evaluated at day 0 (pre-treatment) and 7, 11, 14 and 21 days after treatment. Mice receiving 0.3 mg/kg AD-60940 were evaluated at day 0 (pre-treatment) and at 7 and 11 days after treatment. Hepatic TMPRSS6 mRNA and hepatic hepcidin mRNA levels were determined by qPCR, normalized to GAPDH mRNA levels and expressed relative to the mRNA levels in mice administered PBS alone. Serum hepcidin was measured by ELISA (Intrinsic Life Sciences). Total serum iron and percent transferrin saturation (% TfSat) were measured using an Olympus AU400 Serum Chemistry Analyzer. Each data point represents the mean value from three mice. The standard deviation of the mean is represented by error bars.

Single dose administration of AD-60940 resulted in robust and durable suppression of hepatic TMPRSS6 mRNA relative to the control. TMPRSS6 mRNA concentration was suppressed by greater than 90% for up to three weeks following administration of the 3.0 mg/kg dose (Figure 3A). As a result of the suppression of hepatic TMPRSS6 mRNA concentration, hepcidin mRNA levels, increased two-fold relative to the control (Figure 3B), and serum hepcidin concentration increased greater than 2-fold relative to the control (Figure 3C). In addition, total serum iron (Figure 3D) decreased and percent transferrin saturation decreased by greater than 50% relative to the control (Figure 3E). The decreases in total serum iron and percent transferring saturation were durable for up to three weeks following administration of AD-60940. Figure 3F demonstrates the relative hepatic TMPRSS6 mRNA concentration as a function of AD-60940 dose at 11 days following administration. Each data point represents the maximum suppression of TMPRSS6 mRNA concentration observed at each dose level. The data were fit to the Hill equation.

The degree to which AD-60940 modulates hepcidin and serum iron mobilization is nearly identical to that observed in the previous *Hbb*$^{th3/+}$ mouse studies (Schmidt et al., *Blood* (2013), 121(7), 1200-1208) and indicates that AD-60940 is a potent RNAi therapeutic for producing disease modifying effects in β-Thalassemia.

Example 8. *In vivo* effect of multi-dose administration of TMPRSS6 iRNA agent

Female C57BL/6 mice were administered a subcutaneous injection of AD-60940 at a dose of 0.3 mg/kg, 1.0 mg/kg, or PBS alone (as a control) once per week for three weeks then sacrificed 7 days after the final dose (Figure 4A). Three mice per dose were evaluated for hepatic TMPRSS6 mRNA, hepatic hepcidin mRNA, and percent transferrin saturation.

Hepatic TMPRSS6 mRNA and hepatic hepcidin mRNA levels were determined by qPCR, normalized to GAPDH mRNA levels and expressed relative to the mRNA levels in mice administered PBS alone. Percent transferrin saturation (% TfSat) was measured using an Olympus AU400 Serum Chemistry Analyzer. Each data point represents the mean value from three mice. The standard deviation of the mean is represented by error bars.

Multi-dose administration of 1.0 mg/kg AD-60940 resulted in greater than 90% suppression of TMPRSS6 mRNA concentration (Figure 4B). Hepcidin mRNA concentration increased two-fold and percent transferrin saturation decreased by greater than 50% relative to the control (Figure 4B). Figure 4C demonstrates the relative hepatic TMPRSS6 mRNA concentration as a function of AD-60940 dose. The data were fit to the Hill equation. These data indicate that the multi-dose ED80 is less than 1.0 mg/kg.

This study demonstrates that AD-60940 exhibits robust and durable suppression of TMPRSS6, resulting in hepcidin induction and systemic iron restriction and indicates that AD-60940 is a potent RNAi therapeutic for producing disease modifying effects in β-Thalassemia.

Example 9. Relationship between liver TMPRSS6 mRNA levels and serum hepcidin concentration and percent transferrin saturation

Data generated using AD-59743, AD-61002, AD-60940, and other TMPRSS6 iRNA agents were further analyzed to evaluate the relationship between liver TMPRSS6 mRNA levels and serum hepcidin levels and percent transferrin saturation. Serum hepcidin concentration demonstrated a non-linear relationship to TMPRSS6 mRNA levels using the Hill equation (Figure 5A). The percent transferrin saturation demonstrated a linear relationship to TMPRSS6 mRNA levels when fit to a simple linear regression equation (Figure 5B). The linear relationship between TMPRSS6 mRNA levels and percent transferrin saturation indicate that iron restriction can be precisely and predictably modulated by AD-60940. Serum hepcidin concentration and relative hepcidin mRNA levels also demonstrated a linear relationship when fit to a simple linear regression equation (Figure 5C). In contrast, the relationship between percent transferrin saturation and serum hepcidin concentration was non-linear and fit to the Hill equation (Figure 5D).

Example 10. *In vivo* single dose screen

TMPRSS6 siRNA duplexes as indicated in Figure 6 were evaluated for efficacy by their ability to suppress levels of TMPRSS6 mRNA in the liver of female C57BL/6 mice following administration of the siRNA duplex. A single subcutaneous dose of 3 mg/kg of TMPRSS6 siRNA duplex was administered, and the mice were sacrificed 7 days later. The level of TMPRSS6 mRNA in the liver was measured by qPCR using the methods described above. Mice in a control group received an injection of PBS.

The levels of TMPRSS6 mRNA following administration of a TMPRSS6 siRNA duplex are shown in Figure 6. The results demonstrate that administration of AD-60940, AD-59743 and AD-61002 resulted in substantial suppression of liver TMPRSS6 mRNA with AD60940 producing the greatest silencing. Specifically, TMPRSS6 siRNA duplex AD-60940 reduced TMPRSS6 mRNA by greater than 80% relative to the control. The data also demonstrate that treatment with AD-59743, AD-60940, AD-61002, AD-60994, AD-60998 and AD-61001 result in a decrease in the level of TMPRSS6 transcript that is maintained through day 7.

Example 11. *In vivo* multi-dose screen

TMPRSS6 siRNA duplexes as indicated in Figure 7 were evaluated for efficacy by their ability to suppress levels of TMPRSS6 mRNA in the liver of wild-type C57BL/6 mice following administration of the siRNA duplex. A subcutaneous dose of either 0.3 mg/kg or 1.0 mg/kg of TMPRSS6 siRNA duplex was administered once a week for three weeks. The mice were sacrificed 7 days after the last dose. The level of TMPRSS6 mRNA in the liver was measured by qPCR using the methods described above. Mice in a control group received an injection of PBS.

The levels of TMPRSS6 mRNA following administration of a TMPRSS6 siRNA duplex are shown in Figure 7. The results demonstrate that the 1.0 mg/kg dosing regimen of TMPRSS6 siRNA duplex AD-60940 reduces TMPRSS6 mRNA by greater than 80% relative to the control.

Example 12. Optimization of AD-60940

Based on the observation that administration of AD-60940 durably reduced TMPRSS6 mRNA by greater than 80% relative to the control, additional siRNAs based on the parent sequence of AD-60940 with a variety of chemical modifications were evaluated for efficacy in single dose screens at 10nM and 0.1nM by transfection in Hep3B cells. The sequences of the sense and antisense strands of these agents are shown in Table 8 and the results of this screen are shown in Table 9. The data in Table 9 are expressed as the average fraction message remaining relative to control.

In addition, a subset of siRNA described in Tables 4 and 5, above, were modified to replace a 2'F with a 2'OMe modification at the 5'-end of the sense strand and to add a 5'-phosphate on the antisense strand. These siRNA agents were also evaluated for *in vitro* efficacy in single dose screens at 10nM and 0.1nM by transfection in Hep3B cells. The sequences of the sense and antisense strands of these agents are shown in Table 10 and the results of this screen are shown in Table 11. The data in Table 11 are expressed as the average fraction message remaining relative to control.

Table 8. TMPRSS6 Modified Sequences

DuplexID	SenseID	Sense Sequence	SEQ ID NO:	AntisenseID	Antisense Sequence	SEQ ID NO:
AD-63214	A-126586.2	Y44CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	487	A-126587.2	PusUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	544
AD-63240	A-122745.11	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	488	A-126607.1	usUfsguaCfcCfuAfggaAfaUfaccagsasg	545
AD-63209	A-126594.1	csusgguaUfuUfCfCfuaggGfdTacaaL96	489	A-122746.13	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	546
AD-63208	A-122745.6	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	490	A-126587.1	PusUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	547
AD-63202	A-126586.1	Y44CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	491	A-122746.6	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	548
AD-63216	A-122745.7	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	492	A-126603.1	usUfsgUfaCfccuAfggaAfaUfaCfcAfgsasg	549
AD-63219	A-126617.1	gsgsUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	493	A-126618.1	PusUfsgUfaCfcCfuAfggaAfaUfaCfcsasg	550
AD-63228	A-122745.9	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	494	A-126605.1	usUfsgUfaCfcCfuAfggaAfaUfaccagsasg	551
AD-63205	A-122745.13	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	495	A-126609.1	usUfsgUfaccCfuaggaAfaUfaccAfgsasg	552
AD-63241	A-126589.2	csusgguaUfuUfCfCfuaggGfuacaaL96	496	A-126611.3	usUfsguaCfccUfaggaAfaUfaccagsasg	553
AD-63243	A-126621.3	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	497	A-126624.1	usUfsGfuaCfcCfuAfggaAfAfuaCfcAfgsasg	554
AD-63203	A-126593.1	csusgguaUfuUfCfCfuaggGfuadCaaL96	498	A-122746.12	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	555
AD-63223	A-122745.16	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	499	A-126612.1	usUfsguaCfccuaggaAfaUfaccagsasg	556
AD-63231	A-126621.1	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	500	A-126622.1	usUfsGfuaCfcCfuAfggaAfaUfaCfcAfgsasg	557
AD-63199	A-122745.12	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	501	A-126608.1	usUfsgUfaccCfuAfggaAfaUfaccAfgsasg	558
AD-63217	A-122745.15	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	502	A-126611.1	usUfsguaCfccUfaggaAfaUfaccagsasg	559
AD-63229	A-122745.17	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	503	A-126613.1	usUfsguaCfcCfUfaggaAfaUfaccagsasg	560
AD-63255	A-126621.5	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	504	A-126626.1	usUfsGfuAfCfcCfuAfggaAfAfuaCfcAfgsasg	561
AD-63226	A-126589.1	csusgguaUfuUfCfCfuaggGfuacaaL96	505	A-122746.8	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	562
AD-63211	A-122745.14	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	506	A-126610.1	usUfsgUfacccuAfggaAfaUfaccAfgsasg	563
AD-63273	A-126621.8	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	507	A-126629.1	usUfsGfuaCfcCfuAfggaAfAfuAfccagsasg	564
AD-60940	A-122745.1	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	508	A-122746.1	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	565
AD-63249	A-126621.4	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	509	A-126625.1	usUfsGfuAfCfcCfuAfggaAfAfuAfCfcAfgsasg	566
AD-63256	A-122745.19	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	510	A-126634.1	usUfsgUfaccCfuAfggaAfaUfaCfcAfgsasg	567

AD-63280	A-126639.1	csusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	511	A-126587.3	PusUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	568
AD-63237	A-126621.2	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	512	A-126623.1	usUfsGfuAfCfcCfuAfggaAfaUfaCfcAfgsasg	569
AD-63285	A-126621.10	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	513	A-126631.1	usUfsGfuaCfcCfuAfggaAfAfuAfccAfgsasg	570
AD-63215	A-126595.1	csusgguaUfuUfCfdCuaggGfuacaaL96	514	A-122746.14	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	571
AD-63222	A-122745.8	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	515	A-126604.1	usUfsguaCfcCfuAfggaAfaUfaccAfgsasg	572
AD-63232	A-126590.1	csusgguAfuuUfcCfUfagGfGfuacaaL96	516	A-122746.9	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	573
AD-63218	A-126594.2	csusgguaUfuUfCfCfuaggGfdTacaaL96	517	A-126611.7	usUfsguaCfccUfaggaAfaUfaccagsasg	574
AD-63261	A-126621.6	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	518	A-126627.1	usUfsGfuaCfcCfuAfggaAfAfuAfCfcagsasg	575
AD-63267	A-126621.7	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	519	A-126628.1	usUfsGfuAfCfcCfuAfggaAfAfuAfCfcagsasg	576
AD-63234	A-122745.10	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	520	A-126606.1	usUfsguaCfccuAfggaAfaUfaccAfgsasg	577
AD-63250	A-122745.18	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	521	A-126633.1	ususgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	578
AD-63212	A-126593.2	csusgguaUfuUfCfCfuaggGfuadCaaL96	522	A-126611.6	usUfsguaCfccUfaggaAfaUfaccagsasg	579
AD-63210	A-126602.1	csusgguauuucdCuaggg(Tgn)acaaL96	523	A-122746.21	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	580
AD-63244	A-126621.11	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	524	A-126632.1	usUfsGfuAfCfcCfuAfggaAfAfuAfccAfgsasg	581
AD-63235	A-126588.2	csusgguAfuuuCfCfuAfggGfuacaaL96	525	A-126611.2	usUfsguaCfccUfaggaAfaUfaccagsasg	582
AD-63279	A-126621.9	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	526	A-126630.1	usUfsGfuAfCfcCfuAfggaAfAfuAfccagsasg	583
AD-63227	A-126597.1	csusgguAfuuucCfuagggdTacaaL96	527	A-122746.16	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	584
AD-63220	A-126588.1	csusgguAfuuuCfCfuAfggGfuacaaL96	528	A-122746.7	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	585
AD-63238	A-126591.1	csusgguAfuuucCfuaggguacaaL96	529	A-122746.10	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	586
AD-63242	A-126598.2	csusgguAfuuucCfdTaggguacaaL96	530	A-126611.11	usUfsguaCfccUfaggaAfaUfaccagsasg	587
AD-63239	A-126599.1	csusgguauuucCfdTaggguacaaL96	531	A-122746.18	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	588
AD-63233	A-126598.1	csusgguAfuuucCfdTaggguacaaL96	532	A-122746.17	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	589
AD-63268	A-126636.1	CfsusGfgUfaUfuUfCfcuAfgGfgUfaCfaAfL96	533	A-122746.22	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	590
AD-63221	A-126596.1	csusgguAfuuucCfuaggguadCaaL96	534	A-122746.15	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	591
AD-63236	A-126597.2	csusgguAfuuucCfuagggdTacaaL96	535	A-126611.10	usUfsguaCfccUfaggaAfaUfaccagsasg	592
AD-63197	A-126592.1	csusgguauuucCfUfaggguacaaL96	536	A-122746.11	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	593
AD-63224	A-126595.2	csusgguaUfuUfCfdCuaggGfuacaaL96	537	A-126611.8	usUfsguaCfccUfaggaAfaUfaccagsasg	594

AD-63200	A-126590.2	csusgguAfuuUfcCfUfagGfGfuacaaL96	538	A-126611.4	usUfsguaCfccUfaggaAfaUfaccagsasg	595
AD-63262	A-122745.20	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	539	A-126635.1	usUfsgUfaCfcCfuAfggaaaUfaCfcAfgsasg	596
AD-63204	A-126601.1	csusgguauuucdCuaggguacaaL96	540	A-122746.20	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	597
AD-63230	A-126596.2	csusgguAfuuucCfuaggguadCaaL96	541	A-126611.9	usUfsguaCfccUfaggaAfaUfaccagsasg	598
AD-63198	A-126600.1	csusgguauuucdCdTaggguacaaL96	542	A-122746.19	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	599
AD-63206	A-126591.2	csusgguAfuuucCfuaggguacaaL96	543	A-126611.5	usUfsguaCfccUfaggaAfaUfaccagsasg	600

Table 9. TMPRSS6 Single Dose Screen

	10nM	0.1nM
DuplexID	Avg	Avg
AD-63214	12.40	19.46
AD-63240	12.29	27.03
AD-63209	17.11	23.38
AD-63208	14.77	23.31
AD-63202	14.87	27.08
AD-63216	15.97	34.05
AD-63219	18.47	27.82
AD-63228	19.44	34.52
AD-63205	15.44	38.23
AD-63241	18.81	41.42
AD-63243	19.15	30.87
AD-63203	17.06	42.12
AD-63223	21.98	27.52
AD-63231	22.42	30.68
AD-63199	17.74	39.50
AD-63217	18.81	38.99
AD-63229	22.33	33.42
AD-63255	21.06	34.31
AD-63226	18.36	41.65
AD-63211	26.00	32.07
AD-63273	23.11	34.96
AD-60940	22.99	34.34
AD-63249	30.83	28.35
AD-63256	23.18	35.19
AD-63280	25.10	32.42
AD-63237	23.95	35.43
AD-63285	21.53	39.60
AD-63215	29.27	42.54
AD-63222	23.88	38.24
AD-63232	30.29	35.04
AD-63218	27.02	37.31
AD-63261	24.22	46.61
AD-63267	28.32	38.90
AD-63234	24.42	55.83
AD-63250	26.77	47.92
AD-63212	28.43	46.01
AD-63210	27.91	44.35
AD-63244	30.66	45.65
AD-63235	32.75	51.82
AD-63279	38.00	48.80

AD-63227	33.15	58.12
AD-63220	38.31	54.08
AD-63238	45.56	51.50
AD-63242	47.96	54.26
AD-63239	51.98	49.22
AD-63233	51.37	65.83
AD-63268	41.22	82.16
AD-63221	57.02	65.11
AD-63236	49.86	71.66
AD-63197	47.67	78.29
AD-63224	67.73	60.88
AD-63200	62.89	67.68
AD-63262	64.25	79.72
AD-63204	68.01	80.99
AD-63230	66.88	81.04
AD-63198	65.67	78.28
AD-63206	65.10	82.71

Table 10. TMPRSS6 Modified Sequences

DuplexID	SenseID	Sense Sequence	SEQ ID NO:	AntisenseID	Antisense Sequence	SEQ ID NO:
AD-63214	A-126586.2	Y44CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	601	A-126587.2	PusUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	658
AD-63240	A-122745.11	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	602	A-126607.1	usUfsguaCfcCfuAfggaAfaUfaccagsasg	659
AD-63209	A-126594.1	csusgguaUfuUfCfCfuaggGfdTacaaL96	603	A-122746.13	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	660
AD-63208	A-122745.6	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	604	A-126587.1	PusUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	661
AD-63202	A-126586.1	Y44CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	605	A-122746.6	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	662
AD-63216	A-122745.7	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	606	A-126603.1	usUfsgUfaCfccuAfggaAfaUfaCfcAfgsasg	663
AD-63219	A-126617.1	gsgsUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	607	A-126618.1	PusUfsgUfaCfcCfuAfggaAfaUfaCfcsasg	664
AD-63228	A-122745.9	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	608	A-126605.1	usUfsgUfaCfcCfuAfggaAfaUfaccagsasg	665
AD-63205	A-122745.13	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	609	A-126609.1	usUfsgUfaccCfuaggaAfaUfaccAfgsasg	666
AD-63241	A-126589.2	csusgguaUfuUfCfCfuaggGfuacaaL96	610	A-126611.3	usUfsguaCfccUfaggaAfaUfaccagsasg	667
AD-63243	A-126621.3	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	611	A-126624.1	usUfsGfuaCfcCfuAfggaAfAfuaCfcAfgsasg	668
AD-63203	A-126593.1	csusgguaUfuUfCfCfuaggGfuadCaaL96	612	A-122746.12	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	669
AD-63223	A-122745.16	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	613	A-126612.1	usUfsguaCfccuaggaAfaUfaccagsasg	670
AD-63231	A-126621.1	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	614	A-126622.1	usUfsGfuaCfcCfuAfggaAfaUfaCfcAfgsasg	671
AD-63199	A-122745.12	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	615	A-126608.1	usUfsgUfaccCfuAfggaAfaUfaccAfgsasg	672
AD-63217	A-122745.15	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	616	A-126611.1	usUfsguaCfccUfaggaAfaUfaccagsasg	673
AD-63229	A-122745.17	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	617	A-126613.1	usUfsguaCfcCfUfaggaAfaUfaccagsasg	674
AD-63255	A-126621.5	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	618	A-126626.1	usUfsGfuAfCfcCfuAfggaAfAfuaCfcAfgsasg	675
AD-63226	A-126589.1	csusgguaUfuUfCfCfuaggGfuacaaL96	619	A-122746.8	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	676
AD-63211	A-122745.14	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	620	A-126610.1	usUfsgUfacccuAfggaAfaUfaccAfgsasg	677
AD-63273	A-126621.8	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	621	A-126629.1	usUfsGfuaCfcCfuAfggaAfAfuAfccagsasg	678
AD-60940	A-122745.1	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	622	A-122746.1	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	679
AD-63249	A-126621.4	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	623	A-126625.1	usUfsGfuAfCfcCfuAfggaAfAfuAfCfcAfgsasg	680
AD-63256	A-122745.19	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	624	A-126634.1	usUfsgUfaccCfuAfggaAfaUfaCfcAfgsasg	681
AD-63280	A-126639.1	csusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	625	A-126587.3	PusUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	682

AD-63237	A-126621.2	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	626	A-126623.1	usUfsGfuAfCfcCfuAfggaAfaUfaCfcAfgsasg	683
AD-63285	A-126621.10	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	627	A-126631.1	usUfsGfuaCfcCfuAfggaAfAfuAfccAfgsasg	684
AD-63215	A-126595.1	csusggguaUfuUfCfdCuaggGfuacaaL96	628	A-122746.14	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	685
AD-63222	A-122745.8	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	629	A-126604.1	usUfsguaCfcCfuAfggaAfaUfaccAfgsasg	686
AD-63232	A-126590.1	csusgguAfuuUfcCfUfagGfGfuacaaL96	630	A-122746.9	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	687
AD-63218	A-126594.2	csusgguaUfuUfCfCfuaggGfdTacaaL96	631	A-126611.7	usUfsguaCfccUfaggaAfaUfaccagsasg	688
AD-63261	A-126621.6	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	632	A-126627.1	usUfsGfuaCfcCfuAfggaAfAfuAfCfcagsasg	689
AD-63267	A-126621.7	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	633	A-126628.1	usUfsGfuAfCfcCfuAfggaAfAfuAfCfcagsasg	690
AD-63234	A-122745.10	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	634	A-126606.1	usUfsguaCfccuAfggaAfaUfaccAfgsasg	691
AD-63250	A-122745.18	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	635	A-126633.1	ususgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	692
AD-63212	A-126593.2	csusgguaUfuUfCfCfuaggGfuadCaaL96	636	A-126611.6	usUfsguaCfccUfaggaAfaUfaccagsasg	693
AD-63210	A-126602.1	csusgguauuucdCuaggg(Tgn)acaaL96	637	A-122746.21	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	694
AD-63244	A-126621.11	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	638	A-126632.1	usUfsGfuAfCfcCfuAfggaAfAfuAfccAfgsasg	695
AD-63235	A-126588.2	csusgguAfuuuCfCfuAfggGfuacaaL96	639	A-126611.2	usUfsguaCfccUfaggaAfaUfaccagsasg	696
AD-63279	A-126621.9	csusGfguaUfuUfCfCfuAfgGfguAfcaaL96	640	A-126630.1	usUfsGfuAfCfcCfuAfggaAfAfuAfccagsasg	697
AD-63227	A-126597.1	csusgguAfuuucCfuagggdTacaaL96	641	A-122746.16	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	698
AD-63220	A-126588.1	csusgguAfuuuCfCfuAfggGfuacaaL96	642	A-122746.7	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	699
AD-63238	A-126591.1	csusgguAfuuucCfuaggguacaaL96	643	A-122746.10	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	700
AD-63242	A-126598.2	csusgguAfuuucCfdTaggguacaaL96	644	A-126611.11	usUfsguaCfccUfaggaAfaUfaccagsasg	701
AD-63239	A-126599.1	csusgguauuucCfdTaggguacaaL96	645	A-122746.18	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	702
AD-63233	A-126598.1	csusgguAfuuucCfdTaggguacaaL96	646	A-122746.17	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	703
AD-63268	A-126636.1	CfsusGfgUfaUfuUfCfcuAfgGfgUfaCfaAfL96	647	A-122746.22	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	704
AD-63221	A-126596.1	csusgguAfuuucCfuaggguadCaaL96	648	A-122746.15	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	705
AD-63236	A-126597.2	csusgguAfuuucCfuagggdTacaaL96	649	A-126611.10	usUfsguaCfccUfaggaAfaUfaccagsasg	706
AD-63197	A-126592.1	csusgguauuucCfUfaggguacaaL96	650	A-122746.11	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	707
AD-63224	A-126595.2	csusggguaUfuUfCfdCuaggGfuacaaL96	651	A-126611.8	usUfsguaCfccUfaggaAfaUfaccagsasg	708
AD-63200	A-126590.2	csusgguAfuuUfcCfUfagGfGfuacaaL96	652	A-126611.4	usUfsguaCfccUfaggaAfaUfaccagsasg	709
AD-63262	A-122745.20	CfsusGfgUfaUfuUfCfCfuAfgGfgUfaCfaAfL96	653	A-126635.1	usUfsgUfaCfcCfuAfggaaaUfaCfcAfgsasg	710

AD-63204	A-126601.1	csusgguauuucdCuaggguacaaL96	654	A-122746.20	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	711
AD-63230	A-126596.2	csusgguAfuuucCfuaggguadCaaL96	655	A-126611.9	usUfsguaCfccUfaggaAfaUfaccagsasg	712
AD-63198	A-126600.1	csusgguauuucdCdTaggguacaaL96	656	A-122746.19	usUfsgUfaCfcCfuAfggaAfaUfaCfcAfgsasg	713
AD-63206	A-126591.2	csusgguAfuuucCfuaggguacaaL96	657	A-126611.5	usUfsguaCfccUfaggaAfaUfaccagsasg	714

Table 11. TMPRSS6 Single Dose Screen

	10nM		0.1nM	
DuplexID	Avg	SD	Avg	SD
AD-60998	26.1	3.1	42.9	13.3
AD-60970	24.3	9.3	39.0	24.2
AD-61002	27.5	8.5	32.1	9.8
AD-60994	19.9	5.8	28.2	9.3
AD-60992	57.9	15.4	67.5	13.6
AD-61006	25.8	2.5	33.4	8.7
AD-59743	21.1	3.2	31.7	8.1
AD-60966	64.6	15.6	76.0	18.2
AD-60952	44.1	10.7	76.9	16.5
AD-61000	37.2	5.8	43.3	12.7
AD-60949	94.9	22.3	91.3	13.2
AD-60969	100.7	18.5	124.5	43.0
AD-60967	93.7	6.4	112.1	31.5
AD-60984	44.7	21.4	58.2	9.6
AD-60943	65.6	11.0	61.7	9.8
AD-61001	69.2	8.3	100.8	8.4
AD-60986	38.9	13.9	58.9	4.8
AD-60988	61.7	12.0	68.6	15.2
AD-60993	92.1	13.1	86.5	10.0
AD-60987	113.9	15.3	97.9	21.0
AD-60997	54.8	7.2	75.8	16.4
AD-60973	61.5	15.7	80.8	9.3
AD-61005	116.8	23.4	128.1	10.8
AD-60985	71.2	15.1	78.7	14.6
AD-61003	101.0	15.2	97.5	15.8
AD-60989	75.8	9.8	97.2	20.8
AD-60955	108.6	23.4	102.0	16.6
AD-60991	96.6	19.4	95.6	12.4
AD-61004	111.1	6.4	110.9	18.3
AD-60961	96.9	36.0	84.1	28.2
AD-60999	106.7	12.7	92.3	24.6
AD-60990	92.9	38.4	97.6	16.8
AD-60996	71.2	7.5	101.5	8.9

Example 13. Optimization of AD-60940

Additional duplexes targeting TMPRSS6 were produced and screened *in vitro* for efficacy using the materials and methods below.

Design, Synthesis, and in Vitro Screening of Additional siRNAs

siRNA design

TMPRSS6 duplexes, 19 nucleotides long for both the sense and antisense strand, were designed using the human TMPRSS6 mRNA sequence set forth in GenBank Accession No. NM_153609.3. Three thousand one hundred and eighty duplexes were initially identified that did not contain repeats longer than 7 nucleotides, spanning substantially the entire 3209 nucleotide transcript. All 3180 duplexes were then scored for predicted efficacy according to a linear model that evaluates the nucleotide pair at each duplex position, and the dose and cell line used for screening. The duplexes were also matched against all transcripts in the human RefSeq collection using a custom brute force algorithm, and scored for lowest numbers of mismatches (per strand) to transcripts other than TMPRSS6. Duplexes to be synthesized and screened were then selected from the 3180, according to the following scheme: Beginning at the 5' end of the transcript, a duplex was selected within a "window" of every 10 ± 2 nucleotides that had the highest predicted efficacy, had at least one mismatch in both strands to all transcripts other than TMPRSS6, and had not already been synthesized and screened as part of other duplex sets.

If no duplex is identified within a given window that satisfied all criteria, that window was skipped. Three hundred and three duplexes were selected according to the above criteria. An additional 31 duplexes were also selected.

A detailed list of the 334 TMPRSS6 sense and antisense strand sequences is shown in Table 12.

Cell culture and transfections

Hep3B2.1-7 cells were obtained from American Type Culture Collection (Rockville, Md., cat. No. HB-8064) and cultured in EMEM (ATCC #30-2003), supplemented to contain 10% fetal calf serum (FCS) (Biochrom AG, Berlin, Germany, cat. No. S0115) and Penicillin 100 U/ml, Streptomycin 100 mg/ml (Biochrom AG, Berlin, Germany, cat. No. A2213), at 37°C in an atmosphere with 5% CO_2 in a humidified incubator (Heraeus HERAcell, Kendro Laboratory Products, Langenselbold, Germany).

Transfection of dsRNA was performed directly after seeding 15,000 cells / well on a 96-well plate, and was carried out with Lipofectamine 2000 (Invitrogen GmbH, Karlsruhe, Germany, cat.No. 11668-019) as described by the manufacturer. Transfections were performed in quadruplicates and dsRNAs were transfected at a concentration of 10 nM.

Branched DNA assays- QunatiGene 2.0 (Panomics cat #: QS0011)

For measurement of TMPRSS6 mRNA cells were harvested 24 hours after transfection and lysed at 53°C following procedures recommended by the manufacturer of the Quantigene II Kit for TMPRSS6 and Quantigene I Explore Kit for bDNA (Panomics, Fremont, Calif., USA, cat. No. 15735 or QG0004, respectively). Subsequently, 50 µl of the lysates were incubated with probesets specific to human TMPRSS6 and 10 µl of the lysates for human GAPDH and processed according to the manufacturer's protocol for QuantiGene. Chemoluminescence was measured in a Victor2-Light (Perkin Elmer, Wiesbaden, Germany) as RLUs (relative light units) and values obtained with the human TMPRSS6 probeset were normalized to the respective human GAPDH values for each well and then related to the mean of three unrelated control dsRNAs.

The *in vitro* efficacy of the compounds is shown in Table 13.

Table 12. Additional modified TMPRSS6 siRNAs

Duplex ID	Sense Sequence	SEQ ID NO:	Sense ID	Position in NM_153609.3	Antisense Sequence	SEQ ID NO:	Antisense ID
AD-63290.1	UGAGCCAGACCCAGUCCAGdTdT	715	A-126858.1	3-21	CUGGACUGGGUCUGGCUCAdTdT	1049	A-126859.1
AD-63296.1	GACCCAGUCCAGCUCUGGUdTdT	716	A-126860.1	10-28	ACCAGAGCUGGACUGGGUCdTdT	1050	A-126861.1
AD-63302.1	CUCUGGUGCCUGCCCUCUGdTdT	717	A-126862.1	22-40	CAGAGGGCAGGCACCAGAGdTdT	1051	A-126863.1
AD-63308.1	GCCCUCUGGUGCGAGCUGAdTdT	718	A-126864.1	33-51	UCAGCUCGCACCAGAGGGCdTdT	1052	A-126865.1
AD-63314.1	GGUGCGAGCUGACCUGAGAdTdT	719	A-126866.1	40-58	UCUCAGGUCAGCUCGCACCdTdT	1053	A-126867.1
AD-63320.1	UGACCUGAGAUGCACUUCCdTdT	720	A-126868.1	49-67	GGAAGUGCAUCUCAGGUCAdTdT	1054	A-126869.1
AD-63326.1	UGCACUUCCCUCCUCUGUGdTdT	721	A-126870.1	59-77	CACAGAGGAGGGAAGUGCAdTdT	1055	A-126871.1
AD-63332.1	CUGUGAGCUGUCUCGGCACdTdT	722	A-126872.1	73-91	GUGCCGAGACAGCUCACAGdTdT	1056	A-126873.1
AD-63291.1	GUCUCGGCACCCACUUGCAdTdT	723	A-126874.1	82-100	UGCAAGUGGGUGCCGAGACdTdT	1057	A-126875.1
AD-63297.1	CCACUUGCAGUCACUGCCGdTdT	724	A-126876.1	92-110	CGGCAGUGACUGCAAGUGGdTdT	1058	A-126877.1
AD-63303.1	GUCACUGCCGCCUGAUGUUdTdT	725	A-126878.1	101-119	AACAUCAGGCGGCAGUGACdTdT	1059	A-126879.1
AD-63309.1	GCCUGAUGUUGUUACUCUUdTdT	726	A-126880.1	110-128	AAGAGUAACAACAUCAGGCdTdT	1060	A-126881.1
AD-63315.1	UUACUCUUCCACUCCAAAAdTdT	727	A-126882.1	121-139	UUUUGGAGUGGAAGAGUAAdTdT	1061	A-126883.1
AD-63321.1	ACUCCAAAAGGAUGCCCGUdTdT	728	A-126884.1	131-149	ACGGGCAUCCUUUUGGAGUdTdT	1062	A-126885.1
AD-63327.1	UGCCCGUGGCCGAGGCCCCdTdT	729	A-126886.1	143-161	GGGGCCUCGGCCACGGGCAdTdT	1063	A-126887.1
AD-63333.1	UGGCCGAGGCCCCCCAGGUdTdT	730	A-126888.1	149-167	ACCUGGGGGGCCUCGGCCAdTdT	1064	A-126889.1
AD-63292.1	CCAGGUGGCUGGCGGGCAGdTdT	731	A-126890.1	162-180	CUGCCCGCCAGCCACCUGGdTdT	1065	A-126891.1
AD-63298.1	GCGGGCAGGGGGACGGAGGdTdT	732	A-126892.1	173-191	CCUCCGUCCCCCUGCCCGCdTdT	1066	A-126893.1
AD-63304.1	GGACGGAGGUGAUGGCGAGdTdT	733	A-126894.1	183-201	CUCGCCAUCACCUCCGUCCdTdT	1067	A-126895.1
AD-63310.1	GUGAUGGCGAGGAAGCGGAdTdT	734	A-126896.1	191-209	UCCGCUUCCUCGCCAUCACdTdT	1068	A-126897.1
AD-63316.1	GAAGCGGAGCCGGAGGGGAdTdT	735	A-126898.1	202-220	UCCCCUCCGGCUCCGCUUCdTdT	1069	A-126899.1
AD-63322.1	GCCGGAGGGGAUGUUCAAGdTdT	736	A-126900.1	210-228	CUUGAACAUCCCCUCCGGCdTdT	1070	A-126901.1

AD-63328.1	UGUUCAAGGCCUGUGAGGAdTdT	737	A-126902.1	221-239	UCCUCACAGGCCUUGAACAdTdT	1071	A-126903.1
AD-63334.1	CUGUGAGGACUCCAAGAGAdTdT	738	A-126904.1	231-249	UCUCUUGGAGUCCUCACAGdTdT	1072	A-126905.1
AD-63293.1	ACUCCAAGAGAAAAGCCCGdTdT	739	A-126906.1	239-257	CGGGCUUUUCUCUUGGAGUdTdT	1073	A-126907.1
AD-63299.1	GCCCGGGGCUACCUCCGCCdTdT	740	A-126908.1	253-271	GGCGGAGGUAGCCCCGGGCdTdT	1074	A-126909.1
AD-63305.1	ACCUCCGCCUGGUGCCCCUdTdT	741	A-126910.1	263-281	AGGGGCACCAGGCGGAGGUdTdT	1075	A-126911.1
AD-63311.1	GCCUGGUGCCCCUGUUUGUdTdT	742	A-126912.1	269-287	ACAAACAGGGGCACCAGGCdTdT	1076	A-126913.1
AD-63317.1	UGUUUGUGCUGCUGGCCCUdTdT	743	A-126914.1	281-299	AGGGCCAGCAGCACAAACAdTdT	1077	A-126915.1
AD-63323.1	UGCUGGCCCUGCUCGUGCUdTdT	744	A-126916.1	290-308	AGCACGAGCAGGGCCAGCAdTdT	1078	A-126917.1
AD-63329.1	GCUCGUGCUGGCUUCGGCGdTdT	745	A-126918.1	300-318	CGCCGAAGCCAGCACGAGCdTdT	1079	A-126919.1
AD-63335.1	UCGGCGGGGGUGCUACUCUdTdT	746	A-126920.1	313-331	AGAGUAGCACCCCCGCCGAdTdT	1080	A-126921.1
AD-63294.1	CGGCGGGGGUGCUACUCUGdTdT	747	A-126922.1	314-332	CAGAGUAGCACCCCCGCCGdTdT	1081	A-126923.1
AD-63300.1	GGCGGGGGUGCUACUCUGGdTdT	748	A-126924.1	315-333	CCAGAGUAGCACCCCCGCCdTdT	1082	A-126925.1
AD-63306.1	GCGGGGGUGCUACUCUGGUdTdT	749	A-126926.1	316-334	ACCAGAGUAGCACCCCCGCdTdT	1083	A-126927.1
AD-63312.1	CGGGGGUGCUACUCUGGUAdTdT	750	A-126928.1	317-335	UACCAGAGUAGCACCCCCGdTdT	1084	A-126929.1
AD-63318.1	GGGGGUGCUACUCUGGUAUdTdT	751	A-126930.1	318-336	AUACCAGAGUAGCACCCCCdTdT	1085	A-126931.1
AD-63324.1	GGGUGCUACUCUGGUAUUUdTdT	752	A-126932.1	320-338	AAAUACCAGAGUAGCACCCdTdT	1086	A-126933.1
AD-63330.1	GGUGCUACUCUGGUAUUUCdTdT	753	A-126934.1	321-339	GAAAUACCAGAGUAGCACCdTdT	1087	A-126935.1
AD-63336.1	GUGCUACUCUGGUAUUUCCdTdT	754	A-126936.1	322-340	GGAAAUACCAGAGUAGCACdTdT	1088	A-126937.1
AD-63295.1	GCUACUCUGGUAUUUCCUAdTdT	755	A-126938.1	324-342	UAGGAAAUACCAGAGUAGCdTdT	1089	A-126939.1
AD-63301.1	CUACUCUGGUAUUUCCUAGdTdT	756	A-126940.1	325-343	CUAGGAAAUACCAGAGUAGdTdT	1090	A-126941.1
AD-63307.1	UACUCUGGUAUUUCCUAGGdTdT	757	A-126942.1	326-344	CCUAGGAAAUACCAGAGUAdTdT	1091	A-126943.1
AD-63313.1	ACUCUGGUAUUUCCUAGGGdTdT	758	A-126944.1	327-345	CCCUAGGAAAUACCAGAGUdTdT	1092	A-126945.1
AD-63319.1	CUCUGGUAUUUCCUAGGGUdTdT	759	A-126946.1	328-346	ACCCUAGGAAAUACCAGAGdTdT	1093	A-126947.1
AD-63325.1	CUGGUAUUUCCUAGGGUACdTdT	760	A-126948.1	330-348	GUACCCUAGGAAAUACCAGdTdT	1094	A-126949.1
AD-63331.1	GUAUUUCCUAGGGUACAAGdTdT	761	A-126950.1	333-351	CUUGUACCCUAGGAAAUACdTdT	1095	A-126951.1
AD-63337.1	UAUUUCCUAGGGUACAAGGdTdT	762	A-126952.1	334-352	CCUUGUACCCUAGGAAAUAdTdT	1096	A-126953.1
AD-63343.1	AUUUCCUAGGGUACAAGGCdTdT	763	A-126954.1	335-353	GCCUUGUACCCUAGGAAAUdTdT	1097	A-126955.1
AD-63349.1	UUUCCUAGGGUACAAGGCGdTdT	764	A-126956.1	336-354	CGCCUUGUACCCUAGGAAAdTdT	1098	A-126957.1

AD-63355.1	UUCCUAGGGUACAAGGCGGdTdT	765	A-126958.1	337-355	CCGCCUUGUACCCUAGGAAdTdT	1099	A-126959.1
AD-63361.1	CCUAGGGUACAAGGCGGAGdTdT	766	A-126960.1	339-357	CUCCGCCUUGUACCCUAGGdTdT	1100	A-126961.1
AD-63367.1	CUAGGGUACAAGGCGGAGGdTdT	767	A-126962.1	340-358	CCUCCGCCUUGUACCCUAGdTdT	1101	A-126963.1
AD-63373.1	UAGGGUACAAGGCGGAGGUdTdT	768	A-126964.1	341-359	ACCUCCGCCUUGUACCCUAdTdT	1102	A-126965.1
AD-63379.1	AGGGUACAAGGCGGAGGUGdTdT	769	A-126966.1	342-360	CACCUCCGCCUUGUACCCUdTdT	1103	A-126967.1
AD-63338.1	GGGUACAAGGCGGAGGUGAdTdT	770	A-126968.1	343-361	UCACCUCCGCCUUGUACCCdTdT	1104	A-126969.1
AD-63344.1	GGUACAAGGCGGAGGUGAUdTdT	771	A-126970.1	344-362	AUCACCUCCGCCUUGUACCdTdT	1105	A-126971.1
AD-63350.1	GUACAAGGCGGAGGUGAUGdTdT	772	A-126972.1	345-363	CAUCACCUCCGCCUUGUACdTdT	1106	A-126973.1
AD-63356.1	UACAAGGCGGAGGUGAUGGdTdT	773	A-126974.1	346-364	CCAUCACCUCCGCCUUGUAdTdT	1107	A-126975.1
AD-63362.1	ACAAGGCGGAGGUGAUGGUdTdT	774	A-126976.1	347-365	ACCAUCACCUCCGCCUUGUdTdT	1108	A-126977.1
AD-63368.1	CAAGGCGGAGGUGAUGGUCdTdT	775	A-126978.1	348-366	GACCAUCACCUCCGCCUUGdTdT	1109	A-126979.1
AD-63374.1	AAGGCGGAGGUGAUGGUCAdTdT	776	A-126980.1	349-367	UGACCAUCACCUCCGCCUUdTdT	1110	A-126981.1
AD-63380.1	AGGCGGAGGUGAUGGUCAGdTdT	777	A-126982.1	350-368	CUGACCAUCACCUCCGCCUdTdT	1111	A-126983.1
AD-63339.1	UGAUGGUCAGCCAGGUGUAdTdT	778	A-126984.1	359-377	UACACCUGGCUGACCAUCAdTdT	1112	A-126985.1
AD-63345.1	CCAGGUGUACUCAGGCAGUdTdT	779	A-126986.1	369-387	ACUGCCUGAGUACACCUGGdTdT	1113	A-126987.1
AD-63351.1	GCAGUCUGCGUGUACUCAAdTdT	780	A-126988.1	383-401	UUGAGUACACGCAGACUGCdTdT	1114	A-126989.1
AD-63357.1	GCGUGUACUCAAUCGCCACdTdT	781	A-126990.1	390-408	GUGGCGAUUGAGUACACGCdTdT	1115	A-126991.1
AD-63363.1	UCGCCACUUCUCCCAGGAUdTdT	782	A-126992.1	402-420	AUCCUGGGAGAAGUGGCGAdTdT	1116	A-126993.1
AD-63369.1	CUCCCAGGAUCUUACCCGCdTdT	783	A-126994.1	411-429	GCGGGUAAGAUCCUGGGAGdTdT	1117	A-126995.1
AD-63375.1	UACCCGCCGGGAAUCUAGUdTdT	784	A-126996.1	423-441	ACUAGAUUCCCGGCGGGUAdTdT	1118	A-126997.1
AD-63381.1	CCGGGAAUCUAGUGCCUUCdTdT	785	A-126998.1	429-447	GAAGGCACUAGAUUCCCGGdTdT	1119	A-126999.1
AD-63340.1	AGUGCCUUCCGCAGUGAAAdTdT	786	A-127000.1	439-457	UUUCACUGCGGAAGGCACUdTdT	1120	A-127001.1
AD-63346.1	GUGAAACCGCCAAAGCCCAdTdT	787	A-127002.1	452-470	UGGGCUUUGGCGGUUUCACdTdT	1121	A-127003.1
AD-63352.1	CGCCAAAGCCCAGAAGAUGdTdT	788	A-127004.1	459-477	CAUCUUCUGGGCUUUGGCGdTdT	1122	A-127005.1
AD-63358.1	CAGAAGAUGCUCAAGGAGCdTdT	789	A-127006.1	469-487	GCUCCUUGAGCAUCUUCUGdTdT	1123	A-127007.1
AD-63364.1	UCAAGGAGCUCAUCACCAGdTdT	790	A-127008.1	479-497	CUGGUGAUGAGCUCCUUGAdTdT	1124	A-127009.1
AD-63370.1	ACCAGCACCCGCCUGGGAAdTdT	791	A-127010.1	493-511	UUCCCAGGCGGGUGCUGGUdTdT	1125	A-127011.1
AD-63376.1	GCCUGGGAACUUACUACAAdTdT	792	A-127012.1	503-521	UUGUAGUAAGUUCCCAGGCdTdT	1126	A-127013.1

AD-63382.1	GAACUUACUACAACUCCAGdTdT	793	A-127014.1	509-527	CUGGAGUUGUAGUAAGUUCdTdT	1127	A-127015.1
AD-63341.1	AACUCCAGCUCCGUCUAUUdTdT	794	A-127016.1	520-538	AAUAGACGGAGCUGGAGUUdTdT	1128	A-127017.1
AD-63347.1	CCGUCUAUUCCUUUGGGGAdTdT	795	A-127018.1	530-548	UCCCCAAAGGAAUAGACGGdTdT	1129	A-127019.1
AD-63353.1	UUGGGGAGGGACCCCUCACdTdT	796	A-127020.1	542-560	GUGAGGGGUCCCUCCCCAAdTdT	1130	A-127021.1
AD-63359.1	CCCCUCACCUGCUUCUUCUdTdT	797	A-127022.1	553-571	AGAAGAAGCAGGUGAGGGGdTdT	1131	A-127023.1
AD-63365.1	CUGCUUCUUCUGGUUCAUUdTdT	798	A-127024.1	561-579	AAUGAACCAGAAGAAGCAGdTdT	1132	A-127025.1
AD-63371.1	CUGGUUCAUUCUCCAAAUCdTdT	799	A-127026.1	570-588	GAUUUGGAGAAUGAACCAGdTdT	1133	A-127027.1
AD-63377.1	UCUCCAAAUCCCCGAGCACdTdT	800	A-127028.1	579-597	GUGCUCGGGGAUUUGGAGAdTdT	1134	A-127029.1
AD-63383.1	CCGAGCACCGCCGGCUGAUdTdT	801	A-127030.1	590-608	AUCAGCCGGCGGUGCUCGGdTdT	1135	A-127031.1
AD-63342.1	GGCUGAUGCUGAGCCCCGAdTdT	802	A-127032.1	602-620	UCGGGGCUCAGCAUCAGCCdTdT	1136	A-127033.1
AD-63348.1	UGAGCCCCGAGGUGGUGCAdTdT	803	A-127034.1	611-629	UGCACCACCUCGGGGCUCAdTdT	1137	A-127035.1
AD-63354.1	UGGUGCAGGCACUGCUGGUdTdT	804	A-127036.1	623-641	ACCAGCAGUGCCUGCACCAdTdT	1138	A-127037.1
AD-63360.1	AGGCACUGCUGGUGGAGGAdTdT	805	A-127038.1	629-647	UCCUCCACCAGCAGUGCCUdTdT	1139	A-127039.1
AD-63366.1	GUGGAGGAGCUGCUGUCCAdTdT	806	A-127040.1	640-658	UGGACAGCAGCUCCUCCACdTdT	1140	A-127041.1
AD-63372.1	UGUCCACAGUCAACAGCUCdTdT	807	A-127042.1	653-671	GAGCUGUUGACUGUGGACAdTdT	1141	A-127043.1
AD-63378.1	UCAACAGCUCGGCUGCCGUdTdT	808	A-127044.1	662-680	ACGGCAGCCGAGCUGUUGAdTdT	1142	A-127045.1
AD-63384.1	UCGGCUGCCGUCCCCUACAdTdT	809	A-127046.1	670-688	UGUAGGGGACGGCAGCCGAdTdT	1143	A-127047.1
AD-63390.1	AGUGGACCCCGAGGGCCUAdTdT	810	A-127048.1	702-720	UAGGCCCUCGGGGUCCACUdTdT	1144	A-127049.1
AD-63396.1	AGGGCCUAGUGAUCCUGGAdTdT	811	A-127050.1	713-731	UCCAGGAUCACUAGGCCCUdTdT	1145	A-127051.1
AD-63402.1	UAGUGAUCCUGGAAGCCAGdTdT	812	A-127052.1	719-737	CUGGCUUCCAGGAUCACUAdTdT	1146	A-127053.1
AD-63408.1	AAGCCAGUGUGAAAGACAUdTdT	813	A-127054.1	731-749	AUGUCUUUCACACUGGCUUdTdT	1147	A-127055.1
AD-63414.1	UGAAAGACAUAGCUGCAUUdTdT	814	A-127056.1	740-758	AAUGCAGCUAUGUCUUUCAdTdT	1148	A-127057.1
AD-63420.1	UGCAUUGAAUUCCACGCUGdTdT	815	A-127058.1	753-771	CAGCGUGGAAUUCAAUGCAdTdT	1149	A-127059.1
AD-63426.1	CUACAGCUACGUGGGCCAGdTdT	816	A-127060.1	783-801	CUGGCCCACGUAGCUGUAGdTdT	1150	A-127061.1
AD-63385.1	CUACGUGGGCCAGGGCCAGdTdT	817	A-127062.1	789-807	CUGGCCCUGGCCCACGUAGdTdT	1151	A-127063.1
AD-63391.1	AGGGCCAGGUCCUCCGGCUdTdT	818	A-127064.1	800-818	AGCCGGAGGACCUGGCCCUdTdT	1152	A-127065.1
AD-63397.1	CCGGCUGAAGGGGCCUGACdTdT	819	A-127066.1	813-831	GUCAGGCCCCUUCAGCCGGdTdT	1153	A-127067.1
AD-63403.1	GGGCCUGACCACCUGGCCUdTdT	820	A-127068.1	823-841	AGGCCAGGUGGUCAGGCCCdTdT	1154	A-127069.1

AD-63409.1	CCACCUGGCCUCCAGCUGCdTdT	821	A-127070.1	831-849	GCAGCUGGAGGCCAGGUGGdTdT	1155	A-127071.1
AD-63415.1	CCAGCUGCCUGUGGCACCUdTdT	822	A-127072.1	842-860	AGGUGCCACAGGCAGCUGGdTdT	1156	A-127073.1
AD-63421.1	CUGUGGCACCUGCAGGGCCdTdT	823	A-127074.1	850-868	GGCCCUGCAGGUGCCACAGdTdT	1157	A-127075.1
AD-63427.1	CUGCAGGGCCCCAAGGACCdTdT	824	A-127076.1	859-877	GGUCCUUGGGGCCCUGCAGdTdT	1158	A-127077.1
AD-63386.1	CCAAGGACCUCAUGCUCAAdTdT	825	A-127078.1	869-887	UUGAGCAUGAGGUCCUUGGdTdT	1159	A-127079.1
AD-63392.1	UGCUCAAACUCCGGCUGGAdTdT	826	A-127080.1	881-899	UCCAGCCGGAGUUUGAGCAdTdT	1160	A-127081.1
AD-63398.1	CCGGCUGGAGUGGACGCUGdTdT	827	A-127082.1	891-909	CAGCGUCCACUCCAGCCGGdTdT	1161	A-127083.1
AD-63404.1	GACGCUGGCAGAGUGCCGGdTdT	828	A-127084.1	903-921	CCGGCACUCUGCCAGCGUCdTdT	1162	A-127085.1
AD-63410.1	GGCAGAGUGCCGGGACCGAdTdT	829	A-127086.1	909-927	UCGGUCCCGGCACUCUGCCdTdT	1163	A-127087.1
AD-63416.1	ACCGACUGGCCAUGUAUGAdTdT	830	A-127088.1	923-941	UCAUACAUGGCCAGUCGGUdTdT	1164	A-127089.1
AD-63422.1	CCAUGUAUGACGUGGCCGGdTdT	831	A-127090.1	932-950	CCGGCCACGUCAUACAUGGdTdT	1165	A-127091.1
AD-63428.1	GUGGCCGGGCCCCUGGAGAdTdT	832	A-127092.1	943-961	UCUCCAGGGGCCCGGCCACdTdT	1166	A-127093.1
AD-63387.1	CCCUGGAGAAGAGGCUCAUdTdT	833	A-127094.1	953-971	AUGAGCCUCUUCUCCAGGGdTdT	1167	A-127095.1
AD-63393.1	AGAAGAGGCUCAUCACCUCdTdT	834	A-127096.1	959-977	GAGGUGAUGAGCCUCUUCUdTdT	1168	A-127097.1
AD-63399.1	ACCUCGGUGUACGGCUGCAdTdT	835	A-127098.1	973-991	UGCAGCCGUACACCGAGGUdTdT	1169	A-127099.1
AD-63405.1	ACGGCUGCAGCCGCCAGGAdTdT	836	A-127100.1	983-1001	UCCUGGCGGCUGCAGCCGUdTdT	1170	A-127101.1
AD-63411.1	GCCGCCAGGAGCCCGUGGUdTdT	837	A-127102.1	992-1010	ACCACGGGCUCCUGGCGGCdTdT	1171	A-127103.1
AD-63417.1	AGCCCGUGGUGGAGGUUCUdTdT	838	A-127104.1	1001-1019	AGAACCUCCACCACGGGCUdTdT	1172	A-127105.1
AD-63423.1	GUGGAGGUUCUGGCGUCGGdTdT	839	A-127106.1	1009-1027	CCGACGCCAGAACCUCCACdTdT	1173	A-127107.1
AD-63429.1	UGGCGUCGGGGGCCAUCAUdTdT	840	A-127108.1	1019-1037	AUGAUGGCCCCCGACGCCAdTdT	1174	A-127109.1
AD-63388.1	CCAUCAUGGCGGUCGUCUGdTdT	841	A-127110.1	1031-1049	CAGACGACCGCCAUGAUGGdTdT	1175	A-127111.1
AD-63394.1	GCGGUCGUCUGGAAGAAGGdTdT	842	A-127112.1	1039-1057	CCUUCUUCCAGACGACCGCdTdT	1176	A-127113.1
AD-63400.1	GGAAGAAGGGCCUGCACAGdTdT	843	A-127114.1	1049-1067	CUGUGCAGGCCCUUCUUCCdTdT	1177	A-127115.1
AD-63406.1	CCUGCACAGCUACUACGACdTdT	844	A-127116.1	1059-1077	GUCGUAGUAGCUGUGCAGGdTdT	1178	A-127117.1
AD-63412.1	ACUACGACCCCUUCGUGCUdTdT	845	A-127118.1	1070-1088	AGCACGAAGGGGUCGUAGUdTdT	1179	A-127119.1
AD-63418.1	CCUUCGUGCUCUCCGUGCAdTdT	846	A-127120.1	1079-1097	UGCACGGAGAGCACGAAGGdTdT	1180	A-127121.1
AD-63424.1	CCGUGCAGCCGGUGGUCUUdTdT	847	A-127122.1	1091-1109	AAGACCACCGGCUGCACGGdTdT	1181	A-127123.1
AD-63430.1	CGGUGGUCUUCCAGGCCUGdTdT	848	A-127124.1	1100-1118	CAGGCCUGGAAGACCACCGdTdT	1182	A-127125.1

AD-63389.1	AGGCCUGUGAAGUGAACCUdTdT	849	A-127126.1	1112-1130	AGGUUCACUUCACAGGCCUdTdT	1183	A-127127.1
AD-63395.1	AAGUGAACCUGACGCUGGAdTdT	850	A-127128.1	1121-1139	UCCAGCGUCAGGUUCACUUdTdT	1184	A-127129.1
AD-63401.1	GACGCUGGACAACAGGCUCdTdT	851	A-127130.1	1131-1149	GAGCCUGUUGUCCAGCGUCdTdT	1185	A-127131.1
AD-63407.1	ACAACAGGCUCGACUCCCAdTdT	852	A-127132.1	1139-1157	UGGGAGUCGAGCCUGUUGUdTdT	1186	A-127133.1
AD-63413.1	ACUCCCAGGGCGUCCUCAGdTdT	853	A-127134.1	1151-1169	CUGAGGACGCCCUGGGAGUdTdT	1187	A-127135.1
AD-63419.1	CCCCGUACUUCCCCAGCUAdTdT	854	A-127136.1	1172-1190	UAGCUGGGGAAGUACGGGGdTdT	1188	A-127137.1
AD-63425.1	UUCCCCAGCUACUACUCGCdTdT	855	A-127138.1	1180-1198	GCGAGUAGUAGCUGGGGAAdTdT	1189	A-127139.1
AD-63431.1	ACUACUCGCCCCAAACCCAdTdT	856	A-127140.1	1190-1208	UGGGUUUGGGGCGAGUAGUdTdT	1190	A-127141.1
AD-63437.1	CCCAAACCCACUGCUCCUGdTdT	857	A-127142.1	1199-1217	CAGGAGCAGUGGGUUUGGGdTdT	1191	A-127143.1
AD-63443.1	GCUCCUGGCACCUCACGGUdTdT	858	A-127144.1	1211-1229	ACCGUGAGGUGCCAGGAGCdTdT	1192	A-127145.1
AD-63449.1	ACCUCACGGUGCCCUCUCUdTdT	859	A-127146.1	1220-1238	AGAGAGGGCACCGUGAGGUdTdT	1193	A-127147.1
AD-63455.1	CUCUCUGGACUACGGCUUGdTdT	860	A-127148.1	1233-1251	CAAGCCGUAGUCCAGAGAGdTdT	1194	A-127149.1
AD-63461.1	GACUACGGCUUGGCCCUCUdTdT	861	A-127150.1	1240-1258	AGAGGGCCAAGCCGUAGUCdTdT	1195	A-127151.1
AD-63467.1	CCCUCUGGUUUGAUGCCUAdTdT	862	A-127152.1	1253-1271	UAGGCAUCAAACCAGAGGGdTdT	1196	A-127153.1
AD-63473.1	GUUUGAUGCCUAUGCACUGdTdT	863	A-127154.1	1260-1278	CAGUGCAUAGGCAUCAAACdTdT	1197	A-127155.1
AD-63432.1	GCACUGAGGAGGCAGAAGUdTdT	864	A-127156.1	1273-1291	ACUUCUGCCUCCUCAGUGCdTdT	1198	A-127157.1
AD-63438.1	GGAGGCAGAAGUAUGAUUUdTdT	865	A-127158.1	1280-1298	AAAUCAUACUUCUGCCUCCdTdT	1199	A-127159.1
AD-63444.1	AUGAUUUGCCGUGCACCCAdTdT	866	A-127160.1	1292-1310	UGGGUGCACGGCAAAUCAUdTdT	1200	A-127161.1
AD-63450.1	UGCACCCAGGGCCAGUGGAdTdT	867	A-127162.1	1303-1321	UCCACUGGCCCUGGGUGCAdTdT	1201	A-127163.1
AD-63456.1	GCCAGUGGACGAUCCAGAAdTdT	868	A-127164.1	1313-1331	UUCUGGAUCGUCCACUGGCdTdT	1202	A-127165.1
AD-63462.1	GGACGAUCCAGAACAGGAGdTdT	869	A-127166.1	1319-1337	CUCCUGUUCUGGAUCGUCCdTdT	1203	A-127167.1
AD-63468.1	ACAGGAGGCUGUGUGGCUUdTdT	870	A-127168.1	1331-1349	AAGCCACACAGCCUCCUGUdTdT	1204	A-127169.1
AD-63474.1	CUGUGUGGCUUGCGCAUCCdTdT	871	A-127170.1	1339-1357	GGAUGCGCAAGCCACACAGdTdT	1205	A-127171.1
AD-63433.1	UGCGCAUCCUGCAGCCCUAdTdT	872	A-127172.1	1349-1367	UAGGGCUGCAGGAUGCGCAdTdT	1206	A-127173.1
AD-63439.1	AGCCCUACGCCGAGAGGAUdTdT	873	A-127174.1	1361-1379	AUCCUCUCGGCGUAGGGCUdTdT	1207	A-127175.1
AD-63445.1	CCGAGAGGAUCCCCGUGGUdTdT	874	A-127176.1	1370-1388	ACCACGGGGAUCCUCUCGGdTdT	1208	A-127177.1
AD-63451.1	CCGUGGUGGCCACGGCCGGdTdT	875	A-127178.1	1382-1400	CCGGCCGUGGCCACCACGGdTdT	1209	A-127179.1
AD-63457.1	CCACGGCCGGGAUCACCAUdTdT	876	A-127180.1	1391-1409	AUGGUGAUCCCGGCCGUGGdTdT	1210	A-127181.1

AD-63463.1	GGAUCACCAUCAACUUCACdTdT	877	A-127182.1	1400-1418	GUGAAGUUGAUGGUGAUCCdTdT	1211	A-127183.1
AD-63469.1	UCAACUUCACCUCCCAGAUdTdT	878	A-127184.1	1409-1427	AUCUGGGAGGUGAAGUUGAdTdT	1212	A-127185.1
AD-63475.1	CCCAGAUCUCCCUCACCGGdTdT	879	A-127186.1	1421-1439	CCGGUGAGGGAGAUCUGGGdTdT	1213	A-127187.1
AD-63434.1	CCCUCACCGGGCCCGGUGUdTdT	880	A-127188.1	1430-1448	ACACCGGGCCCGGUGAGGGdTdT	1214	A-127189.1
AD-63440.1	CCCGGUGUGCGGGUGCACUdTdT	881	A-127190.1	1441-1459	AGUGCACCCGCACACCGGGdTdT	1215	A-127191.1
AD-63446.1	GCUUGUACAACCAGUCGGAdTdT	882	A-127192.1	1463-1481	UCCGACUGGUUGUACAAGCdTdT	1216	A-127193.1
AD-63452.1	ACAACCAGUCGGACCCCUGdTdT	883	A-127194.1	1469-1487	CAGGGGUCCGACUGGUUGUdTdT	1217	A-127195.1
AD-63458.1	ACCCCUGCCCUGGAGAGUUdTdT	884	A-127196.1	1481-1499	AACUCUCCAGGGCAGGGGUdTdT	1218	A-127197.1
AD-63464.1	CCUGGAGAGUUCCUCUGUUdTdT	885	A-127198.1	1489-1507	AACAGAGGAACUCUCCAGGdTdT	1219	A-127199.1
AD-63470.1	UCUGUUCUGUGAAUGGACUdTdT	886	A-127200.1	1502-1520	AGUCCAUUCACAGAACAGAdTdT	1220	A-127201.1
AD-63476.1	GAAUGGACUCUGUGUCCCUdTdT	887	A-127202.1	1512-1530	AGGGACACAGAGUCCAUUCdTdT	1221	A-127203.1
AD-63435.1	CUGUGUCCCUGCCUGUGAUdTdT	888	A-127204.1	1521-1539	AUCACAGGCAGGGACACAGdTdT	1222	A-127205.1
AD-63441.1	CUGCCUGUGAUGGGGUCAAdTdT	889	A-127206.1	1529-1547	UUGACCCCAUCACAGGCAGdTdT	1223	A-127207.1
AD-63447.1	GGUCAAGGACUGCCCCAACdTdT	890	A-127208.1	1542-1560	GUUGGGGCAGUCCUUGACCdTdT	1224	A-127209.1
AD-63453.1	UGCCCCAACGGCCUGGAUGdTdT	891	A-127210.1	1552-1570	CAUCCAGGCCGUUGGGGCAdTdT	1225	A-127211.1
AD-63459.1	CGGCCUGGAUGAGAGAAACdTdT	892	A-127212.1	1560-1578	GUUUCUCUCAUCCAGGCCGdTdT	1226	A-127213.1
AD-63465.1	GAGAGAAACUGCGUUUGCAdTdT	893	A-127214.1	1570-1588	UGCAAACGCAGUUUCUCUCdTdT	1227	A-127215.1
AD-63471.1	UUUGCAGAGCCACAUUCCAdTdT	894	A-127216.1	1583-1601	UGGAAUGUGGCUCUGCAAAdTdT	1228	A-127217.1
AD-63477.1	GCCACAUUCCAGUGCAAAGdTdT	895	A-127218.1	1591-1609	CUUUGCACUGGAAUGUGGCdTdT	1229	A-127219.1
AD-63436.1	GUGCAAAGAGGACAGCACAdTdT	896	A-127220.1	1602-1620	UGUGCUGUCCUCUUUGCACdTdT	1230	A-127221.1
AD-63442.1	GAGGACAGCACAUGCAUCUdTdT	897	A-127222.1	1609-1627	AGAUGCAUGUGCUGUCCUCdTdT	1231	A-127223.1
AD-63448.1	GCAUCUCACUGCCCAAGGUdTdT	898	A-127224.1	1622-1640	ACCUUGGGCAGUGAGAUGCdTdT	1232	A-127225.1
AD-63454.1	GCCCAAGGUCUGUGAUGGGdTdT	899	A-127226.1	1632-1650	CCCAUCACAGACCUUGGGCdTdT	1233	A-127227.1
AD-63460.1	UGUGAUGGGCAGCCUGAUUdTdT	900	A-127228.1	1642-1660	AAUCAGGCUGCCCAUCACAdTdT	1234	A-127229.1
AD-63466.1	GCAGCCUGAUUGUCUCAACdTdT	901	A-127230.1	1650-1668	GUUGAGACAAUCAGGCUGCdTdT	1235	A-127231.1
AD-63472.1	GUCUCAACGGCAGCGACGAdTdT	902	A-127232.1	1661-1679	UCGUCGCUGCCGUUGAGACdTdT	1236	A-127233.1
AD-63478.1	GCGACGAAGAGCAGUGCCAdTdT	903	A-127234.1	1673-1691	UGGCACUGCUCUUCGUCGCdTdT	1237	A-127235.1
AD-63484.1	AGCAGUGCCAGGAAGGGGUdTdT	904	A-127236.1	1682-1700	ACCCCUUCCUGGCACUGCUdTdT	1238	A-127237.1

AD-63490.1	GAAGGGGUGCCAUGUGGGAdTdT	905	A-127238.1	1693-1711	UCCCACAUGGCACCCCUUCdTdT	1239	A-127239.1
AD-63496.1	CCAUGUGGGACAUUCACCUdTdT	906	A-127240.1	1702-1720	AGGUGAAUGUCCCACAUGGdTdT	1240	A-127241.1
AD-63502.1	CAUUCACCUUCCAGUGUGAdTdT	907	A-127242.1	1712-1730	UCACACUGGAAGGUGAAUGdTdT	1241	A-127243.1
AD-63508.1	CAGUGUGAGGACCGGAGCUdTdT	908	A-127244.1	1723-1741	AGCUCCGGUCCUCACACUGdTdT	1242	A-127245.1
AD-63514.1	GACCGGAGCUGCGUGAAGAdTdT	909	A-127246.1	1732-1750	UCUUCACGCAGCUCCGGUCdTdT	1243	A-127247.1
AD-63520.1	CUGCGUGAAGAAGCCCAACdTdT	910	A-127248.1	1740-1758	GUUGGGCUUCUUCACGCAGdTdT	1244	A-127249.1
AD-63479.1	AGCCCAACCCGCAGUGUGAdTdT	911	A-127250.1	1751-1769	UCACACUGCGGGUUGGGCUdTdT	1245	A-127251.1
AD-63485.1	CAGUGUGAUGGGCGGCCCGdTdT	912	A-127252.1	1762-1780	CGGGCCGCCCAUCACACUGdTdT	1246	A-127253.1
AD-63491.1	GCGGCCCGACUGCAGGGACdTdT	913	A-127254.1	1773-1791	GUCCCUGCAGUCGGGCCGCdTdT	1247	A-127255.1
AD-63497.1	CUGCAGGGACGGCUCGGAUdTdT	914	A-127256.1	1782-1800	AUCCGAGCCGUCCCUGCAGdTdT	1248	A-127257.1
AD-63503.1	ACGGCUCGGAUGAGGAGCAdTdT	915	A-127258.1	1790-1808	UGCUCCUCAUCCGAGCCGUdTdT	1249	A-127259.1
AD-63509.1	UGAGGAGCACUGUGACUGUdTdT	916	A-127260.1	1800-1818	ACAGUCACAGUGCUCCUCAdTdT	1250	A-127261.1
AD-63515.1	CUGUGACUGUGGCCUCCAGdTdT	917	A-127262.1	1809-1827	CUGGAGGCCACAGUCACAGdTdT	1251	A-127263.1
AD-63521.1	GCCUCCAGGGCCCCUCCAGdTdT	918	A-127264.1	1820-1838	CUGGAGGGGCCCUGGAGGCdTdT	1252	A-127265.1
AD-63480.1	CCCCUCCAGCCGCAUUGUUdTdT	919	A-127266.1	1830-1848	AACAAUGCGGCUGGAGGGGdTdT	1253	A-127267.1
AD-63486.1	CCGCAUUGUUGGUGGAGCUdTdT	920	A-127268.1	1839-1857	AGCUCCACCAACAAUGCGGdTdT	1254	A-127269.1
AD-63492.1	GUGGAGCUGUGUCCUCCGAdTdT	921	A-127270.1	1850-1868	UCGGAGGACACAGCUCCACdTdT	1255	A-127271.1
AD-63498.1	CUCCGAGGGUGAGUGGCCAdTdT	922	A-127272.1	1863-1881	UGGCCACUCACCCUCGGAGdTdT	1256	A-127273.1
AD-63504.1	GGGUGAGUGGCCAUGGCAGdTdT	923	A-127274.1	1869-1887	CUGCCAUGGCCACUCACCCdTdT	1257	A-127275.1
AD-63510.1	AUGGCAGGCCAGCCUCCAGdTdT	924	A-127276.1	1881-1899	CUGGAGGCUGGCCUGCCAUdTdT	1258	A-127277.1
AD-63516.1	CCUCCAGGUUCGGGGUCGAdTdT	925	A-127278.1	1893-1911	UCGACCCCGAACCUGGAGGdTdT	1259	A-127279.1
AD-63522.1	GGUUCGGGGUCGACACAUCdTdT	926	A-127280.1	1899-1917	GAUGUGUCGACCCCGAACCdTdT	1260	A-127281.1
AD-63481.1	ACAUCUGUGGGGGGGCCCUdTdT	927	A-127282.1	1913-1931	AGGGCCCCCCCACAGAUGUdTdT	1261	A-127283.1
AD-63487.1	GUGGGGGGGCCCUCAUCGCdTdT	928	A-127284.1	1919-1937	GCGAUGAGGGCCCCCCCACdTdT	1262	A-127285.1
AD-63493.1	AUCGCUGACCGCUGGGUGAdTdT	929	A-127286.1	1933-1951	UCACCCAGCGGUCAGCGAUdTdT	1263	A-127287.1
AD-63499.1	ACCGCUGGGUGAUAACAGCdTdT	930	A-127288.1	1940-1958	GCUGUUAUCACCCAGCGGUdTdT	1264	A-127289.1
AD-63505.1	UGAUAACAGCUGCCCACUGdTdT	931	A-127290.1	1949-1967	CAGUGGGCAGCUGUUAUCAdTdT	1265	A-127291.1
AD-63511.1	CCCACUGCUUCCAGGAGGAdTdT	932	A-127292.1	1961-1979	UCCUCCUGGAAGCAGUGGGdTdT	1266	A-127293.1

AD-63517.1	CCAGGAGGACAGCAUGGCCdTdT	933	A-127294.1	1971-1989	GGCCAUGCUGUCCUCCUGGdTdT	1267	A-127295.1
AD-63523.1	ACAGCAUGGCCUCCACGGUdTdT	934	A-127296.1	1979-1997	ACCGUGGAGGCCAUGCUGUdTdT	1268	A-127297.1
AD-63482.1	CCACGGUGCUGUGGACCGUdTdT	935	A-127298.1	1991-2009	ACGGUCCACAGCACCGUGGdTdT	1269	A-127299.1
AD-63488.1	GGACCGUGUUCCUGGGCAAdTdT	936	A-127300.1	2003-2021	UUGCCCAGGAACACGGUCCdTdT	1270	A-127301.1
AD-63494.1	UCCUGGGCAAGGUGUGGCAdTdT	937	A-127302.1	2012-2030	UGCCACACCUUGCCCAGGAdTdT	1271	A-127303.1
AD-63500.1	GUGUGGCAGAACUCGCGCUdTdT	938	A-127304.1	2023-2041	AGCGCGAGUUCUGCCACACdTdT	1272	A-127305.1
AD-63506.1	GAACUCGCGCUGGCCUGGAdTdT	939	A-127306.1	2031-2049	UCCAGGCCAGCGCGAGUUCdTdT	1273	A-127307.1
AD-63512.1	GGCCUGGAGAGGUGUCCUUdTdT	940	A-127308.1	2042-2060	AAGGACACCUCUCCAGGCCdTdT	1274	A-127309.1
AD-63518.1	AGGUGUCCUUCAAGGUGAGdTdT	941	A-127310.1	2051-2069	CUCACCUUGAAGGACACCUdTdT	1275	A-127311.1
AD-63524.1	CAAGGUGAGCCGCCUGCUCdTdT	942	A-127312.1	2061-2079	GAGCAGGCGGCUCACCUUGdTdT	1276	A-127313.1
AD-63483.1	GCCUGCUCCUGCACCCGUAdTdT	943	A-127314.1	2072-2090	UACGGGUGCAGGAGCAGGCdTdT	1277	A-127315.1
AD-63489.1	GCACCCGUACCACGAAGAGdTdT	944	A-127316.1	2082-2100	CUCUUCGUGGUACGGGUGCdTdT	1278	A-127317.1
AD-63495.1	CCACGAAGAGGACAGCCAUdTdT	945	A-127318.1	2091-2109	AUGGCUGUCCUCUUCGUGGdTdT	1279	A-127319.1
AD-63501.1	AGGACAGCCAUGACUACGAdTdT	946	A-127320.1	2099-2117	UCGUAGUCAUGGCUGUCCUdTdT	1280	A-127321.1
AD-63507.1	ACUACGACGUGGCGCUGCUdTdT	947	A-127322.1	2111-2129	AGCAGCGCCACGUCGUAGUdTdT	1281	A-127323.1
AD-63513.1	UGGCGCUGCUGCAGCUCGAdTdT	948	A-127324.1	2120-2138	UCGAGCUGCAGCAGCGCCAdTdT	1282	A-127325.1
AD-63519.1	AGCUCGACCACCCGGUGGUdTdT	949	A-127326.1	2132-2150	ACCACCGGGUGGUCGAGCUdTdT	1283	A-127327.1
AD-63525.1	CCGGUGGUGCGCUCGGCCGdTdT	950	A-127328.1	2143-2161	CGGCCGAGCGCACCACCGGdTdT	1284	A-127329.1
AD-63531.1	UGCGCUCGGCCGCCGUGCGdTdT	951	A-127330.1	2150-2168	CGCACGGCGGCCGAGCGCAdTdT	1285	A-127331.1
AD-63537.1	CCGUGCGCCCCGUCUGCCUdTdT	952	A-127332.1	2162-2180	AGGCAGACGGGGCGCACGGdTdT	1286	A-127333.1
AD-63543.1	CCGUCUGCCUGCCCGCGCGdTdT	953	A-127334.1	2171-2189	CGCGCGGGCAGGCAGACGGdTdT	1287	A-127335.1
AD-63549.1	CCGCGCGCUCCCACUUCUUdTdT	954	A-127336.1	2183-2201	AAGAAGUGGGAGCGCGCGGdTdT	1288	A-127337.1
AD-63555.1	CCCACUUCUUCGAGCCCGGdTdT	955	A-127338.1	2192-2210	CCGGGCUCGAAGAAGUGGGdTdT	1289	A-127339.1
AD-63561.1	GAGCCCGGCCUGCACUGCUdTdT	956	A-127340.1	2203-2221	AGCAGUGCAGGCCGGGCUCdTdT	1290	A-127341.1
AD-63567.1	GGCCUGCACUGCUGGAUUAdTdT	957	A-127342.1	2209-2227	UAAUCCAGCAGUGCAGGCCdTdT	1291	A-127343.1
AD-63526.1	UGGAUUACGGGCUGGGGCGdTdT	958	A-127344.1	2221-2239	CGCCCCAGCCCGUAAUCCAdTdT	1292	A-127345.1
AD-63532.1	GCUGGGGCGCCUUGCGCGAdTdT	959	A-127346.1	2231-2249	UCGCGCAAGGCGCCCCAGCdTdT	1293	A-127347.1
AD-63538.1	UGCGCGAGGGCGGCCCCAUdTdT	960	A-127348.1	2243-2261	AUGGGGCCGCCCUCGCGCAdTdT	1294	A-127349.1

AD-63544.1	AGGGCGGCCCCAUCAGCAAdTdT	961	A-127350.1	2249-2267	UUGCUGAUGGGGCCGCCCUdTdT	1295	A-127351.1
AD-63550.1	UCAGCAACGCUCUGCAGAAdTdT	962	A-127352.1	2261-2279	UUCUGCAGAGCGUUGCUGAdTdT	1296	A-127353.1
AD-63556.1	UGCAGAAAGUGGAUGUGCAdTdT	963	A-127354.1	2273-2291	UGCACAUCCACUUUCUGCAdTdT	1297	A-127355.1
AD-63562.1	AAGUGGAUGUGCAGUUGAUdTdT	964	A-127356.1	2279-2297	AUCAACUGCACAUCCACUUdTdT	1298	A-127357.1
AD-63568.1	GCAGUUGAUCCCACAGGACdTdT	965	A-127358.1	2289-2307	GUCCUGUGGGAUCAACUGCdTdT	1299	A-127359.1
AD-63527.1	CACAGGACCUGUGCAGCGAdTdT	966	A-127360.1	2300-2318	UCGCUGCACAGGUCCUGUGdTdT	1300	A-127361.1
AD-63533.1	GCAGCGAGGUCUAUCGCUAdTdT	967	A-127362.1	2312-2330	UAGCGAUAGACCUCGCUGCdTdT	1301	A-127363.1
AD-63539.1	GUCUAUCGCUACCAGGUGAdTdT	968	A-127364.1	2320-2338	UCACCUGGUAGCGAUAGACdTdT	1302	A-127365.1
AD-63545.1	CCAGGUGACGCCACGCAUGdTdT	969	A-127366.1	2331-2349	CAUGCGUGGCGUCACCUGGdTdT	1303	A-127367.1
AD-63551.1	CCACGCAUGCUGUGUGCCGdTdT	970	A-127368.1	2341-2359	CGGCACACAGCAUGCGUGGdTdT	1304	A-127369.1
AD-63557.1	CUGUGUGCCGGCUACCGCAdTdT	971	A-127370.1	2350-2368	UGCGGUAGCCGGCACACAGdTdT	1305	A-127371.1
AD-63563.1	ACCGCAAGGGCAAGAAGGAdTdT	972	A-127372.1	2363-2381	UCCUUCUUGCCCUUGCGGUdTdT	1306	A-127373.1
AD-63569.1	GCAAGAAGGAUGCCUGUCAdTdT	973	A-127374.1	2372-2390	UGACAGGCAUCCUUCUUGCdTdT	1307	A-127375.1
AD-63528.1	GCCUGUCAGGGUGACUCAGdTdT	974	A-127376.1	2383-2401	CUGAGUCACCCUGACAGGCdTdT	1308	A-127377.1
AD-63534.1	GUGACUCAGGUGGUCCGCUdTdT	975	A-127378.1	2393-2411	AGCGGACCACCUGAGUCACdTdT	1309	A-127379.1
AD-63540.1	GUGGUCCGCUGGUGUGCAAdTdT	976	A-127380.1	2402-2420	UUGCACACCAGCGGACCACdTdT	1310	A-127381.1
AD-63546.1	UGGUGUGCAAGGCACUCAGdTdT	977	A-127382.1	2411-2429	CUGAGUGCCUUGCACACCAdTdT	1311	A-127383.1
AD-63552.1	GCACUCAGUGGCCGCUGGUdTdT	978	A-127384.1	2422-2440	ACCAGCGGCCACUGAGUGCdTdT	1312	A-127385.1
AD-63558.1	GCCGCUGGUUCCUGGCGGGdTdT	979	A-127386.1	2432-2450	CCCGCCAGGAACCAGCGGCdTdT	1313	A-127387.1
AD-63564.1	UCCUGGCGGGGCUGGUCAGdTdT	980	A-127388.1	2441-2459	CUGACCAGCCCCGCCAGGAdTdT	1314	A-127389.1
AD-63570.1	GCUGGUCAGCUGGGGCCUGdTdT	981	A-127390.1	2451-2469	CAGGCCCCAGCUGACCAGCdTdT	1315	A-127391.1
AD-63529.1	GGGCCUGGGCUGUGGCCGGdTdT	982	A-127392.1	2463-2481	CCGGCCACAGCCCAGGCCCdTdT	1316	A-127393.1
AD-63535.1	GGCUGUGGCCGGCCUAACUdTdT	983	A-127394.1	2470-2488	AGUUAGGCCGGCCACAGCCdTdT	1317	A-127395.1
AD-63541.1	CUAACUACUUCGGCGUCUAdTdT	984	A-127396.1	2483-2501	UAGACGCCGAAGUAGUUAGdTdT	1318	A-127397.1
AD-63547.1	CGGCGUCUACACCCGCAUCdTdT	985	A-127398.1	2493-2511	GAUGCGGGUGUAGACGCCGdTdT	1319	A-127399.1
AD-63553.1	ACACCCGCAUCACAGGUGUdTdT	986	A-127400.1	2501-2519	ACACCUGUGAUGCGGGUGUdTdT	1320	A-127401.1
AD-63559.1	ACAGGUGUGAUCAGCUGGAdTdT	987	A-127402.1	2512-2530	UCCAGCUGAUCACACCUGUdTdT	1321	A-127403.1
AD-63565.1	UCAGCUGGAUCCAGCAAGUdTdT	988	A-127404.1	2522-2540	ACUUGCUGGAUCCAGCUGAdTdT	1322	A-127405.1

AD-63571.1	CAGCAAGUGGUGACCUGAGdTdT	989	A-127406.1	2533-2551	CUCAGGUCACCACUUGCUGdTdT	1323	A-127407.1
AD-63530.1	UGACCUGAGGAACUGCCCCdTdT	990	A-127408.1	2543-2561	GGGGCAGUUCCUCAGGUCAdTdT	1324	A-127409.1
AD-63536.1	GGAACUGCCCCCCUGCAAAdTdT	991	A-127410.1	2551-2569	UUUGCAGGGGGGCAGUUCCdTdT	1325	A-127411.1
AD-63542.1	CUGCAAAGCAGGGCCCACCdTdT	992	A-127412.1	2563-2581	GGUGGGCCCUGCUUUGCAGdTdT	1326	A-127413.1
AD-63548.1	GCAGGGCCCACCUCCUGGAdTdT	993	A-127414.1	2570-2588	UCCAGGAGGUGGGCCCUGCdTdT	1327	A-127415.1
AD-63554.1	CCUCCUGGACUCAGAGAGCdTdT	994	A-127416.1	2580-2598	GCUCUCUGAGUCCAGGAGGdTdT	1328	A-127417.1
AD-63560.1	CUCAGAGAGCCCAGGGCAAdTdT	995	A-127418.1	2589-2607	UUGCCCUGGGCUCUCUGAGdTdT	1329	A-127419.1
AD-63566.1	CCAGGGCAACUGCCAAGCAdTdT	996	A-127420.1	2599-2617	UGCUUGGCAGUUGCCCUGGdTdT	1330	A-127421.1
AD-63572.1	GGACAAGUAUUCUGGCGGGdTdT	997	A-127422.1	2621-2639	CCCGCCAGAAUACUUGUCCdTdT	1331	A-127423.1
AD-63578.1	CUGGCGGGGGGUGGGGGAGdTdT	998	A-127424.1	2632-2650	CUCCCCCACCCCCCGCCAGdTdT	1332	A-127425.1
AD-63584.1	GGGUGGGGGAGAGAGCAGGdTdT	999	A-127426.1	2640-2658	CCUGCUCUCUCCCCCACCCdTdT	1333	A-127427.1
AD-63590.1	AGAGAGCAGGCCCUGUGGUdTdT	1000	A-127428.1	2649-2667	ACCACAGGGCCUGCUCUCUdTdT	1334	A-127429.1
AD-63596.1	CCCUGUGGUGGCAGGAGGUdTdT	1001	A-127430.1	2659-2677	ACCUCCUGCCACCACAGGGdTdT	1335	A-127431.1
AD-63602.1	GGAGGUGGCAUCUUGUCUCdTdT	1002	A-127432.1	2672-2690	GAGACAAGAUGCCACCUCCdTdT	1336	A-127433.1
AD-63608.1	CAUCUUGUCUCGUCCCUGAdTdT	1003	A-127434.1	2680-2698	UCAGGGACGAGACAAGAUGdTdT	1337	A-127435.1
AD-63614.1	CCCUGAUGUCUGCUCCAGUdTdT	1004	A-127436.1	2693-2711	ACUGGAGCAGACAUCAGGGdTdT	1338	A-127437.1
AD-63573.1	CUGCUCCAGUGAUGGCAGGdTdT	1005	A-127438.1	2702-2720	CCUGCCAUCACUGGAGCAGdTdT	1339	A-127439.1
AD-63579.1	AUGGCAGGAGGAUGGAGAAdTdT	1006	A-127440.1	2713-2731	UUCUCCAUCCUCCUGCCAUdTdT	1340	A-127441.1
AD-63585.1	GGAUGGAGAAGUGCCAGCAdTdT	1007	A-127442.1	2722-2740	UGCUGGCACUUCUCCAUCCdTdT	1341	A-127443.1
AD-63591.1	UGCCAGCAGCUGGGGGUCAdTdT	1008	A-127444.1	2733-2751	UGACCCCCAGCUGCUGGCAdTdT	1342	A-127445.1
AD-63597.1	AGCUGGGGGUCAAGACGUCdTdT	1009	A-127446.1	2740-2758	GACGUCUUGACCCCCAGCUdTdT	1343	A-127447.1
AD-63603.1	UCAAGACGUCCCCUGAGGAdTdT	1010	A-127448.1	2749-2767	UCCUCAGGGGACGUCUUGAdTdT	1344	A-127449.1
AD-63609.1	CCCUGAGGACCCAGGCCCAdTdT	1011	A-127450.1	2759-2777	UGGGCCUGGGUCCUCAGGGdTdT	1345	A-127451.1
AD-63615.1	GCCCACACCCAGCCCUUCUdTdT	1012	A-127452.1	2773-2791	AGAAGGGCUGGGUGUGGGCdTdT	1346	A-127453.1
AD-63574.1	AGCCCUUCUGCCUCCCAAUdTdT	1013	A-127454.1	2783-2801	AUUGGGAGGCAGAAGGGCUdTdT	1347	A-127455.1
AD-63580.1	CCUCCCAAUUCUCUCUCCUdTdT	1014	A-127456.1	2793-2811	AGGAGAGAGAAUUGGGAGGdTdT	1348	A-127457.1
AD-63586.1	CUCUCUCCUCCGUCCCCUUdTdT	1015	A-127458.1	2803-2821	AAGGGGACGGAGGAGAGAGdTdT	1349	A-127459.1
AD-63592.1	UCCGUCCCCUUCCUCCACUdTdT	1016	A-127460.1	2811-2829	AGUGGAGGAAGGGGACGGAdTdT	1350	A-127461.1

AD-63598.1	CUUCCUCCACUGCUGCCUAdTdT	1017	A-127462.1	2819-2837	UAGGCAGCAGUGGAGGAAGdTdT	1351	A-127463.1
AD-63604.1	CUGCCUAAUGCAAGGCAGUdTdT	1018	A-127464.1	2831-2849	ACUGCCUUGCAUUAGGCAGdTdT	1352	A-127465.1
AD-63610.1	GCAAGGCAGUGGCUCAGCAdTdT	1019	A-127466.1	2840-2858	UGCUGAGCCACUGCCUUGCdTdT	1353	A-127467.1
AD-63616.1	UGGCUCAGCAGCAAGAAUGdTdT	1020	A-127468.1	2849-2867	CAUUCUUGCUGCUGAGCCAdTdT	1354	A-127469.1
AD-63575.1	CAAGAAUGCUGGUUCUACAdTdT	1021	A-127470.1	2860-2878	UGUAGAACCAGCAUUCUUGdTdT	1355	A-127471.1
AD-63581.1	UGGUUCUACAUCCCGAGGAdTdT	1022	A-127472.1	2869-2887	UCCUCGGGAUGUAGAACCAdTdT	1356	A-127473.1
AD-63587.1	CCCGAGGAGUGUCUGAGGUdTdT	1023	A-127474.1	2880-2898	ACCUCAGACACUCCUCGGGdTdT	1357	A-127475.1
AD-63593.1	GUCUGAGGUGCGCCCCACUdTdT	1024	A-127476.1	2890-2908	AGUGGGGCGCACCUCAGACdTdT	1358	A-127477.1
AD-63599.1	GCCCCACUCUGUACAGAGGdTdT	1025	A-127478.1	2901-2919	CCUCUGUACAGAGUGGGGCdTdT	1359	A-127479.1
AD-63605.1	CUGUACAGAGGCUGUUUGGdTdT	1026	A-127480.1	2909-2927	CCAAACAGCCUCUGUACAGdTdT	1360	A-127481.1
AD-63611.1	CUGUUUGGGCAGCCUUGCCdTdT	1027	A-127482.1	2920-2938	GGCAAGGCUGCCCAAACAGdTdT	1361	A-127483.1
AD-63617.1	CUUGCCUCCAGAGAGCAGAdTdT	1028	A-127484.1	2933-2951	UCUGCUCUCUGGAGGCAAGdTdT	1362	A-127485.1
AD-63576.1	UCCAGAGAGCAGAUUCCAGdTdT	1029	A-127486.1	2939-2957	CUGGAAUCUGCUCUCUGGAdTdT	1363	A-127487.1
AD-63582.1	GAUUCCAGCUUCGGAAGCCdTdT	1030	A-127488.1	2950-2968	GGCUUCCGAAGCUGGAAUCdTdT	1364	A-127489.1
AD-63588.1	GAAUGGAAGGUGCUCCCAUdTdT	1031	A-127490.1	2991-3009	AUGGGAGCACCUUCCAUUCdTdT	1365	A-127491.1
AD-63594.1	GUGCUCCCAUCGGAGGGGAdTdT	1032	A-127492.1	3000-3018	UCCCCUCCGAUGGGAGCACdTdT	1366	A-127493.1
AD-63600.1	UCGGAGGGGACCCUCAGAGdTdT	1033	A-127494.1	3009-3027	CUCUGAGGGUCCCCUCCGAdTdT	1367	A-127495.1
AD-63606.1	CCCUCAGAGCCCUGGAGACdTdT	1034	A-127496.1	3019-3037	GUCUCCAGGGCUCUGAGGGdTdT	1368	A-127497.1
AD-63612.1	GAGACUGCCAGGUGGGCCUdTdT	1035	A-127498.1	3033-3051	AGGCCCACCUGGCAGUCUCdTdT	1369	A-127499.1
AD-63618.1	AGGUGGGCCUGCUGCCACUdTdT	1036	A-127500.1	3042-3060	AGUGGCAGCAGGCCCACCUdTdT	1370	A-127501.1
AD-63577.1	CUGCCACUGUAAGCCAAAAdTdT	1037	A-127502.1	3053-3071	UUUUGGCUUACAGUGGCAGdTdT	1371	A-127503.1
AD-63583.1	CUGUAAGCCAAAAGGUGGGdTdT	1038	A-127504.1	3059-3077	CCCACCUUUUGGCUUACAGdTdT	1372	A-127505.1
AD-63589.1	GUGGGGAAGUCCUGACUCCdTdT	1039	A-127506.1	3073-3091	GGAGUCAGGACUUCCCCACdTdT	1373	A-127507.1
AD-63595.1	CCUGACUCCAGGGUCCUUGdTdT	1040	A-127508.1	3083-3101	CAAGGACCCUGGAGUCAGGdTdT	1374	A-127509.1
AD-63601.1	GGGUCCUUGCCCCACCCCUdTdT	1041	A-127510.1	3093-3111	AGGGGUGGGGCAAGGACCCdTdT	1375	A-127511.1
AD-63607.1	GCCCCACCCCUGCCUGCCAdTdT	1042	A-127512.1	3101-3119	UGGCAGGCAGGGGUGGGGCdTdT	1376	A-127513.1
AD-63613.1	CCUGCCACCUGGGCCCUCAdTdT	1043	A-127514.1	3113-3131	UGAGGGCCCAGGUGGCAGGdTdT	1377	A-127515.1
AD-63619.1	CUGGGCCCUCACAGCCCAGdTdT	1044	A-127516.1	3121-3139	CUGGGCUGUGAGGGCCCAGdTdT	1378	A-127517.1

AD-63620.1	UCACAGCCCAGACCCUCACdTdT	1045	A-127518.1	3129-3147	GUGAGGGUCUGGGCUGUGAdTdT	1379	A-127519.1
AD-63621.1	CUCACUGGGAGGUGAGCUCdTdT	1046	A-127520.1	3143-3161	GAGCUCACCUCCCAGUGAGdTdT	1380	A-127521.1
AD-63622.1	GGUGAGCUCAGCUGCCCUUdTdT	1047	A-127522.1	3153-3171	AAGGGCAGCUGAGCUCACCdTdT	1381	A-127523.1
AD-63623.1	UGGAAUAAAGCUGCCUGAUdTdT	1048	A-127524.1	3172-3190	AUCAGGCAGCUUUAUUCCAdTdT	1382	A-127525.1

Table 13:

TMPRSS6 single dose screen (10nM) in Hep3B cells with dT modified siRNAs

Duplex ID	Avg % message remaining	SD
AD-63290.1	122.8	18.0
AD-63296.1	87.4	6.0
AD-63302.1	71.4	16.9
AD-63308.1	82.1	10.3
AD-63314.1	59.1	5.3
AD-63320.1	90.7	4.5
AD-63326.1	121.0	18.2
AD-63332.1	114.4	11.6
AD-63291.1	84.7	15.0
AD-63297.1	82.8	3.9
AD-63303.1	67.6	5.5
AD-63309.1	55.8	6.5
AD-63315.1	64.2	7.4
AD-63321.1	85.8	6.4
AD-63327.1	91.9	14.9
AD-63333.1	76.4	5.2
AD-63292.1	54.4	22.9
AD-63298.1	54.6	5.0
AD-63304.1	24.6	7.3
AD-63310.1	23.3	0.6
AD-63316.1	50.9	7.2
AD-63322.1	53.7	10.5
AD-63328.1	29.2	2.3
AD-63334.1	28.5	1.2
AD-63293.1	50.9	6.8
AD-63299.1	85.5	2.3
AD-63305.1	43.0	7.2
AD-63311.1	28.9	2.6
AD-63317.1	40.9	2.7
AD-63323.1	40.2	7.3
AD-63329.1	27.9	12.0
AD-63335.1	82.0	4.2
AD-63294.1	21.8	1.0
AD-63300.1	32.3	8.0
AD-63306.1	32.9	8.3
AD-63312.1	26.5	4.6
AD-63318.1	31.3	2.4
AD-63324.1	25.7	1.9
AD-63330.1	24.5	2.0

AD-63336.1	36.1	8.6
AD-63295.1	29.2	1.8
AD-63301.1	28.9	5.2
AD-63307.1	68.8	10.6
AD-63313.1	90.2	8.2
AD-63319.1	21.9	3.3
AD-63325.1	26.1	4.8
AD-63331.1	36.7	4.5
AD-63337.1	67.7	9.3
AD-63343.1	83.9	15.0
AD-63349.1	71.6	3.5
AD-63355.1	62.8	10.4
AD-63361.1	56.0	3.3
AD-63367.1	49.3	8.7
AD-63373.1	54.1	8.2
AD-63379.1	47.5	6.3
AD-63338.1	28.0	2.8
AD-63344.1	29.7	5.7
AD-63350.1	23.0	2.3
AD-63356.1	81.5	13.7
AD-63362.1	19.7	2.9
AD-63368.1	42.2	4.7
AD-63374.1	24.5	2.0
AD-63380.1	24.9	4.9
AD-63339.1	28.9	10.1
AD-63345.1	29.9	5.6
AD-63351.1	20.4	3.7
AD-63357.1	35.8	6.8
AD-63363.1	30.4	2.5
AD-63369.1	29.0	3.1
AD-63375.1	36.6	2.4
AD-63381.1	29.1	4.3
AD-63340.1	40.4	18.8
AD-63346.1	36.4	3.5
AD-63352.1	25.8	3.9
AD-63358.1	42.6	8.1
AD-63364.1	48.1	6.6
AD-63370.1	24.6	2.8
AD-63376.1	22.1	4.2
AD-63382.1	31.0	7.5
AD-63341.1	37.6	13.7
AD-63347.1	27.6	2.0
AD-63353.1	76.4	14.5
AD-63359.1	25.3	1.1

AD-63365.1	27.3	3.4
AD-63371.1	16.3	1.3
AD-63377.1	65.4	7.1
AD-63383.1	72.2	7.0
AD-63342.1	30.8	7.3
AD-63348.1	72.7	9.2
AD-63354.1	38.7	5.0
AD-63360.1	28.7	3.0
AD-63366.1	30.9	6.8
AD-63372.1	84.0	9.0
AD-63378.1	64.1	8.6
AD-63384.1	38.0	2.6
AD-63390.1	48.3	10.6
AD-63396.1	45.6	7.0
AD-63402.1	42.0	9.9
AD-63408.1	40.4	9.1
AD-63414.1	23.8	6.2
AD-63420.1	55.3	5.2
AD-63426.1	61.6	8.5
AD-63385.1	61.6	10.2
AD-63391.1	38.0	3.1
AD-63397.1	66.7	16.8
AD-63403.1	77.2	15.4
AD-63409.1	60.3	10.7
AD-63415.1	35.0	5.4
AD-63421.1	60.6	2.9
AD-63427.1	40.5	7.2
AD-63386.1	42.0	7.4
AD-63392.1	34.2	3.1
AD-63398.1	62.6	18.5
AD-63404.1	65.9	8.1
AD-63410.1	19.7	4.0
AD-63416.1	51.3	9.0
AD-63422.1	59.3	2.7
AD-63428.1	58.2	9.7
AD-63387.1	42.2	4.8
AD-63393.1	27.9	4.4
AD-63399.1	49.6	8.4
AD-63405.1	72.5	9.3
AD-63411.1	45.4	14.9
AD-63417.1	36.7	9.4
AD-63423.1	76.8	4.9
AD-63429.1	77.8	14.4
AD-63388.1	37.4	4.4

AD-63394.1	31.5	4.6
AD-63400.1	60.9	28.6
AD-63406.1	40.7	14.3
AD-63412.1	22.0	7.0
AD-63418.1	22.8	4.3
AD-63424.1	25.5	2.8
AD-63430.1	21.5	3.2
AD-63389.1	34.4	5.3
AD-63395.1	31.1	0.7
AD-63401.1	44.3	9.5
AD-63407.1	41.5	4.9
AD-63413.1	52.4	6.4
AD-63419.1	26.3	5.6
AD-63425.1	78.8	4.6
AD-63431.1	32.8	6.6
AD-63437.1	42.3	1.4
AD-63443.1	56.4	8.9
AD-63449.1	26.0	5.9
AD-63455.1	28.0	9.7
AD-63461.1	32.1	11.1
AD-63467.1	33.8	19.8
AD-63473.1	28.9	3.4
AD-63432.1	36.5	7.4
AD-63438.1	27.3	4.3
AD-63444.1	54.6	36.0
AD-63450.1	42.0	6.1
AD-63456.1	36.6	10.2
AD-63462.1	23.3	3.0
AD-63468.1	48.8	27.3
AD-63474.1	23.8	3.2
AD-63433.1	51.8	13.8
AD-63439.1	41.7	5.5
AD-63445.1	74.6	6.1
AD-63451.1	49.6	9.0
AD-63457.1	26.7	4.9
AD-63463.1	27.8	3.8
AD-63469.1	48.4	14.0
AD-63475.1	40.3	1.4
AD-63434.1	93.3	9.9
AD-63440.1	37.6	4.7
AD-63446.1	38.1	15.4
AD-63452.1	42.3	4.0
AD-63458.1	29.7	7.9
AD-63464.1	25.7	3.4

AD-63470.1	44.8	7.8
AD-63476.1	33.9	4.7
AD-63435.1	23.4	5.2
AD-63441.1	37.1	4.5
AD-63447.1	46.5	9.0
AD-63453.1	73.1	16.8
AD-63459.1	31.8	4.6
AD-63465.1	27.3	6.6
AD-63471.1	19.5	3.1
AD-63477.1	35.2	4.7
AD-63436.1	21.8	4.7
AD-63442.1	44.1	11.2
AD-63448.1	33.6	6.0
AD-63454.1	58.2	16.8
AD-63460.1	27.7	2.4
AD-63466.1	27.1	4.4
AD-63472.1	20.5	4.1
AD-63478.1	36.3	7.3
AD-63484.1	48.4	31.3
AD-63490.1	44.0	6.1
AD-63496.1	45.5	19.9
AD-63502.1	49.0	18.3
AD-63508.1	41.4	2.7
AD-63514.1	36.0	5.1
AD-63520.1	40.9	4.2
AD-63479.1	35.1	6.5
AD-63485.1	45.5	24.0
AD-63491.1	69.0	14.5
AD-63497.1	57.1	25.1
AD-63503.1	36.0	15.3
AD-63509.1	29.7	6.4
AD-63515.1	33.9	5.7
AD-63521.1	117.2	10.2
AD-63480.1	38.6	0.7
AD-63486.1	48.5	12.1
AD-63492.1	38.7	3.7
AD-63498.1	64.6	20.3
AD-63504.1	41.7	1.9
AD-63510.1	39.6	4.0
AD-63516.1	30.9	4.8
AD-63522.1	56.4	15.6
AD-63481.1	72.0	7.3
AD-63487.1	128.8	48.9
AD-63493.1	31.7	6.7

AD-63499.1	44.2	17.7
AD-63505.1	69.4	7.6
AD-63511.1	43.8	5.3
AD-63517.1	75.3	2.2
AD-63523.1	82.1	10.6
AD-63482.1	40.1	12.2
AD-63488.1	42.3	12.7
AD-63494.1	19.0	1.1
AD-63500.1	30.2	11.2
AD-63506.1	30.5	7.6
AD-63512.1	38.1	15.2
AD-63518.1	35.0	7.3
AD-63524.1	60.5	3.7
AD-63483.1	22.7	3.6
AD-63489.1	47.6	13.7
AD-63495.1	31.0	12.7
AD-63501.1	24.3	2.1
AD-63507.1	37.4	7.0
AD-63513.1	32.3	5.1
AD-63519.1	46.0	6.6
AD-63525.1	66.5	14.5
AD-63531.1	104.0	24.1
AD-63537.1	32.1	3.4
AD-63543.1	31.2	3.8
AD-63549.1	35.2	5.2
AD-63555.1	41.7	9.3
AD-63561.1	44.2	7.0
AD-63567.1	39.2	4.9
AD-63526.1	66.9	15.7
AD-63532.1	90.3	17.8
AD-63538.1	50.8	11.5
AD-63544.1	31.9	2.4
AD-63550.1	35.0	8.8
AD-63556.1	31.0	6.0
AD-63562.1	20.2	2.4
AD-63568.1	30.6	2.7
AD-63527.1	28.8	2.4
AD-63533.1	63.3	6.9
AD-63539.1	28.4	3.5
AD-63545.1	26.9	8.5
AD-63551.1	52.5	4.7
AD-63557.1	26.7	2.2
AD-63563.1	28.1	2.7
AD-63569.1	29.2	2.8

AD-63528.1	52.9	9.0
AD-63534.1	42.5	6.8
AD-63540.1	50.5	10.9
AD-63546.1	53.6	10.5
AD-63552.1	38.8	5.0
AD-63558.1	49.3	3.0
AD-63564.1	69.2	3.1
AD-63570.1	50.6	6.0
AD-63529.1	59.5	6.5
AD-63535.1	21.0	1.7
AD-63541.1	40.1	23.4
AD-63547.1	26.0	9.6
AD-63553.1	31.5	6.0
AD-63559.1	34.9	2.7
AD-63565.1	43.3	5.3
AD-63571.1	41.6	4.4
AD-63530.1	127.6	15.0
AD-63536.1	38.0	16.0
AD-63542.1	48.3	8.4
AD-63548.1	41.9	7.9
AD-63554.1	88.2	15.2
AD-63560.1	48.8	17.7
AD-63566.1	33.6	6.8
AD-63572.1	82.4	67.9
AD-63578.1	78.5	11.5
AD-63584.1	55.7	7.2
AD-63590.1	53.4	2.9
AD-63596.1	63.5	8.6
AD-63602.1	49.3	3.6
AD-63608.1	29.2	4.4
AD-63614.1	30.0	7.4
AD-63573.1	96.1	14.7
AD-63579.1	38.1	4.5
AD-63585.1	40.0	2.1
AD-63591.1	30.5	2.5
AD-63597.1	55.1	5.8
AD-63603.1	43.6	4.0
AD-63609.1	37.7	2.7
AD-63615.1	44.4	9.7
AD-63574.1	44.3	10.3
AD-63580.1	33.1	3.5
AD-63586.1	39.3	2.9
AD-63592.1	73.7	1.6
AD-63598.1	32.4	6.6

AD-63604.1	98.7	7.1
AD-63610.1	42.1	7.1
AD-63616.1	55.2	10.4
AD-63575.1	27.8	3.0
AD-63581.1	36.3	3.2
AD-63587.1	36.1	3.3
AD-63593.1	39.2	4.7
AD-63599.1	37.0	5.6
AD-63605.1	49.3	3.7
AD-63611.1	88.8	7.7
AD-63617.1	45.6	6.6
AD-63576.1	59.9	2.9
AD-63582.1	82.9	8.3
AD-63588.1	33.5	6.7
AD-63594.1	64.7	18.0
AD-63600.1	99.5	11.9
AD-63606.1	40.8	2.7
AD-63612.1	44.5	5.3
AD-63618.1	41.7	4.6
AD-63577.1	31.1	0.3
AD-63583.1	57.3	8.6
AD-63589.1	61.9	5.9
AD-63595.1	51.2	8.5
AD-63601.1	70.7	15.4
AD-63607.1	39.4	1.9
AD-63613.1	36.8	2.7
AD-63619.1	83.8	13.8
AD-63620.1	69.4	7.3
AD-63621.1	30.6	3.1
AD-63622.1	51.8	8.4
AD-63623.1	37.3	8.6

5

We claim:

1. A double stranded RNAi agent capable of inhibiting expression of TMPRSS6 in a cell, wherein said double stranded RNAi agent comprises a sense strand and an antisense strand forming a double-stranded region, wherein said sense strand comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the nucleotide sequences of SEQ ID NO:1, SEQ ID NO:2, or SEQ ID NO:3, SEQ ID NO:4, or SEQ ID NO:5, and said antisense strand comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the nucleotide sequences of SEQ ID NO:6, SEQ ID NO:7, or SEQ ID NO:8, SEQ ID NO:9, or SEQ ID NO:10,

wherein substantially all of the nucleotides of said sense strand and substantially all of the nucleotides of said antisense strand are modified nucleotides, and

wherein said sense strand is conjugated to a ligand attached at the 3'-terminus.

2. The double stranded RNAi agent of claim 1, wherein all of the nucleotides of said sense strand and all of the nucleotides of said antisense strand are modified nucleotides.

3. The double stranded RNAi agent of claim 1, wherein said sense strand and said antisense strand comprise a region of complementarity which comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the antisense sequences listed in any one of Tables 1, 2, 4, 5, 8, 10, and 12.

4. The double stranded RNAi agent of any one of claims 1-3, wherein at least one of said modified nucleotides is selected from the group consisting of a 3'-terminal deoxy-thymine (dT) nucleotide, a 2'-O-methyl modified nucleotide, a 2'-fluoro modified nucleotide, a 2'-deoxy-modified nucleotide, a locked nucleotide, an abasic nucleotide, a 2'-amino-modified nucleotide, a 2'-alkyl-modified nucleotide, a morpholino nucleotide, a phosphoramidate, a non-natural base comprising nucleotide, a nucleotide comprising a 5'-phosphorothioate group, a nucleotide comprising a 5' phosphate or 5' phosphate mimic, and a terminal nucleotide linked to a cholesteryl derivative or a dodecanoic acid bisdecylamide group.

5. The double stranded RNAi agent of any claim 1, wherein at least one strand comprises a 3' overhang of at least 1 nucleotide.

6. The double stranded RNAi agent of claim 1, wherein at least one strand comprises a 3' overhang of at least 2 nucleotides.

7. A double stranded RNAi agent capable of inhibiting expression of TMPRSS6 (matriptase-2) in a cell, wherein said double stranded RNAi agent comprises a sense strand complementary to an antisense strand, wherein said antisense strand comprises a region complementary to part of an mRNA encoding TMPRSS6, wherein each strand is about 14 to about 30 nucleotides in length, wherein said double stranded RNAi agent is represented by formula (III):

sense: 5' n_p -N_a -(X X X) $_i$-N_b -Y Y Y -N_b -(Z Z Z)$_j$ -N_a - n_q 3'

antisense: 3' n_p'-N_a'-(X'X'X')$_k$-N_b'-Y'Y'Y'-N_b'-(Z'Z'Z')$_l$-N_a'- n_q' 5' (III)

wherein:

i, j, k, and l are each independently 0 or 1;

p, p', q, and q' are each independently 0-6;

each N_a and N_a' independently represents an oligonucleotide sequence comprising 0-25 nucleotides which are either modified or unmodified or combinations thereof, each sequence comprising at least two differently modified nucleotides;

each N_b and N_b' independently represents an oligonucleotide sequence comprising 0-10 nucleotides which are either modified or unmodified or combinations thereof;

each n_p, n_p', n_q, and n_q', each of which may or may not be present, independently represents an overhang nucleotide;

XXX, YYY, ZZZ, X'X'X', Y'Y'Y', and Z'Z'Z' each independently represent one motif of three identical modifications on three consecutive nucleotides;

modifications on N_b differ from the modification on Y and modifications on N_b' differ from the modification on Y'; and

wherein the sense strand is conjugated to at least one ligand.

8. The double stranded RNAi agent of claim 7, wherein i is 0; j is 0; i is 1; j is 1; both i and j are 0; or both i and j are 1.

9. The double stranded RNAi agent of claim 7, wherein k is 0; l is 0; k is 1; l is 1; both k and l are 0; or both k and l are 1.

10. The double stranded RNAi agent of claim 7, wherein XXX is complementary to X'X'X', YYY is complementary to Y'Y'Y', and ZZZ is complementary to Z'Z'Z'.

11. The double stranded RNAi agent of claim 7, wherein the YYY motif occurs at or near the cleavage site of the sense strand.

12. The double stranded RNAi agent of claim 7, wherein the Y′Y′Y′ motif occurs at the 11, 12 and 13 positions of the antisense strand from the 5'-end.

13. The double stranded RNAi agent of claim 12, wherein the Y′ is 2′-O-methyl.

14. The double stranded RNAi agent of claim 7, wherein formula (III) is represented by formula (IIIa):

sense: 5' n_p -N_a -Y Y Y -N_a - n_q 3'

antisense: 3' $n_{p'}$-$N_{a'}$- Y′Y′Y′- $N_{a'}$- $n_{q'}$ 5' (IIIa).

15. The double stranded RNAi agent of claim 7, wherein formula (III) is represented by formula (IIIb):

sense: 5' n_p -N_a -Y Y Y -N_b -Z Z Z -N_a - n_q 3'

antisense: 3' $n_{p'}$-$N_{a'}$- Y′Y′Y′-$N_{b'}$-Z′Z′Z′- $N_{a'}$- $n_{q'}$ 5' (IIIb)

wherein each N_b and N_b' independently represents an oligonucleotide sequence comprising 1-5 modified nucleotides.

16. The double stranded RNAi agent of claim 7, wherein formula (III) is represented by formula (IIIc):

sense: 5' n_p -N_a –X X X -N_b -Y Y Y -N_a - n_q 3'

antisense: 3' $n_{p'}$-$N_{a'}$- X′X′X′-$N_{b'}$- Y′Y′Y′- $N_{a'}$- $n_{q'}$ 5' (IIIc)

wherein each N_b and N_b' independently represents an oligonucleotide sequence comprising 1-5 modified nucleotides.

17. The double stranded RNAi agent of claim 7, wherein formula (III) is represented by formula (IIId):

sense: 5' n_p -N_a –X X X- N_b -Y Y Y -N_b -Z Z Z -N_a - n_q 3'

antisense: 3' $n_{p'}$-$N_{a'}$- X′X′X′- $N_{b'}$-Y′Y′Y′-$N_{b'}$-Z′Z′Z′- $N_{a'}$- $n_{q'}$ 5'

(IIId)

wherein each N_b and N_b' independently represents an oligonucleotide sequence comprising 1-5 modified nucleotides and each N_a and N_a' independently represents an oligonucleotide sequence comprising 2-10 modified nucleotides.

18. The double stranded RNAi agent of claim 7, wherein the double-stranded region is 15-30 nucleotide pairs in length.

19. The double stranded RNAi agent of claim 18, wherein the double-stranded region is 17-23 nucleotide pairs in length.

20. The double stranded RNAi agent of claim 18, wherein the double-stranded region is 17-25 nucleotide pairs in length.

21. The double stranded RNAi agent of claim 18, wherein the double-stranded region is 23-27 nucleotide pairs in length.

22. The double stranded RNAi agent of claim 18, wherein the double-stranded region is 19-21 nucleotide pairs in length.

23. The double stranded RNAi agent of claim 18, wherein the double-stranded region is 21-23 nucleotide pairs in length.

24. The double stranded RNAi agent of claim 7, wherein each strand has 15-30 nucleotides.

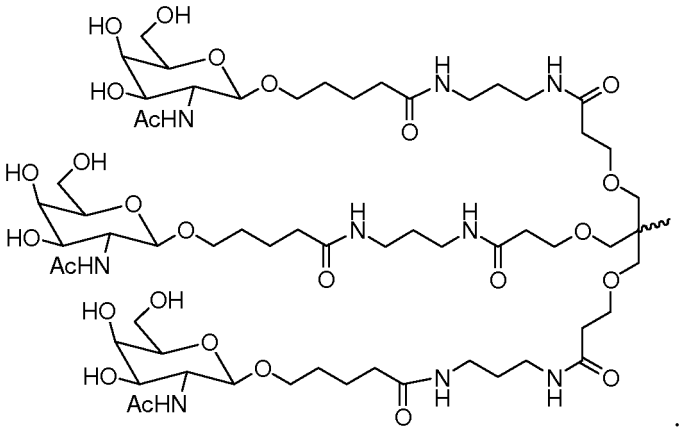
25. The double stranded RNAi agent of claim 1 or 7, wherein each strand has 19-30 nucleotides.

26. The double stranded RNAi agent of claim 7, wherein the modifications on the nucleotides are selected from the group consisting of LNA, HNA, CeNA, 2′-methoxyethyl, 2′-O-alkyl, 2′-O-allyl, 2′-C- allyl, 2′-fluoro, 2′-deoxy, 2'-hydroxyl, and combinations thereof.

27. The double stranded RNAi agent of claim 26, wherein the modifications on the nucleotides are 2′-O-methyl or 2′-fluoro modifications.

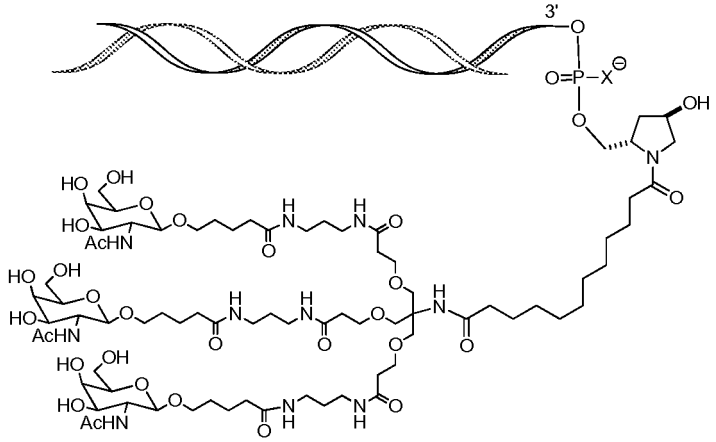
28. The double stranded RNAi agent of claim 1 or 7, wherein the ligand is one or more GalNAc derivatives attached through a bivalent or trivalent branched linker.

29. The double stranded RNAi agent of claim 1 or 7, wherein the ligand is



30. The double stranded RNAi agent of claim 1 or 7, wherein the ligand is attached to the 3′ end of the sense strand.

31. The double stranded RNAi agent of claim 30, wherein the RNAi agent is conjugated to the ligand as shown in the following schematic



wherein X is O or S.

32. The double stranded RNAi agent of claim 1 or 7, wherein said agent further comprises at least one phosphorothioate or methylphosphonate internucleotide linkage.

33. The double stranded RNAi agent of claim 32, wherein the phosphorothioate or methylphosphonate internucleotide linkage is at the 3'-terminus of one strand.

34. The double stranded RNAi agent of claim 33, wherein said strand is the antisense strand.

35. The double stranded RNAi agent of claim 33, wherein said strand is the sense strand.

36. The double stranded RNAi agent of claim 32, wherein the phosphorothioate or methylphosphonate internucleotide linkage is at the 5'-terminus of one strand.

37. The double stranded RNAi agent of claim 36, wherein said strand is the antisense strand.

38. The double stranded RNAi agent of claim 36, wherein said strand is the sense strand.

39. The double stranded RNAi agent of claim 32, wherein the phosphorothioate or methylphosphonate internucleotide linkage is at the both the 5'- and 3'-terminus of one strand.

40. The double stranded RNAi agent of claim 39, wherein said strand is the antisense strand.

41. The double stranded RNAi agent of claim 32, wherein said RNAi agent comprises 6-8 phosphorothioate internucleotide linkages.

42. The double stranded RNAi of claim 41, wherein the antisense strand comprises two phosphorothioate internucleotide linkages at the 5'-terminus and two phosphorothioate internucleotide linkages at the 3'-terminus, and the sense strand comprises at least two phosphorothioate internucleotide linkages at either the 5'-terminus or the 3'-terminus.

43. The double stranded RNAi agent of claim 1 or 7, wherein the base pair at the 1 position of the 5′-end of the antisense strand of the duplex is an AU base pair.

44. The double stranded RNAi agent of claim 7, wherein the Y nucleotides contain a 2′-fluoro modification.

45. The double stranded RNAi agent of claim 7, wherein the Y′ nucleotides contain a 2′-O-methyl modification.

46. The double stranded RNAi agent of claim 7, wherein p′>0.

47. The double stranded RNAi agent of claim 7, wherein p′=2.

48. The double stranded RNAi agent of claim 47, wherein q'=0, p=0, q=0, and p' overhang nucleotides are complementary to the target mRNA.

49. The double stranded RNAi agent of claim 47, wherein q'=0, p=0, q=0, and p' overhang nucleotides are non-complementary to the target mRNA.

50. The double stranded RNAi agent of claim 41, wherein the sense strand has a total of 21 nucleotides and the antisense strand has a total of 23 nucleotides.

51. The double stranded RNAi agent of any one of claims 46-50, wherein at least one n_p' is linked to a neighboring nucleotide via a phosphorothioate linkage.

52. The double stranded RNAi agent of claim 51, wherein all n_p' are linked to neighboring nucleotides via phosphorothioate linkages.

53. The double stranded RNAi agent of claim 1 or 7, wherein said RNAi agent is selected from the group of RNAi agents listed in any one of Tables 1, 2, 4, 5, 8, 10, and 12.

54. The double stranded RNAi agent of claim 1 or 7, wherein the RNAi agent is selected from the group consisting of AD-59743, AD-60940, and AD-61002.

55. The double stranded RNAi agent of claim 1 or 7, wherein said RNAi agent is AD-60940.

56. A double stranded RNAi agent capable of inhibiting expression of TMPRSS6 in a cell,

wherein said double stranded RNAi agent comprises a sense strand and an antisense strand forming a double stranded region,

wherein said sense strand comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the nucleotide sequences of SEQ ID NO:1, SEQ ID NO:2, or SEQ ID NO:3, SEQ ID NO:4, or SEQ ID NO:5, and said antisense strand comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the nucleotide sequences of SEQ ID NO:6, SEQ ID NO:7, or SEQ ID NO:8, SEQ ID NO:9, or SEQ ID NO:10,

wherein substantially all of the nucleotides of said sense strand comprise a modification selected from the group consisting of a 2'-O-methyl modification and a 2'-fluoro modification,

wherein said sense strand comprises two phosphorothioate internucleotide linkages at the 5'-terminus,

wherein substantially all of the nucleotides of said antisense strand comprise a modification selected from the group consisting of a 2'-O-methyl modification and a 2'-fluoro modification,

wherein said antisense strand comprises two phosphorothioate internucleotide linkages at the 5'-terminus and two phosphorothioate internucleotide linkages at the 3'-terminus, and

wherein said sense strand is conjugated to one or more GalNAc derivatives attached through a branched bivalent or trivalent linker at the 3'-terminus.

57. The double stranded RNAi agent of claim 56, wherein all of the nucleotides of said sense strand and all of the nucleotides of said antisense strand comprise a modification.

58. A double stranded RNAi agent capable of inhibiting expression of TMPRSS6(matriptase-2) in a cell, wherein said double stranded RNAi agent comprises a sense strand complementary to an antisense strand, wherein said antisense strand comprises a region complementary to part of an mRNA encoding TMPRSS6, wherein each strand is about 14 to about 30 nucleotides in length, wherein said double stranded RNAi agent is represented by formula (III):

sense: 5' n_p -N_a -(X X X) $_i$-N_b -Y Y Y -N_b -(Z Z Z)$_j$ -N_a - n_q 3'

antisense: 3' n_p'-N_a'-(X'X'X')$_k$-N_b'-Y'Y'Y'-N_b'-(Z'Z'Z')$_l$-N_a'- n_q' 5' (III)

wherein:

i, j, k, and l are each independently 0 or 1;

p, p', q, and q' are each independently 0-6;

each N_a and N_a' independently represents an oligonucleotide sequence comprising 0-25 nucleotides which are either modified or unmodified or combinations thereof, each sequence comprising at least two differently modified nucleotides;

each N_b and N_b' independently represents an oligonucleotide sequence comprising 0-10 nucleotides which are either modified or unmodified or combinations thereof;

each n_p, n_p', n_q, and n_q', each of which may or may not be present independently represents an overhang nucleotide;

XXX, YYY, ZZZ, X'X'X', Y'Y'Y', and Z'Z'Z' each independently represent one

motif of three identical modifications on three consecutive nucleotides, and wherein the modifications are 2′-O-methyl or 2′-fluoro modifications;

modifications on N_b differ from the modification on Y and modifications on N_b' differ from the modification on Y′; and

wherein the sense strand is conjugated to at least one ligand.

59. A double stranded RNAi agent capable of inhibiting the expression of TMPRSS6 (matriptase-2) in a cell, wherein said double stranded RNAi agent comprises a sense strand complementary to an antisense strand, wherein said antisense strand comprises a region complementary to part of an mRNA encoding TMPRSS6, wherein each strand is about 14 to about 30 nucleotides in length, wherein said double stranded RNAi agent is represented by formula (III):

sense: $5'\ n_p\text{-}N_a\text{-}(X\ X\ X)_i\text{-}N_b\text{-}Y\ Y\ Y\text{-}N_b\text{-}(Z\ Z\ Z)_j\text{-}N_a\text{-}n_q\ 3'$

antisense: $3'\ n_p'\text{-}N_a'\text{-}(X'X'X')_k\text{-}N_b'\text{-}Y'Y'Y'\text{-}N_b'\text{-}(Z'Z'Z')_l\text{-}N_a'\text{-}n_q'\ 5'$ (III)

wherein:

i, j, k, and l are each independently 0 or 1;

each n_p, n_q, and n_q', each of which may or may not be present, independently represents an overhang nucleotide;

p, q, and q′ are each independently 0-6;

$n_p' > 0$ and at least one n_p' is linked to a neighboring nucleotide via a phosphorothioate linkage;

each N_a and N_a' independently represents an oligonucleotide sequence comprising 0-25 nucleotides which are either modified or unmodified or combinations thereof, each sequence comprising at least two differently modified nucleotides;

each N_b and N_b' independently represents an oligonucleotide sequence comprising 0-10 nucleotides which are either modified or unmodified or combinations thereof;

XXX, YYY, ZZZ, X′X′X′, Y′Y′Y′, and Z′Z′Z′ each independently represent one motif of three identical modifications on three consecutive nucleotides, and wherein the modifications are 2′-O-methyl or 2′-fluoro modifications;

modifications on N_b differ from the modification on Y and modifications on N_b' differ from the modification on Y′; and

wherein the sense strand is conjugated to at least one ligand.

60. A double stranded RNAi agent capable of inhibiting the expression of TMPRSS6 (matriptase-2) in a cell, wherein said double stranded RNAi agent comprises a sense strand complementary to an antisense strand, wherein said antisense strand comprises a region complementary to part of an mRNA encoding TMPRSS6, wherein each strand is about 14 to about 30 nucleotides in length, wherein said double stranded RNAi agent is

represented by formula (III):

sense: 5' n_p -N_a -(X X X) $_i$-N_b -Y Y Y -N_b -(Z Z Z)$_j$ -N_a - n_q 3'

antisense: 3' n_p'-N_a'-(X'X'X')$_k$-N_b'-Y'Y'Y'-N_b'-(Z'Z'Z')$_l$-N_a'- n_q' 5' (III)

wherein:

i, j, k, and l are each independently 0 or 1;

each n_p, n_q, and n_q', each of which may or may not be present, independently represents an overhang nucleotide;

p, q, and q' are each independently 0-6;

n_p' >0 and at least one n_p' is linked to a neighboring nucleotide via a phosphorothioate linkage;

each N_a and N_a' independently represents an oligonucleotide sequence comprising 0-25 nucleotides which are either modified or unmodified or combinations thereof, each sequence comprising at least two differently modified nucleotides;

each N_b and N_b' independently represents an oligonucleotide sequence comprising 0-10 nucleotides which are either modified or unmodified or combinations thereof;

XXX, YYY, ZZZ, X'X'X', Y'Y'Y', and Z'Z'Z' each independently represent one motif of three identical modifications on three consecutive nucleotides, and wherein the modifications are 2'-O-methyl or 2'-fluoro modifications;

modifications on N_b differ from the modification on Y and modifications on N_b' differ from the modification on Y'; and

wherein the sense strand is conjugated to at least one ligand, wherein the ligand is one or more GalNAc derivatives attached through a bivalent or trivalent branched linker.

61. A double stranded RNAi agent capable of inhibiting the expression of TMPRSS6 (matriptase-2) in a cell, wherein said double stranded RNAi agent comprises a sense strand complementary to an antisense strand, wherein said antisense strand comprises a region complementary to part of an mRNA encoding TMPRSS6, wherein each strand is about 14 to about 30 nucleotides in length, wherein said double stranded RNAi agent is represented by formula (III):

sense: 5' n_p -N_a -(X X X) $_i$-N_b -Y Y Y -N_b -(Z Z Z)$_j$ -N_a - n_q 3'

antisense: 3' n_p'-N_a'-(X'X'X')$_k$-N_b'-Y'Y'Y'-N_b'-(Z'Z'Z')$_l$-N_a'- n_q' 5' (III)

wherein:

i, j, k, and l are each independently 0 or 1;

each n_p, n_q, and n_q', each of which may or may not be present, independently represents an overhang nucleotide;

p, q, and q' are each independently 0-6;

n_p' >0 and at least one n_p' is linked to a neighboring nucleotide via a phosphorothioate linkage;

each N_a and N_a' independently represents an oligonucleotide sequence comprising 0-25 nucleotides which are either modified or unmodified or combinations thereof, each sequence comprising at least two differently modified nucleotides;

each N_b and N_b' independently represents an oligonucleotide sequence comprising 0-10 nucleotides which are either modified or unmodified or combinations thereof;

XXX, YYY, ZZZ, X′X′X′, Y′Y′Y′, and Z′Z′Z′ each independently represent one motif of three identical modifications on three consecutive nucleotides, and wherein the modifications are 2′-O-methyl or 2′-fluoro modifications;

modifications on N_b differ from the modification on Y and modifications on N_b' differ from the modification on Y′;

wherein the sense strand comprises at least one phosphorothioate linkage; and

wherein the sense strand is conjugated to at least one ligand, wherein the ligand is one or more GalNAc derivatives attached through a bivalent or trivalent branched linker.

62. A double stranded RNAi agent capable of inhibiting the expression of TMPRSS6 (matriptase-2) in a cell, wherein said double stranded RNAi agent comprises a sense strand complementary to an antisense strand, wherein said antisense strand comprises a region complementary to part of an mRNA encoding TMPRSS6, wherein each strand is about 14 to about 30 nucleotides in length, wherein said double stranded RNAi agent is represented by formula (III):

sense: 5' n_p -N_a -Y Y Y - N_a - n_q 3'

antisense: 3' n_p'-N_a'- Y′Y′Y′- N_a'- n_q' 5' (IIIa)

wherein:

each n_p, n_q, and n_q', each of which may or may not be present, independently represents an overhang nucleotide;

p, q, and q′ are each independently 0-6;

$n_p' > 0$ and at least one n_p' is linked to a neighboring nucleotide via a phosphorothioate linkage;

each N_a and N_a' independently represents an oligonucleotide sequence comprising 0-25 nucleotides which are either modified or unmodified or combinations thereof, each sequence comprising at least two differently modified nucleotides;

YYY and Y′Y′Y′ each independently represent one motif of three identical modifications on three consecutive nucleotides, and wherein the modifications are 2′-O-methyl or 2′-fluoro modifications;

wherein the sense strand comprises at least one phosphorothioate linkage; and

wherein the sense strand is conjugated to at least one ligand, wherein the ligand is one or more GalNAc derivatives attached through a bivalent or trivalent branched linker.

63. An RNAi agent selected from the group of RNAi agents listed in any one of Tables 1, 2, 4, 5, 8, 10, and 12.

64. The RNAi agent of claim 52, wherein the RNAi agent is selected from the group consisting of AD-59743, AD-60940, and AD-61002.

65. A composition comprising a modified antisense polynucleotide agent capable of inhibiting expression of TMPRSS6 in a cell, wherein said agent comprises a sequence complementary to a sense sequence selected from the group of the sequences listed in any one of Tables 1, 2, 4, 5, 8, 10, and 12, wherein the polynucleotide is about 14 to about 30 nucleotides in length.

66. A vector containing the double stranded RNAi agent of any one of claims 1, 7, 56, and 58-64.

67. A cell containing the double stranded RNAi agent of any one of claims 1, 7, 56, and 58-64 .

68. A pharmaceutical composition comprising the double stranded RNAi agent of any one of claims 1, 7, 56, and 58-64, or the modified antisense polynucleotide agent of claim 65, or the vector of claim 66 .

69. The pharmaceutical composition of claim 68, wherein RNAi agent is administered in an unbuffered solution.

70. The pharmaceutical composition of claim 69, wherein said unbuffered solution is saline or water.

71. The pharmaceutical composition of claim 68, wherein said siRNA is administered with a buffer solution.

72. The pharmaceutical composition of claim 71, wherein said buffer solution comprises acetate, citrate, prolamine, carbonate, or phosphate or any combination thereof.

73. The pharmaceutical composition of claim 72, wherein said buffer solution is phosphate buffered saline (PBS).

74. A method of inhibiting TMPRSS6 expression in a cell, the method comprising:

(a) contacting the cell with the double stranded RNAi agent of any one of claims 1, 7, 56, and 58-64 , or the modified antisense polynucleotide agent of claim 65, or the vector of claim 66, or a pharmaceutical composition of any one of claims 68-73; and

(b) maintaining the cell produced in step (a) for a time sufficient to obtain degradation of the mRNA transcript of a TMPRSS6 gene, thereby inhibiting expression of the TMPRSS6 gene in the cell.

75. The method of claim 74, wherein said cell is within a subject.

76. The method of claim 75, wherein the subject is a human.

77. The method of any one of claims 74-76, wherein the TMPRSS6 expression is inhibited by at least about 30%, about 40%, about 50%, about 60%, about 70%, about 80%, about 90%, about 95%, about 98% or about 100%.

78. The method of any one of claims 74-76, wherein hepcidin gene expression is increased by at least about 1.5-fold, about 2-fold, about 3-fold, about 4-fold or about 5-fold.

79. The method of any one of claims 74-76, wherein serum hepcidin concentration is increased by at least about 10%, about 25%, about 50%, about 100%, about 150%, about 200%, about 250%, or about 300%.

80. The method of any one of claims 74-76, wherein serum iron concentration is decreased by at least about 20%, about 30%, about 40%, about 50%, about 60%, about 70%, about 80%, about 90%, about 95%, about 98% or about 100%.

81. The method of any one of claims 74-76, wherein a percent transferrin saturation is decreased by at least about 20%, about 30%, about 40%, about 50%, about 60%, about 70%, about 80%, about 90%, about 95%, about 98% or about 100%.

82. A method of treating a subject having a TMPRSS6 associated disorder, comprising administering to the subject a therapeutically effective amount of the double stranded RNAi agent of any one of claims 1, 7, 56, and 58-64 , or the modified antisense polynucleotide agent of claim 65, or the vector of claim 66, or a pharmaceutical composition of any one of claims 68-73 , thereby treating said subject.

83. A method of treating a subject having a TMPRSS6-associated disorder, comprising subcutaneously administering to the subject a therapeutically effective amount of a double stranded RNAi agent,

wherein said double stranded RNAi agent comprises a sense strand and an antisense strand forming a double stranded region,

wherein said sense strand comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the nucleotide sequences of SEQ ID NO:1, SEQ ID NO:2, or SEQ ID NO:3, SEQ ID NO:4, or SEQ ID NO:5, and said antisense strand comprises at least 15 contiguous nucleotides differing by no more than 3 nucleotides from any one of the nucleotide sequences of SEQ ID NO:6, SEQ ID NO:7, or SEQ ID NO:8, SEQ ID NO:9, or SEQ ID NO:10,

wherein substantially all of the nucleotides of said antisense strand comprise a modification selected from the group consisting of a 2'-O-methyl modification and a 2'-fluoromodification,

wherein said antisense strand comprises two phosphorothioate internucleotide linkages at the 5'-terminus and two phosphorothioate internucleotide linkages at the 3'-terminus,

wherein substantially all of the nucleotides of said sense strand comprise a modification selected from the group consisting of a 2'-O-methyl modification and a 2'-fluoromodification,

wherein said sense strand comprises two phosphorothioate internucleotide linkages at the 5'-terminus and,

wherein said sense strand is conjugated to one or more GalNAc derivatives attached through a branched bivalent or trivalent linker at the 3'-terminus, thereby treating the subject.

84. The method of claim of claim 83, wherein all of the nucleotides of said sense strand and all of the nucleotides of said antisense strand comprise a modification.

85. The method of claim 82 or 83, wherein the subject is a human.

86. The method of claim 85, wherein the human has hereditary hemochromatosis, β-thalassemia, or erythropoietic porphyria.

87. The method of claim 85, wherein the human has β-thalassemia.

88. The method of claim 87, wherein the β-thalassemia is thalassemia major.

89. The method of claim 87, wherein the β-thalassemia is thalassemia intermedia.

90. The method of claim 85, wherein the human has a disorder associated with iron overload.

91. The method of 90, wherein the disorder associated with iron overload is Parkinson's Disease, Alzheimer's Disease or Friedreich's Ataxia.

92. The method of claim 82 or 83, wherein the double stranded RNAi agent is administered at a dose of about 0.01 mg/kg to about 10 mg/kg or about 1 mg/kg to about 10 mg/kg.

93. The method of claim 92, wherein the double stranded RNAi agent is administered at a dose of about 0.1 mg/kg, about 1.0 mg/kg, or about 3.0 mg/kg.

94. The method of claim 92, wherein the double stranded RNAi agent is administered at a dose of about 1 mg/kg to about 10 mg/kg.

95. The method of claim 92, wherein the double stranded RNAi agent is administered subcutaneously.

96. The method of claim 92, wherein the double stranded RNAi agent is administered intravenously.

97. The method of claim 92, wherein said RNAi agent is administered in two or more doses.

98. The method of claim 97, wherein said RNAi agent is administered at intervals selected from the group consisting of once every about 12 hours, once every about 24 hours, once every about 48 hours, once every about 72 hours, and once every about 96 hours.

99. The method of claim 97, wherein said RNAi agent is administered once a week for up to 2 weeks, up to 3 weeks, up to 4 weeks, up to 5 weeks, or longer.

100. The method of claim 82 or 83, further comprising administering an iron chelator to said dusbject.

101. The method of claim 100, wherein the iron chelator is selected from the group consisting of deferiprone, deferoxamine, and deferasirox.