GENE THERAPY FOR RETINITIS PIGMENTOSA

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of U.S. Provisional Application Serial No. 61/969,027, filed March 21, 2014, which is incorporated herein by reference in its entirety.

SEQUENCE LISTING

[0002] The content of the following submission on ASCII text file is incorporated herein by reference in its entirety: a computer readable form (CRF) of the Sequence Listing (file name: 159792010040SeqList.txt, date recorded: March 17, 2015, size: 63 KB).

FIELD OF THE INVENTION

[0003] The present invention relates to AAV vectors and methods of using AAV vectors for treating retinitis pigmentosa.

BRIEF SUMMARY OF THE INVENTION

[0004] Retinitis pigmentosa (RP) is the most common cause of inherited retinal degeneration, which is clinically characterized by night blindness and the loss of peripheral vision. Mutations in the rod visual pigment rhodopsin are recognized as the most common cause of autosomal dominant RP (ADRP), and although a number of treatments for rhodopsin RP have been proposed and tested in animal models and clinical studies, the disease remains incurable (Kalloniatis, M., *et al.* (2004) *Clin. Exp. Optom.* 87(2):65-80). Much data supports the view that rhodopsin RP is a protein-misfolding disease in which the misfolding or misassembly of a mutant protein alters its cellular fate and induces cell death (Gregersen, N. *et al.* (2006) *Annu. Rev. Genomics Hum. Genet.* 7:103-24). Known RP mutations in the rhodopsin gene include missense and short, in-frame deletion mutations, with a single base substitution in codon 23 (P23H) of the rhodopsin gene accounting for ~7% of all cases of dominant Retinitis Pigmentosa in the US (Dryja, T.P., *et al.* (1995) *Proc. Natl. Acad. Sci. U.S.A.* 92(22):10177-81). In cultured cells, the P23H mutant protein, unlike wild type (WT) protein, is retained in the ER, leading to induction of the unfolded protein response (UPR), inhibition of the proteasome, and aggregation of the mutant protein

into oligomeric, high molecular weight species that form intracellular inclusions (Saliba, R.S., *et al.* (2002) *J. Cell Sci.* 115:2907-18). Similarly, P23H rhodopsin mislocalizes and/or aggregates in the rod cells of animal RP models (Olsson, J.E., *et al.* (1992) *Neuron* 9(5):815-30), suggesting that cell culture models may be predictive of *in vivo* models of this disease. What is needed is a means of ameliorating the symptoms of RP.

[0005] The invention described herein provides methods for treating retinitis pigmentosa in a mammal, comprising administering to the eye of the mammal a recombinant adeno-associated virus (rAAV) viral particle comprising a vector encoding a miR-708. In some embodiments, the rAAV vector comprising nucleic acid encoding a miR-708 and rhodopsin. In some embodiments, the invention provides methods for treating retinitis pigmentosa comprising administering to the eye of the mammal a first rAAV viral particle comprising a first rAAV vector comprising nucleic acid encoding a miR-708 and a second rAAV viral particle comprising a second rAAV vector comprising nucleic acid encoding a rhodopsin. In other embodiments, the invention provides methods for treating retinitis pigmentosa comprising administering to the eye of the mammal a rAAV viral particle comprising a rAAV vector comprising nucleic acid encoding a miR-708 and rhodopsin. In some embodiments, treating retinitis pigmentosa comprises reducing or preventing symptoms associated with the retinitis pigmentosa. In some embodiments or the invention, methods of treating retinitis pigmentosa include methods of reducing a symptom associated with RP, methods of preventing retinal degeneration, methods for arresting progression of RP, methods for increasing photoreceptor function, and the like. Symptoms and/or pathology of RP include but are not limited to loss of sight, loss of night vision, loss of peripheral visual fields, loss of ERG function; loss of visual acuity and contrast sensitivity; loss of visually guided behavior, reduction in rod photoreceptor function, rod photoreceptor cell death, decreased scotopic vision, reduction in retinal cell changes (loss of photoreceptor structure or function; thinning or thickening of the outer nuclear layer (ONL); thinning or thickening of the outer plexiform layer (OPL); disorganization followed by loss of rod and cone outer segments; shortening of the rod and cone inner segments; retraction of bipolar cell dendrites; thinning or thickening of the inner retinal layers including inner nuclear layer, inner plexiform layer, ganglion cell layer and nerve fiber layer; opsin mislocalization; overexpression of neurofilaments; and the like. In some embodiments, the invention provides methods to prevent deterioration of rod cell function and rod cell death and cone cell function and cone cell death.

[0006] In some aspects, the invention provides methods for treating endoplasmic reticulum (ER) stress in a cell comprising administering to the mammal a rAAV viral particle comprising a rAAV vector comprising nucleic acid encoding a miR-708. In some embodiments, the mammal has or is at risk of having RP. In some embodiments, the mammal is a human that has or is at risk of having RP. In some embodiments, the rAAV particle is administered to an eye of the mammal. In some embodiments, the cell is an ocular cell. In further embodiments, the cell is a photoreceptor cell. In yet further embodiments, the cell is a rod photoreceptor cell. In some embodiments, the method comprises reducing one or more cellular markers of ER stress. In further embodiments, the one or more cellular marker of ER stress is spliced XBP-1, CHOP or Grp78. In some embodiments, the rAAV vector comprises nucleic acid encoding a miR-708 and rhodopsin. In other embodiments, the invention provides methods for treating endoplasmic reticulum (ER) stress in a cell comprising administering to the mammal a first rAAV vector comprising nucleic acid encoding a miR-708 and a second rAAV viral particle comprising a second rAAV vector comprising nucleic acid encoding a rhodopsin.

[0007] In some embodiments of the invention, the nucleic acid encoding miR-708 is operably linked to a promoter. In some embodiments, the promoter is capable of expressing the miR-708 in photoreceptor cells (*e.g.*, a rod photoreceptor cell). In further embodiments, the promoter comprises a rhodopsin kinase (RK) promoter or an opsin promoter. In other embodiments of the invention, the nucleic acid encoding rhodopsin is operably linked to a promoter. In some embodiments, the promoter is capable of expressing the rhodopsin in photoreceptor cells (*e.g.*, a rod photoreceptor cell). In further embodiments, the promoter comprises a RK promoter or an opsin promoter.

[0008] In some embodiments, the invention provides methods to treat RP and/or ER stress comprising administering to a mammal, a rAAV particle comprising a rAAV vector comprising nucleic acid encoding miR-708 and rhodopsin. In some embodiments, the nucleic acid encoding miR-708 and the nucleic acid encoding rhodopsin are operably linked to one RK promoter. In other embodiments, the nucleic acid encoding miR-708 is operably linked to a first RK promoter or a first opsin promoter and the nucleic acid encoding rhodopsin is operably linked to a second RK promoter or a second opsin promoter. In some embodiments, the first and/or second opsin promoter includes an MVM intron (*e.g.*, an intron of SEQ ID NO:23). In some embodiments, the nucleic acid encoding miR-708 is 5'

to the nucleic acid encoding rhodopsin. In other embodiments, the nucleic acid encoding miR-708 is 3' to the nucleic acid encoding rhodopsin. In some embodiments, the nucleic acid encoding miR-708 is operably linked to the chicken β-actin (CBA) promoter. In some embodiments, the nucleic acid encoding rhodopsin is operably linked to the chicken β-actin (CBA) promoter. In some embodiments, a sequence derived from a minute virus of mouse (MVM) intron is located 3' to the promoter. In some embodiments, the MMV intron comprises the nucleotide sequence of SEQ ID NO:23. In some embodiments, the promoter further comprises i) a CMV enhancer; ii) a sequence derived from a photoreceptor specific transcription factor; iii)a sequence derived from a rod photoreceptor specific transcription factor; iv) a sequence derived from a neural retinal basic zipper factor; v) a sequence derived from a cone rod homeobox-containing transcription factor sequence; vi) a CMV enhancer and at least one or more of a sequence derived from a photoreceptor specific transcription factor, a sequence derived from a rod photoreceptor specific transcription factor, a sequence derived from a neural retinal basic zipper factor; a sequence derived from a cone rod homeobox-containing transcription factor sequence; vii)a neural retinal basic leucine zipper factor, a CMV enhancer and an Opsin promoter (-500 to +17); viii) a neural retinal basic leucine zipper factor, a CMV enhancer, an Opsin promoter (-500 to +17), and an MVM intron; ix) a CMV enhancer comprising SEQ ID NO:29; x) a neural retinal basic leucine zipper factor sequence comprising SEQ ID NO:30; xi) a sequence derived from a cone rod homeobox-containing transcription factor sequence comprising SEQ ID NO:28; xii) a CMV enhancer comprising SEQ ID NO:29 and at least one or more of a sequence derived from a photoreceptor specific transcription factor, a sequence derived from a rod photoreceptor specific transcription factor, a sequence derived from a neural retinal basic zipper factor comprising SEQ ID NO:30; a sequence derived from a cone rod homeobox-containing transcription factor sequence comprising SEQ ID NO:28; xiii) a neural retinal basic leucine zipper factor comprising SEQ ID NO:30, a CMV enhancer comprising SEQ ID NO:29 and an Opsin promoter (-500 to +17) comprising SEQ ID NO:22; or xiv) a neural retinal basic leucine zipper factor comprising SEQ ID NO:28, a CMV enhancer comprising SEQ ID NO:29, an Opsin promoter (-500 to +17) comprising SEQ ID NO:22, and an MVM intron comprising SEQ ID NO:23. In some embodiments, the nucleic acid encoding miR-708 is embedded in an intron. In some embodiments, the nucleic acid encoding miR-708 comprises an endogenous miR-708 scaffold or a miR-155 scaffold.

[0009] In some embodiments, the invention provides methods to treat RP and/or ER stress comprising administering to a mammal, a rAAV particle comprising a rAAV vector comprising nucleic acid encoding miR-708. In some embodiments, the nucleic acid encoding miR-708 comprises the nucleic acid of SEQ ID NO:1. In some embodiments, the nucleic acid encoding miR-708 comprises a nucleic acid having about at least 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity to SEQ ID NO:1.

[0010] In some embodiments, the invention provides methods to treat RP and/or ER stress comprising administering to a mammal, a rAAV particle comprising a rAAV vector comprising nucleic acid encoding rhodopsin. In some embodiments, the rhodopsin is mammalian rhodopsin or functional equivalent thereof. In some embodiments, the rhodopsin is human rhodopsin or functional equivalent thereof. In some embodiments, the rhodopsin lacks the 3' untranslated region (UTR) miR-708 target sequence. In some embodiments, the nucleic acid encoding rhodopsin comprises a substitution, insertion or deletion of nucleic acid in the miR-708 target sequence. In some embodiments, the substitution, insertion or deletion reduces or prevents recognition by miR-708. In some embodiments, the nucleic acid encoding rhodopsin comprises a substitution, insertion or deletion of nucleic acid in the miR-708 target sequence wherein the miR-708 target sequence is SEQ ID NO:19. In some embodiments, expression of the rhodopsin is refractory to suppression by miR-708. In some embodiments, the rhodopsin comprises the amino acid sequence of SEQ ID NO:2. In some embodiments, the rhodopsin comprises an amino acid sequence having about at least t 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity to SEQ ID NO:2. In some embodiments, the nucleic acid encoding the rhodopsin comprises nucleic acid of SEQ ID NO:3. In some embodiments, the nucleic acid encoding the rhodopsin comprises a nucleic acid having about 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity to SEQ ID NO:3.

[0011] In some embodiments, the invention provides methods to treat RP and/or ER stress comprising administering to a mammal, a rAAV particle comprising a polynucleotide of SEQ ID NO:5., SEQ ID NO:6, SEQ ID NO:7, SEQ ID NO:8 or SEQ ID NO:9. In some embodiments, the AAV viral particle comprises a recombinant viral genome comprises a polynucleotide having about at least t 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity to SEQ ID NO:5, SEQ ID NO:6 SEQ ID NO:7, SEQ ID NO:8, SEQ ID NO:9, SEQ ID NO:24, SEQ ID NO:25, SEQ ID NO:26, or SEQ ID NO:27.

[0012] In some embodiments, the invention provides methods to treat RP and/or ER stress comprising administering to a mammal, a rAAV particle wherein the AAV viral particle comprises an AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV2/2-7m8, AAV DJ, AAV2 N587A, AAV2 E548A, AAV2 N708A, AAV V708K, a goat AAV, AAV1/AAV2 chimeric, bovine AAV, or mouse AAV capsid rAAV2/HBoV1 serotype capsid. In some embodiments, the rAAV viral particle comprises an AAV serotype 5 capsid. In some embodiments, the rAAV viral particle comprises an AAV serotype 5 tyrosine mutant capsid.

[0013] In some embodiments, the invention provides methods of treating RP and/or ER stress comprising administering to a mammal a first rAAV virus particle comprising nucleic acid encoding miR-708 and a second rAAV virus particle encoding rhodopsin. In some embodiments, the first rAAV particle and/or the second rAAV virus particle comprises an AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV2/2-7m8, AAV DJ, AAV2 N587A, AAV2 E548A, AAV2 N708A, AAV V708K, a goat AAV, AAV1/AAV2 chimeric, bovine AAV, or mouse AAV capsid rAAV2/HBoV1 serotype capsid. In some embodiments, the first rAAV viral particle and/or the second rAAV viral particle comprise an AAV serotype 5 capsid. In some embodiments, the first rAAV viral particle and/or the second rAAV viral particle comprise an AAV serotype 5 tyrosine mutant capsid.

[0014] In some embodiments, the invention provides methods to treat RP and/or ER stress comprising administering to a mammal, a rAAV particle wherein the AAV vector comprises an AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV DJ, a goat AAV, bovine AAV, or mouse AAV serotype ITR. In some embodiments, the invention provides methods of treating RP and/or ER stress comprising administering to a mammal a first rAAV virus particle comprising a first rAAV vector comprising nucleic acid encoding miR-708 and a second rAAV virus particle comprising a second rAAV vector encoding rhodopsin. In some embodiments, the first rAAV vector and/or the second rAAV virus vector comprises an AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV DJ, a goat AAV, bovine AAV, or mouse AAV serotype ITR.

[0015] In some embodiments of the invention, the rAAV vectors of the method comprise AAV serotype 2 ITRs. In some embodiments, the ITR and the capsid of the rAAV viral particle are derived from the same AAV serotype. In other embodiments, the ITR and the capsid of the rAAV viral particles are derived from different AAV serotypes. In some embodiments, the rAAV viral particle comprises an AAV-5 capsid, and wherein the vector comprises AAV2 ITRs. In some embodiments, the rAAV viral particle comprises an AAV-5 tyrosine mutant capsid, and wherein the vector comprises AAV2 ITRs.

[0016] In some embodiments, the invention provides methods to treat RP and/or ER stress in a mammal wherein the rAAV particles are injected into the subretinal space of the retina of the mammal. In some embodiments, the rAAV is administered to more than one location of the subretinal space of the retina of the mammal. In other embodiments, the rAAV particles are injected intravitreally to the mammal. In some embodiments, at least 10-30% of the photoreceptor cells (*e.g.*, rod photoreceptor cells) are transduced by the AAV.

[0017] In some embodiments, the invention provides methods to treat RP and/or ER stress in a mammal, wherein the mammal has a mutation in the endogenous rhodopsin gene. In some embodiments, the mutation in the endogenous rhodopsin gene is an autosomal dominant mutation. In some embodiments, the retinitis pigmentosa is autosomal dominant retinitis pigmentosa. In some embodiments, the mammal is a human. In some embodiments, the human has a P23H mutation in the endogenous rhodopsin gene.

[0018] In some embodiments, the invention provides methods of treating RP and/or ER stress comprising administering to a mammal a first rAAV virus particle comprising nucleic acid encoding miR-708 and a second rAAV virus particle encoding rhodopsin wherein the first rAAV viral particle encoding the miR-708 and the second rAAV viral particle encoding the rhodopsin are administered to the mammal at the same time. In some embodiments, the first rAAV viral particle encoding the miR-708 and the rAAV viral particle encoding the rhodopsin are administered to the mammal sequentially. In some embodiments, the rAAV viral particle encoding the miR-708 is administered to the mammal first and the rAAV viral particle encoding the rhodopsin is administered to the mammal second. In some embodiments, the rAAV viral particle encoding the rhodopsin is administered to the mammal first and the rAAV viral particle encoding the miR-708 is administered to the mammal second.

[0019] In some embodiments of the invention, the rAAV viral particles are in a pharmaceutical composition. In some embodiments, the pharmaceutical composition further comprises a pharmaceutically acceptable carrier. In some embodiments, the invention provides a composition comprising a rAAV particle comprising a rAAV vector comprising nucleic acid encoding miR-708 used in the methods described herein. In some embodiments, the invention provides a rAAV particle comprising a rAAV vector comprising nucleic acid encoding a miR708 for use in treating retitinis pigmentosa or reducing ER stress according to any of the methods described herein. In some embodiments, the invention provides a first rAAV particle comprising a rAAV vector comprising nucleic acid encoding a miR708 and a second rAAV particle comprising a rAAV vector comprising nucleic acid encoding rhodopsin for use in treating retitinis pigmentosa or reducing ER stress according to any of the methods described herein. In some embodiments, the rAAV particle comprises a rAAV vector comprising nucleic acid encoding a miR708 and rhodopsin for use in treating retitinis pigmentosa or reducing ER stress according to any one of the methods described herein.

[0020] In some aspects, the invention described herein provides compositions for treating retinitis pigmentosa in a mammal, comprising a recombinant adeno-associated virus (rAAV) viral particle comprising a vector encoding a miR-708. In some embodiments, the rAAV vector comprising nucleic acid encoding a miR-708 further comprises nucleic acid encoding rhodopsin. In some embodiments, the invention provides compositions for treating retinitis pigmentosa comprising a first rAAV viral particle comprising a first rAAV vector comprising nucleic acid encoding a miR-708 and a second rAAV viral particle comprising a second rAAV vector comprising nucleic acid encoding a rhodopsin. In other embodiments, the invention provides compositions for treating retinitis pigmentosa comprising a rAAV viral particle comprising a rAAV vector comprising nucleic acid encoding a miR-708 and rhodopsin.

[0021] In some aspects, the invention provides compositions for treating endoplasmic reticulum (ER) stress in a cell comprising a rAAV viral particle comprising a rAAV vector comprising nucleic acid encoding a miR-708. In some aspects, the invention provides compositions for treating endoplasmic reticulum (ER) stress in a cell comprising a rAAV viral particle comprising a rAAV vector comprising nucleic acid encoding a miR-708 and rhodopsin. In some embodiments, the mammal with ER stress has or is at risk of having

RP. In some embodiments, the mammal with ER stress is a human who has or is at risk of having RP. In some embodiments, the rAAV particle is administered to an eye of the mammal. In some embodiments, the cell is an ocular cell. In further embodiments, the cell is a photoreceptor cell. In yet further embodiments, the cell is a rod photoreceptor cell. In some embodiments, the composition reduces one or more cellular markers of ER stress. In further embodiments, the one or more cellular marker of ER stress is spliced XBP-1, CHOP or Grp78. In some embodiments, the rAAV vector comprises nucleic acid encoding a miR-708 further comprises nucleic acid encoding rhodopsin. In other embodiments, the invention provides compositions for treating endoplasmic reticulum (ER) stress in a cell comprising a first rAAV vector comprising nucleic acid encoding a miR-708 and a second rAAV viral particle comprising a second rAAV vector comprising nucleic acid encoding a rhodopsin.

[0022] In some embodiments of the invention, the nucleic acid encoding miR-708 is operably linked to a promoter. In some embodiments, the promoter is capable of expressing the miR-708 in photoreceptor cells (*e.g.*, rod photoreceptor cells). In further embodiments, the promoter comprises a rhodopsin kinase (RK) promoter or an opsin promoter. In other embodiments of the invention, the nucleic acid encoding rhodopsin is operably linked to a promoter. In some embodiments, the promoter is capable of expressing the rhodopsin in photoreceptor cells (*e.g.*, rod photoreceptor cells). In further embodiments, the promoter comprises a RK promoter or an opsin promoter.

[0023] In some embodiments, the invention provides compositions to treat RP and/or ER stress comprising a rAAV particle comprising a rAAV vector comprising nucleic acid encoding miR-708 and rhodopsin. In some embodiments, the nucleic acid encoding miR-708 and the nucleic acid encoding rhodopsin are operably linked to one RK promoter. In other embodiments, the nucleic acid encoding miR-708 is operably linked to a first RK promoter or a first opsin promoter and the nucleic acid encoding rhodopsin is operably linked to a second RK promoter or a second opsin promoter. In some embodiments, the first and/or second opsin promoter includes an MVM intron (*e.g.*, an intron of SEQ ID NO:23). In some embodiments, the nucleic acid encoding miR-708 is 5' to the nucleic acid encoding rhodopsin. In other embodiments, the nucleic acid encoding miR-708 is 3' to the nucleic acid encoding rhodopsin. In some embodiments, the nucleic acid encoding miR-708 is operably linked to the chicken β-actin (CBA) promoter. In some embodiments, the

nucleic acid encoding rhodopsin is operably linked to the chicken β-actin (CBA) promoter. In some embodiments, the first and/or second opsin promoter includes an MVM intron (*e.g.*, an intron of SEQ ID NO:23). In some embodiments, the nucleic acid encoding miR-708 is 5' to the nucleic acid encoding rhodopsin. In other embodiments, the nucleic acid encoding miR-708 is 3' to the nucleic acid encoding rhodopsin. In some embodiments, the nucleic acid encoding miR-708 is operably linked to the chicken β-actin (CBA) promoter. In some embodiments, the nucleic acid encoding rhodopsin is operably linked to the chicken β-actin (CBA) promoter. In some embodiments, a sequence derived from a minute virus of mouse (MVM) intron is located 3' to the promoter. In some embodiments, the MMV intron comprises the nucleotide sequence of SEQ ID NO:23. In some embodiments, the promoter further comprises i) a CMV enhancer; ii) a sequence derived from a photoreceptor specific transcription factor; iii)a sequence derived from a rod photoreceptor specific transcription factor; iv) a sequence derived from a neural retinal basic zipper factor; v) a sequence derived from a cone rod homeobox-containing transcription factor sequence; vi) a CMV enhancer and at least one or more of a sequence derived from a photoreceptor specific transcription factor, a sequence derived from a rod photoreceptor specific transcription factor, a sequence derived from a neural retinal basic zipper factor; a sequence derived from a cone rod homeobox-containing transcription factor sequence; vii) a neural retinal basic leucine zipper factor, a CMV enhancer and an Opsin promoter (-500 to +17); viii) a neural retinal basic leucine zipper factor, a CMV enhancer, an Opsin promoter (-500 to +17), and an MVM intron; ix) a CMV enhancer comprising SEQ ID NO:29; x) a neural retinal basic leucine zipper factor sequence comprising SEQ ID NO:30; xi) a sequence derived from a cone rod homeobox-containing transcription factor sequence comprising SEQ ID NO:28; xii) a CMV enhancer comprising SEQ ID NO:29 and at least one or more of a sequence derived from a photoreceptor specific transcription factor, a sequence derived from a rod photoreceptor specific transcription factor, a sequence derived from a neural retinal basic zipper factor comprising SEQ ID NO:30; a sequence derived from a cone rod homeobox-containing transcription factor sequence comprising SEQ ID NO:28; xiii) a neural retinal basic leucine zipper factor comprising SEQ ID NO:30, a CMV enhancer comprising SEQ ID NO:29 and an Opsin promoter (-500 to +17) comprising SEQ ID NO:22; or xiv) a neural retinal basic leucine zipper factor comprising SEQ ID NO:28, a CMV enhancer comprising SEQ ID NO:29, an Opsin promoter (-500 to +17) comprising SEQ ID NO:22, and an MVM intron comprising SEQ ID NO:23. In some embodiments,

the nucleic acid encoding miR-708 is embedded in an intron. In some embodiments, the nucleic acid encoding miR-708 comprises an endogenous miR-708 scaffold or a miR-155 scaffold.

[0024] In some embodiments, the invention provides compositions to treat RP and/or ER stress comprising a rAAV particle comprising a rAAV vector comprising nucleic acid encoding miR-708. In some embodiments, the nucleic acid encoding miR-708 comprises the nucleic acid of SEQ ID NO:1. In some embodiments, the nucleic acid encoding miR-708 comprises a nucleic acid having about at least 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity to SEQ ID NO:1.

[0025] In some embodiments, the invention provides compositions to treat RP and/or ER stress comprising a rAAV particle comprising a rAAV vector comprising nucleic acid encoding rhodopsin. In some embodiments, the rhodopsin is mammalian rhodopsin or functional equivalent thereof. In some embodiments, the rhodopsin is human rhodopsin or functional equivalent thereof. In some embodiments, the rhodopsin lacks the 3' untranslated region (UTR) miR-708 target sequence. In some embodiments, the nucleic acid encoding rhodopsin comprises a substitution, insertion or deletion of nucleic acid in the miR-708 target sequence. In some embodiments, the substitution, insertion or deletion reduces or prevents recognition by miR-708. In some embodiments, the nucleic acid encoding rhodopsin comprises a substitution, insertion or deletion of nucleic acid in the miR-708 target sequence wherein the miR-708 target sequence is SEQ ID NO:19. In some embodiments, expression of the rhodopsin is refractory to suppression by miR-708. In some embodiments, the rhodopsin comprises the amino acid sequence of SEQ ID NO:2. In some embodiments, the rhodopsin comprises an amino acid sequence having about at least 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity to SEQ ID NO:2. In some embodiments, the nucleic acid encoding the rhodopsin comprises nucleic acid of SEQ ID NO:3. In some embodiments, the nucleic acid encoding the rhodopsin comprises a nucleic acid having about 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity to SEQ ID NO:3.

[0026] In some embodiments, the invention provides compositions to treat RP and/or ER stress comprising a rAAV particle comprising a polynucleotide of SEQ ID NO:5, SEQ ID NO:6, SEQ ID NO:7, SEQ ID NO:8 or SEQ ID NO:9. In some embodiments, the AAV viral particle comprises a recombinant viral genome comprises a polynucleotide having

about at least t 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity to SEQ ID NO:5, SEQ ID NO:6, SEQ ID NO:7, SEQ ID NO:8 SEQ ID NO:9, SEQ ID NO:24, SEQ ID NO:25, SEQ ID NO:26, or SEQ ID NO:27.

[0027] In some embodiments, the invention provides compositions to treat RP and/or ER stress comprising a rAAV particle wherein the AAV viral particle comprises an AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV2/2-7m8, AAV DJ, AAV2 N587A, AAV2 E548A, AAV2 N708A, AAV V708K, a goat AAV, AAV1/AAV2 chimeric, bovine AAV, or mouse AAV capsid rAAV2/HBoV1 serotype capsid. In some embodiments, the rAAV viral particle comprises an AAV serotype 5 capsid. In some embodiments, the rAAV viral particle comprises an AAV serotype 5 tyrosine mutant capsid.

[0028] In some embodiments, the invention provides compositions for treating RP and/or ER stress comprising a first rAAV virus particle comprising nucleic acid encoding miR-708 and a second rAAV virus particle encoding rhodopsin. In some embodiments, the first rAAV particle and/or the second rAAV virus particle comprises an AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV2/2-7m8, AAV DJ, AAV2 N587A, AAV2 E548A, AAV2 N708A, AAV V708K, a goat AAV, AAV1/AAV2 chimeric, bovine AAV, or mouse AAV capsid rAAV2/HBoV1 serotype capsid. In some embodiments, the first rAAV viral particle and/or the second rAAV viral particle comprise an AAV serotype 5 capsid. In some embodiments, the first rAAV viral particle and/or the second rAAV viral particle comprise an AAV serotype 5 tyrosine mutant capsid.

[0029] In some embodiments, the invention provides compositions to treat RP and/or ER stress comprising a rAAV particle wherein the AAV vector comprises an AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV DJ, a goat AAV, bovine AAV, or mouse AAV serotype ITR. In some embodiments, the invention provides compositions for treating RP and/or ER stress comprising a first rAAV virus particle comprising a first rAAV vector comprising nucleic acid encoding miR-708 and a second rAAV virus particle comprising a second rAAV vector encoding rhodopsin. In some embodiments, the first rAAV vector and/or the second rAAV virus vector comprises an AAV1, AAV2, AAV3,

AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV DJ, a goat AAV, bovine AAV, or mouse AAV serotype ITR.

[0030] In some embodiments of the invention, the rAAV vectors of the composition comprise AAV serotype 2 ITRs. In some embodiments, the ITR and the capsid of the rAAV viral particle are derived from the same AAV serotype. In other embodiments, the ITR and the capsid of the rAAV viral particles are derived from different AAV serotypes. In some embodiments, the rAAV viral particle comprises an AAV-5 capsid, and wherein the vector comprises AAV2 ITRs. In some embodiments, the rAAV viral particle comprises an AAV-5 tyrosine mutant capsid, and wherein the vector comprises AAV2 ITRs.

[0031] In some embodiments, the invention provides compositions to treat RP and/or ER stress in a mammal, wherein the mammal has a mutation in the endogenous rhodopsin gene. In some embodiments, the mutation in the endogenous rhodopsin gene is an autosomal dominant mutation. In some embodiments, the retinitis pigmentosa is autosomal dominant retinitis pigmentosa. In some embodiments, the mammal is a human. In some embodiments, the human has a P23H mutation in the endogenous rhodopsin gene.

[0032] In some embodiments, the invention provides kits to treat RP or to reduce ER stress in a mammal comprising an effective amount of rAAV particles according to the methods described herein. In some embodiments, the kits comprise an effective amount of a composition as described herein. In some embodiments, the kit comprises an effective amount of rAAV particles comprising a rAAV vector comprising nucleic acid encoding miR-708. In some embodiments, the kit comprises an effective amount of rAAV particles comprising a rAAV vector comprising nucleic acid encoding miR-708 and rhodopsin. In some embodiments, the kit comprises an effective amount of first rAAV particles comprising a rAAV vector comprising nucleic acid encoding miR-708 and an effective amount of second rAAV particles comprising a second rAAV vector comprising nucleic acid encoding rhodopsin. In further embodiments, the kit comprising instructions for use of the rAAV particles in the treatment of retinitis pigmentosa and/or reduction of ER stress. In further embodiments, the kit comprising instructions for use in any one of the methods described herein.

[0033] In some aspects, the invention provides an article of manufacture comprising an effective amount of rAAV particles according to the methods described herein. In some embodiments, the article of manufacture comprises an effective amount of any of the compositions described herein. In some embodiments, the article of manufacture comprises an effective amount of rAAV particles comprising a rAAV vector comprising nucleic acid encoding miR-708. In some embodiments, the article of manufacture comprises an effective amount of rAAV particles comprising a rAAV vector comprising nucleic acid encoding miR-708 and rhodopsin. In some embodiments, the article of manufacture comprises an effective amount of first rAAV particles comprising a rAAV vector comprising nucleic acid encoding miR-708 and an effective amount of second rAAV particles comprising a second rAAV vector comprising nucleic acid encoding rhodopsin.

[0034] Is some aspects, the invention provides a nucleic acid comprising an intron derived from an MVM. In some embodiments, the MVM intron comprises SEQ ID NO:23. In some embodiments, the nucleic acid further comprises a promoter. In some embodiments, the nucleic acid further comprises an enhancer. In some embodiments, the promoter is located 5' to the MVM intron. In some embodiments, the invention provides an expression construct comprising the nucleic acid. In some embodiments, the invention provides a vector comprising the nucleic acid or the expression construct. In some embodiments, the invention provides a cell comprising the nucleic acid, the expression construct, or the vector.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] **FIGS. 1A & 1B** show the localization of wild-type (**FIG. 1A**) and P23H mutant (**FIG. 1B**) rhodopsin in human retinal pigmented epithelial cells. Cells are stained for rhodopsin (green), α-tubulin (red), and DNA (blue). The staining pattern of wild-type rhodopsin is characteristic of membrane localization (solid arrow), whereas the staining pattern of P23H mutant rhodopsin is characteristic of perinuclear/reticular localization (dashed arrow).

[0036] **FIGS. 2A & 2B** show that P23H mutant rhodopsin forms non-native oligomers and retains ER-specific oligosaccharides. (**FIG. 2A**) Western blot of detergent soluble extracts from cells expressing wild-type ("wt") or P23H mutant rhodopsin. (**FIG. 2B**)

Western blot of detergent soluble extracts from cells expressing wild-type ("wt") or P23H mutant rhodopsin. Extracts were treated with Endoglycosidase H ("Endo-H") or left untreated.

[0037] **FIGS. 3A & 3B** show that cells expressing P23H rhodopsin have higher expression of UPR markers and a higher propensity toward apoptosis. (**FIG. 3A**) Relative expression of C/EBP homologous protein (CHOP; a.k.a. *Ddit3*), binding immunoglobulin protein (BiP; a.k.a. *Hspa5*), and rhodopsin genes in cells expressing wild-type ("wt") or P23H mutant rhodopsin. The relative expression of each gene was compared to beta-glucoronidase expression using the $\Delta\Delta C_t$ method. (**FIG. 3B**) Percentage of apoptotic cells in cells expressing control (pcDNA), wild-type rhodopsin, or P23H mutant rhodopsin, as measured by TUNEL staining.

[0038] **FIG. 4** shows a diagram of the construction of an expression vector for expressing miR-708 under the control of a ubiquitous promoter (chicken β-actin, CBA) or a photoreceptor-specific promoter (rhodopsin kinase, RK). DNA encoding the miR-708 stem and loop sequences was synthesized and cloned between 5' and 3' miR-155 scaffold sequence. This scaffold sequence contains the target sites required for Drosha to process pri-miR-708 into pre-miR-708 in the nucleus, allowing subsequent processing of pre-miR-708 by Dicer in the cytoplasm.

[0039] **FIG. 5** shows the expression of rhodopsin protein in cells expressing miR-708 or a control miRNA, relative to untransfected cells. All cells are HEK-293 cells expressing mP23H rhodopsin which has a 3'UTR miR708 target sequence. Rhodopsin protein expression is normalized to hGAPDH expression. Rhodopsin protein levels are decreased in the presence of miR708 compared to control miR.

[0040] **FIG. 6** shows that HEK-293 cells expressing mP23H rhodopsin have reduced RNA levels of the UPR marker genes CHOP and BiP upon expression of miR-708, compared to cells expressing a control miRNA ("Scramble").

[0041] **FIGS. 7A & 7B** show that down-regulation of rhodopsin by endogenous miR-708 is dependent upon the presence of a miR-708 target sequence in the rhodopsin 3' UTR. HEK-293 cells were transfected with a mouse P23H rhodopsin gene including the miR-708 target sequence (**FIG. 7A**), or with a human P23H rhodopsin gene lacking the miR-708 target sequence (**FIG. 7B**). Cells were also transfected with a control pre-miRNA or an

anti-miR-708 pre-miRNA to inhibit endogenous miR-708. Rhodopsin protein was measured relative to hGAPDH protein, and rhodopsin mRNA was measured relative to hGAPDH mRNA. Levels of endogenous miR-708 are also shown (right axis and rightmost two columns in **FIGS. 7A & 7B**).

[0042] **FIG. 8** depicts a diagram of an AAV vector for expressing miR-708 in rod photoreceptors. Relevant vector features are labeled.

[0043] **FIGS. 9A & 9B** show that expression of miR-708 using an AAV vector down-regulates P23H mutant rhodopsin. (**FIG. 9A**) Expression of miR-708 in WERI or RPE cells upon transfection of a vector encoding miR-708 driven by the RK promoter or a control miRNA ("Scramble"). Expression is depicted relative to expression of miR-16. (**FIG. 9B**) Expression of P23H rhodopsin mRNA in WERI cells transfected with a pRK-miR-708 plasmid, relative to cells transfected with a control plasmid.

[0044] **FIGS. 10A-10C** show that subretinal delivery of an AAV5 miR-708 vector results in knockdown of mouse rhodopsin. (**FIG. 10A**) Expression of mRhodopsin in mouse retinas injected with AAV5 miR-708 or AAV5 miR-Control. (**FIG. 10B**) Expression of RdCVF in mouse retinas injected with AAV5 miR-708 or AAV5 miR-Control. (**FIG. 10C**) Expression of miR-708 in mouse retinas injected with AAV5 miR-708 or AAV5 miR-Control.

[0045] **FIGS. 11A & 11B** show that treatment of eyes with AAV5 miR-708 reduces rod-mediated, but not cone-mediated, responses. (**FIG. 11A**) Three representative electroretinograms representing scoptopic responses in eyes receiving AAV5 miR-708 or AAV5 miR-Control ("Scram"). (**FIG. 11B**) Three representative electroretinograms representing photopic responses in the same eyes as in (**FIG. 11A**) receiving AAV5 miR-708 or AAV5 miR-Control ("Scram").

[0046] **FIG. 12** provides a diagram of the miR-708 intron-embedded hRhodopsin suppression/replacement vector.

[0047] **FIG. 13** shows that an intron-embedded miR-708 vector reduces expression of mRhodopsin, hCHOP, and hBiP in WERI cells transfected with P23H mRhodopsin, as compared to a miR-Control vector.

[0048] **FIG. 14** shows that miR-708 expression from the intron-embedded vector has reduced expression compared to the non-embedded vector in WERI cells, the caveat being that the intron-embedded vector pRK-hRHO-intron miR-708 also co-expresses hRhodopsin. All vectors driving miR-708 expression using the RK promoter had orders of magnitude lower expression than a vector using the CBA promoter.

[0049] **FIG. 15** shows that hRhodopsin expression from the intron-embedded suppression/replacement vector is refractory to knockdown by co-expressed miR-708. The levels of hRhodopsin RNA are the same in cells transfected with vectors expressing miR-708 or miR-Control.

[0050] **FIG. 16** shows that the miR-708 suppression/replacement vector reduces XBP-1 splicing, a marker of ER stress, in WERI cells expressing mutant rhodopsin. This reduction is observed only if the 3'UTR miR-708 target sequence is present in the rhodopsin transcript.

[0051] **FIG. 17** shows a diagram of a vector with the miR-708 human β-globin intron scaffold in the 3' UTR of the rhodopsin cDNA.

[0052] **FIG. 18** shows that a vector with the miR-708 human β-globin intron scaffold in the 3' UTR of the rhodopsin cDNA produces higher hRhodopsin and miR-708 expression than a vector with the scaffold in the 5' UTR.

[0053] **FIG. 19** shows a diagram of an alternate vector design using separate promoters to drive expression of miR-708 (RK promoter) and hRhodopsin (mouse opsin promoter).

[0054] **FIG. 20** shows hRhodopsin (left) and miR-708 (right) expression in WERI cells transfected with the specified vector. Expression is expressed as copy number calculated against a DNA standard.

[0055] **FIGS. 21A-C** show the levels of miR-708 (**FIG. 21A**), mouse rhodopsin (**FIG. 21B**), and human rhodopsin (**FIG. 21C**) in mouse retinas three weeks after subretinal injection with an AAV5 capsid vector driving expression of human rhodopsin and miR-708 (miR 708/708), or human rhodopsin and control miRNA (miR-Cont), in a miR-708 scaffold using the opsin promoter. For each experiment, expression is shown as fold expression, as compared to the contralateral, uninjected eye.

[0056] **FIG. 22** shows a schematic of the opsin promoter construct, including the neural retinal basic zipper factor sequence (NRL), the CMV enhancer, the opsin promoter, and the MVM intron sequence, which includes a hybrid intron sequence from CBA exon 1 and an intron from the minute virus of mice (MVM).

[0057] **FIG. 23A** shows a schematic of the miR-708 sequence embedded in a beta-globin intron.

[0058] **FIGS. 23B & 23C** show schematics of the miR-708 sequence in the context of either the miR-708 endogenous scaffold (**FIG. 23B**) or the miR-155 scaffold (**FIG. 23C**), embedded in a beta globin intron. The miR-155 "loop sequence" between the 5' and 3' miR flanking sequences is labeled in **FIG. 23C**.

[0059] **FIG. 24** shows the evaluation of candidate vectors harboring the miR-708 sequence, either in the miR-155 or the miR-708 scaffold (embedded in the beta-globin intron), and the human rhodopsin coding sequence (hRhodopsin; also lacking a 3'UTR miR-708 target sequence) driven by either the rhodopsin kinase (GRK1) promoter or the opsin (Ops) promoter. All four combinations were tested for effects on miR-708 and hRhodopsin expression, as shown.

DETAILED DESCRIPTION

[0060] The present invention provides methods for treating retinitis pigmentosa (RP) in a mammal, comprising administering to the eye of the mammal a recombinant adeno-associated virus (rAAV) viral particle comprising a vector encoding a miR-708. The miR-708 targets a region in the 3' untranslated region of the rhodopsin gene and as such, may suppress activity of a mutant rhodopsin associated with RP. In some aspects, the invention provides methods for treating retinitis pigmentosa in a mammal, comprising administering to the eye of the mammal a recombinant adeno-associated virus (rAAV) viral particle comprising a vector encoding a miR-708 and a wild-type rhodopsin nucleic acid. As such, the vector may suppress the activity of a mutant rhodopsin associated with RP while concurrently replacing the mutant rhodopsin with a wild-type rhodopsin. In some embodiments, the nucleic acid encoding the wild-type rhodopsin does not include the 3' UTR target of miR-708 such that the miR-708 will only target expression of mutant rhodopsin. The invention also provides compositions comprising rAAV particles encoding

miR-708 and rAAV particles encoding rhodopsin. In some embodiments, the invention provides compositions comprising rAAV particles encoding both miR-708 and rhodopsin.

I. General Techniques

[0061] The techniques and procedures described or referenced herein are generally well understood and commonly employed using conventional methodology by those skilled in the art, such as, for example, the widely utilized methodologies described in *Molecular Cloning: A Laboratory Manual* (Sambrook *et al*., 4th ed., Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 2012); *Current Protocols in Molecular Biology* (F.M. Ausubel, *et al*. eds., 2003); the series *Methods in Enzymology* (Academic Press, Inc.); *PCR 2: A Practical Approach* (M.J. MacPherson, B.D. Hames and G.R. Taylor eds., 1995); *Antibodies, A Laboratory Manual (*Harlow and Lane, eds., 1988); *Culture of Animal Cells: A Manual of Basic Technique and Specialized Applications* (R.I. Freshney, 6th ed., J. Wiley and Sons, 2010); *Oligonucleotide Synthesis* (M.J. Gait, ed., 1984); *Methods in Molecular Biology*, Humana Press; *Cell Biology: A Laboratory Notebook* (J.E. Cellis, ed., Academic Press, 1998); *Introduction to Cell and Tissue Culture* (J.P. Mather and P.E. Roberts, Plenum Press, 1998); *Cell and Tissue Culture: Laboratory Procedures* (A. Doyle, J.B. Griffiths, and D.G. Newell, eds., J. Wiley and Sons, 1993-8); *Handbook of Experimental Immunology* (D.M. Weir and C.C. Blackwell, eds., 1996); *Gene Transfer Vectors for Mammalian Cells* (J.M. Miller and M.P. Calos, eds., 1987); *PCR: The Polymerase Chain Reaction*, (Mullis *et al*., eds., 1994); *Current Protocols in Immunology* (J.E. Coligan *et al*., eds., 1991); *Short Protocols in Molecular Biology* (Ausubel *et al*., eds., J. Wiley and Sons, 2002); *Immunobiology* (C.A. Janeway *et al*., 2004); *Antibodies* (P. Finch, 1997); *Antibodies: A Practical Approach* (D. Catty., ed., IRL Press, 1988-1989); *Monoclonal Antibodies: A Practical Approach* (P. Shepherd and C. Dean, eds., Oxford University Press, 2000); *Using Antibodies: A Laboratory Manual* (E. Harlow and D. Lane, Cold Spring Harbor Laboratory Press, 1999); *The Antibodies* (M. Zanetti and J. D. Capra, eds., Harwood Academic Publishers, 1995); and *Cancer: Principles and Practice of Oncology* (V.T. DeVita *et al*., eds., J.B. Lippincott Company, 2011).

II. Definitions

[0062] A "vector," as used herein, refers to a recombinant plasmid or virus that comprises a nucleic acid to be delivered into a host cell, either in vitro or in vivo.

[0063] The term "polynucleotide" or "nucleic acid" as used herein refers to a polymeric form of nucleotides of any length, either ribonucleotides or deoxyribonucleotides. Thus, this term includes, but is not limited to, single-, double- or multi-stranded DNA or RNA, genomic DNA, cDNA, DNA-RNA hybrids, or a polymer comprising purine and pyrimidine bases, or other natural, chemically or biochemically modified, non-natural, or derivatized nucleotide bases. The backbone of the polynucleotide can comprise sugars and phosphate groups (as may typically be found in RNA or DNA), or modified or substituted sugar or phosphate groups. Alternatively, the backbone of the polynucleotide can comprise a polymer of synthetic subunits such as phosphoramidates and thus can be an oligodeoxynucleoside phosphoramidate ($P\text{-}NH_2$) or a mixed phosphoramidate-phosphodiester oligomer. In addition, a double-stranded polynucleotide can be obtained from the single stranded polynucleotide product of chemical synthesis either by synthesizing the complementary strand and annealing the strands under appropriate conditions, or by synthesizing the complementary strand de novo using a DNA polymerase with an appropriate primer.

[0064] The terms "polypeptide" and "protein" are used interchangeably to refer to a polymer of amino acid residues, and are not limited to a minimum length. Such polymers of amino acid residues may contain natural or non-natural amino acid residues, and include, but are not limited to, peptides, oligopeptides, dimers, trimers, and multimers of amino acid residues. Both full-length proteins and fragments thereof are encompassed by the definition. The terms also include post-expression modifications of the polypeptide, for example, glycosylation, sialylation, acetylation, phosphorylation, and the like. Furthermore, for purposes of the present invention, a "polypeptide" refers to a protein which includes modifications, such as deletions, additions, and substitutions (generally conservative in nature), to the native sequence, as long as the protein maintains the desired activity. These modifications may be deliberate, as through site-directed mutagenesis, or may be accidental, such as through mutations of hosts which produce the proteins or errors due to PCR amplification.

[0065] A "recombinant viral vector" refers to a recombinant polynucleotide vector comprising one or more heterologous sequences (*i.e.*, nucleic acid sequence not of viral origin). In the case of recombinant AAV vectors, the recombinant nucleic acid is flanked by at least one, preferably two, inverted terminal repeat sequences (ITRs).

[0066] A "recombinant AAV vector (rAAV vector)" refers to a polynucleotide vector comprising one or more heterologous sequences (*i.e.*, nucleic acid sequence not of AAV origin) that are flanked by at least one, preferably two, AAV inverted terminal repeat sequences (ITRs). Such rAAV vectors can be replicated and packaged into infectious viral particles when present in a host cell that has been infected with a suitable helper virus (or that is expressing suitable helper functions) and that is expressing AAV rep and cap gene products (*i.e.* AAV Rep and Cap proteins). When a rAAV vector is incorporated into a larger polynucleotide (*e.g.*, in a chromosome or in another vector such as a plasmid used for cloning or transfection), then the rAAV vector may be referred to as a "pro-vector" which can be "rescued" by replication and encapsidation in the presence of AAV packaging functions and suitable helper functions. An rAAV vector can be in any of a number of forms, including, but not limited to, plasmids, linear artificial chromosomes, complexed with lipids, encapsulated within liposomes, and, most preferable, encapsidated in a viral particle, particularly an AAV particle. A rAAV vector can be packaged into an AAV virus capsid to generate a "recombinant adeno-associated viral particle (rAAV particle)".

[0067] "Heterologous" means derived from a genotypically distinct entity from that of the rest of the entity to which it is compared or into which it is introduced or incorporated. For example, a polynucleotide introduced by genetic engineering techniques into a different cell type is a heterologous polynucleotide (and, when expressed, can encode a heterologous polypeptide). Similarly, a cellular sequence (*e.g.*, a gene or portion thereof) that is incorporated into a viral vector is a heterologous nucleotide sequence with respect to the vector.

[0068] The term "transgene" refers to a polynucleotide that is introduced into a cell and is capable of being transcribed into RNA and optionally, translated and/or expressed under appropriate conditions. In aspects, it confers a desired property to a cell into which it was introduced, or otherwise leads to a desired therapeutic or diagnostic outcome. In another aspect, it may be transcribed into a molecule that mediates RNA interference, such as siRNA.

[0069] The terms "genome particles (gp)," "genome equivalents," or "genome copies" as used in reference to a viral titer, refer to the number of virions containing the recombinant AAV DNA genome, regardless of infectivity or functionality. The number of genome particles in a particular vector preparation can be measured by procedures such as described

in the Examples herein, or for example, in Clark *et al*. (1999) *Hum. Gene Ther*., 10:1031-1039; Veldwijk *et al*. (2002) *Mol. Ther*., 6:272-278.

[0070] The terms "infection unit (iu)," "infectious particle," or "replication unit," as used in reference to a viral titer, refer to the number of infectious and replication-competent recombinant AAV vector particles as measured by the infectious center assay, also known as replication center assay, as described, for example, in McLaughlin *et al*. (1988) *J. Virol*., 62:1963-1973.

[0071] The term "transducing unit (tu)" as used in reference to a viral titer, refers to the number of infectious recombinant AAV vector particles that result in the production of a functional transgene product as measured in functional assays such as described in Examples herein, or for example, in Xiao *et al*. (1997) *Exp. Neurobiol*., 144:113-124; or in Fisher *et al*. (1996) *J. Virol.*, 70:520-532 (LFU assay).

[0072] An "inverted terminal repeat" or "ITR" sequence is a term well understood in the art and refers to relatively short sequences found at the termini of viral genomes which are in opposite orientation.

[0073] An "AAV inverted terminal repeat (ITR)" sequence, a term well-understood in the art, is an approximately 145-nucleotide sequence that is present at both termini of the native single-stranded AAV genome. The outermost 125 nucleotides of the ITR can be present in either of two alternative orientations, leading to heterogeneity between different AAV genomes and between the two ends of a single AAV genome. The outermost 125 nucleotides also contains several shorter regions of self-complementarity (designated A, A', B, B', C, C' and D regions), allowing intrastrand base-pairing to occur within this portion of the ITR.

[0074] A "terminal resolution sequence" or "trs" is a sequence in the D region of the AAV ITR that is cleaved by AAV rep proteins during viral DNA replication. A mutant terminal resolution sequence is refractory to cleavage by AAV rep proteins.

[0075] A "helper virus" for AAV refers to a virus that allows AAV (which is a defective parvovirus) to be replicated and packaged by a host cell. A number of such helper viruses have been identified, including adenoviruses, herpesviruses and poxviruses such as vaccinia. The adenoviruses encompass a number of different subgroups, although

Adenovirus type 5 of subgroup C (Ad5) is most commonly used. Numerous adenoviruses of human, non-human mammalian and avian origin are known and are available from depositories such as the ATCC. Viruses of the herpes family, which are also available from depositories such as ATCC, include, for example, herpes simplex viruses (HSV), Epstein-Barr viruses (EBV), cytomegaloviruses (CMV) and pseudorabies viruses (PRV).

[0076] "Percent (%) sequence identity" with respect to a reference polypeptide or nucleic acid sequence is defined as the percentage of amino acid residues or nucleotides in a candidate sequence that are identical with the amino acid residues or nucleotides in the reference polypeptide or nucleic acid sequence, after aligning the sequences and introducing gaps, if necessary, to achieve the maximum percent sequence identity, and not considering any conservative substitutions as part of the sequence identity. Alignment for purposes of determining percent amino acid or nucleic acid sequence identity can be achieved in various ways that are within the skill in the art, for instance, using publicly available computer software programs, for example, those described in Current Protocols in Molecular Biology (Ausubel et al., eds., 1987), Supp. 30, section 7.7.18, Table 7.7.1, and including BLAST, BLAST-2, ALIGN or Megalign (DNASTAR) software. A preferred alignment program is ALIGN Plus (Scientific and Educational Software, Pennsylvania). Those skilled in the art can determine appropriate parameters for measuring alignment, including any algorithms needed to achieve maximal alignment over the full length of the sequences being compared. For purposes herein, the % amino acid sequence identity of a given amino acid sequence A to, with, or against a given amino acid sequence B (which can alternatively be phrased as a given amino acid sequence A that has or comprises a certain % amino acid sequence identity to, with, or against a given amino acid sequence B) is calculated as follows: 100 times the fraction X/Y, where X is the number of amino acid residues scored as identical matches by the sequence alignment program in that program's alignment of A and B, and where Y is the total number of amino acid residues in B. It will be appreciated that where the length of amino acid sequence A is not equal to the length of amino acid sequence B, the % amino acid sequence identity of A to B will not equal the % amino acid sequence identity of B to A. For purposes herein, the % nucleic acid sequence identity of a given nucleic acid sequence C to, with, or against a given nucleic acid sequence D (which can alternatively be phrased as a given nucleic acid sequence C that has or comprises a certain % nucleic acid sequence identity to, with, or against a given nucleic acid sequence D) is calculated as follows: 100 times the fraction W/Z, where W is the

number of nucleotides scored as identical matches by the sequence alignment program in that program's alignment of C and D, and where Z is the total number of nucleotides in D. It will be appreciated that where the length of nucleic acid sequence C is not equal to the length of nucleic acid sequence D, the % nucleic acid sequence identity of C to D will not equal the % nucleic acid sequence identity of D to C.

[0077] An "isolated" molecule (*e.g.*, nucleic acid or protein) or cell means it has been identified and separated and/or recovered from a component of its natural environment.

[0078] An "effective amount" is an amount sufficient to effect beneficial or desired results, including clinical results (e.g., amelioration of symptoms, achievement of clinical endpoints, and the like). An effective amount can be administered in one or more administrations. In terms of a disease state, an effective amount is an amount sufficient to ameliorate, stabilize, or delay development of a disease.

[0079] An "individual" or "subject" is a mammal. Mammals include, but are not limited to, domesticated animals (*e.g.*, cows, sheep, cats, dogs, and horses), primates (*e.g.*, humans and non-human primates such as monkeys), rabbits, and rodents (*e.g.*, mice and rats). In certain embodiments, the individual or subject is a human.

[0080] As used herein, "treatment" is an approach for obtaining beneficial or desired clinical results. For purposes of this invention, beneficial or desired clinical results include, but are not limited to, alleviation of symptoms, diminishment of extent of disease, stabilized (e.g., not worsening) state of disease, preventing spread (e.g., metastasis) of disease, delay or slowing of disease progression, amelioration or palliation of the disease state, and remission (whether partial or total), whether detectable or undetectable. "Treatment" can also mean prolonging survival as compared to expected survival if not receiving treatment.

[0081] "Retinitis pigmentosa (RP)" refers to a heterogeneous group of diseases characterized by progressive loss of sight. Symptoms generally stem from degeneration or abnormalities of the retina, which may include the loss of photoreceptor cell function.

[0082] "Rhodopsin" refers to a member of the G-protein-coupled receptor family that functions in light perception in the rod photoreceptor cells of the retina. A visual pigment, rhodopsin contains a polypeptide opsin reversibly bound to its cofactor retinal. Light causes isomerization of retinal from an 11-cis to an all-trans form. This in turn causes a

conformational change in the polypeptide that leads to G-protein activation. By converting the presence of light into a biochemical response, rhodopsin enables visual perception. Its function is required for scotopic vision (*i.e.,* noncolor vision in dim light), and it is also thought to be required for photoreceptor cell viability.

[0083] As used herein, "rhodopsin" may refer to the full visual pigment including retinal or simply the amino acid component or sequence of the molecule. Rhodopsin may also be known as OPN2, Opsin-2, or RP4. Examples of rhodopsin proteins may include without limitation human, mouse, dog, and cat rhodopsin, *e.g.,* NCBI Reference Sequences NP_000530, NP_663358, NP_001008277, and NP_001009242. Examples of rhodopsin genes may include without limitation human, mouse, dog, and cat rhodopsin genes, *e.g.,* GenBank Entrez Gene ID 6010 (*RHO,* a.k.a. *RP4, OPN2,* and *CSNBAD1*), GenBank Entrez Gene ID 212541 (*Rho,* a.k.a. *Ops, RP4, Opn2,* and *Noerg1*), GenBank Entrez Gene ID 493763, and GenBank Entrez Gene ID 493762. The term rhodopsin as used herein also includes functional equivalents of rhodopsin (*e.g.,* rhodopsin variants) including mutations, truncations, deletions, and/or insertions, provided that the functional equivalent maintains at least a portion of the activity of wild-type rhodopsin to ameliorate symptoms of retinitis pigmentosa.

[0084] As used herein "refractory" refers to resistance to modulation. For example, a rhodopsin gene that is refractory to suppression by miR-708 is substantially or totally resistant to suppression by miR-708.

[0085] "Opsin promoter" refers to a polynucleotide sequence derived from an opsin gene (*e.g.,* mouse opsin) that drives expression specifically in rod photoreceptor cells (*e.g.,* rod photoreceptor cells). As used herein, "opsin promoter" may refer to an entire promoter sequence or a fragment of the promoter sequence sufficient to drive rod-specific expression, such as the sequences described in Quiambao, A.B., *et al.* (1997) *Vis. Neurosci.* 14(4):617-25 and Le, Y.Z., *et al.* (2006) *Mol. Vis.* 12:389-98. In some embodiments, the opsin promoter contains a 676bp fragment encoding a 400bp CMV enhancer upstream of a portion of the opsin promoter sequence (-500bp - +15bp). In addition 65bp NRL sequence is included; this encodes a neural retinal basic zipper factor (a Rod photoreceptor specific transcription factor).

[0086] "Rhodopsin kinase (RK) promoter" refers to a polynucleotide sequence derived from a rhodopsin kinase gene (*e.g.,* human RK, represented by GenBank Entrez Gene ID 6011) that drives expression specifically in rod and cone photoreceptor cells, as well as retinal cell lines such as WERI Rb-1. As used herein, "rhodopsin kinase promoter" may refer to an entire promoter sequence or a fragment of the promoter sequence sufficient to drive photoreceptor-specific expression, such as the sequences described in Khani, S.C., *et al.* (2007) *Invest. Ophthalmol. Vis. Sci.* 48(9):3954-61 and Young, J.E., *et al.* (2003) *Invest. Ophthalmol. Vis. Sci.* 44(9):4076-85. In some embodiments, the RK promoter spans from -112 to +180 relative to the transcription start site.

[0087] "miR-708" refers to a micro-RNA (miRNA) polynucleotide sequence comprising the stem and loop sequences as shown in **FIG. 4**. Examples of miR-708 polynucleotides may include without limitation human, mouse, dog, and cat miR-708, *e.g.,* as represented by GenBank Entrez Gene IDs 100126333, 735284, and 100885899. miRNAs are small, non-coding RNA molecules that regulate the expression of genes (*e.g.,* by downregulation of the gene transcript) containing a target site recognized by the miRNA (Bartel, D.P. (2004) *Cell* 116(2):281-97). miR-708 is known to be induced by CHOP and may be involved in the regulating rhodopsin expression (Behrman, S., *et al.* (2011) *J. Cell Biol.* 192(6):919-27). As used herein, "miR-708" may refer to the processed miR-708 polynucleotide or any intermediate in the processing pathway, *e.g.,* pri-miRNA or pre-miRNA. As used herein, "miR-708" may refer to a DNA sequence that is transcribed to yield miR-708 RNA, or the RNA sequence itself.

[0088] Reference to "about" a value or parameter herein includes (and describes) embodiments that are directed to that value or parameter *per se*. For example, description referring to "about X" includes description of "X."

[0089] As used herein, the singular form of the articles "a," "an," and "the" includes plural references unless indicated otherwise.

[0090] It is understood that aspects and embodiments of the invention described herein include "comprising," "consisting," and/or "consisting essentially of" aspects and embodiments.

III. Retinitis pigmentosa and experimental models thereof

[0091] As described above, retinitis pigmentosa (RP) refers to a group of degenerative eye diseases that can cause progressive loss of sight, including loss of night vision, loss of peripheral visual fields, and total blindness. In America, the incidence of RP is thought to be approximately 1 in 4,000 people. RP is often inherited, and autosomal dominant, autosomal recessive, and X-linked RP disorders have been described. Mutations in more than 50 different genes have been associated with RP, including components involved in the phototransduction cascade, the retinal cycle, and splicing factors, as well as over 100 distinct mutations in rhodopsin itself. In many cases, mutations associated with RP lead to loss of rod photoreceptor function and/or cell death. This loss results in decreased scotopic vision and may manifest as night blindness or decreased peripheral vision. Rod cell death has also been associated with subsequent cone cell death, causing loss of high acuity vision and, combined with rod cell death, blindness.

[0092] A variety of cell- and animal-based models have been established for examining the cellular basis of RP and for testing experimental treatments. One cell-based model for RP is cultured human retinal pigmented epithelial (RPE) cells (Adamowicz, M., *et al.* (2012) *Adv. Exp. Med. Biol.* 723:573-9). This model may be used to express mutant proteins implicated in RP and test the effect of these mutations on protein function, or the effect of mutant proteins on cellular function and/or viability. For example, human wild-type and mutant rhodopsin may be expressed, using any appropriate promoter (*e.g.*, CMV). Without wishing to be bound to theory, it is thought that misfolding of opsin polypeptides results in ER retention and stress, induction of the unfolded protein response (UPR), and increased cell death. This model may be used to examine the effect of any RP-associated mutation, for example a rhodopsin mutation such as P23H.

[0093] Animal-based RP models may include mice harboring mutations known or suspected to cause RP in mice, or mutations orthologous to those found in humans. In some embodiments, mouse models may include mice engineered to express a rhodopsin, for example a mutated human or mouse form, in photoreceptor cells. Examples of mouse models include the rhodopsin P347S mouse (Li, T., *et al.* (1996) *Proc. Natl. Acad. Sci.* 93(24):14176-81), the *Rho*$^{-/-}$ mouse (Humphries, M.M., *et al.* (1997) *Nat. Genet.* 15(2):216-9), and a mouse expressing P23H mutant rhodopsin ("P23H mouse") (Olsson, J.E., *et al.* (1992) *Neuron* 9(5):815-30). In the P23H mouse, mutant human rhodopsin may be inserted into the mouse germline. Any promoter known in the art to express in photoreceptor cells

may be used (*e.g.*, the mouse opsin or human RK promoter). In some embodiments, rhodopsin may be expressed using an AAV vector.

[0094] Other animal models for RP may also be used. In addition to mouse models, rat, dog, pig, frog (Tam, B.M. and Moritz, O.L. (2006) *Invest. Ophthalmol. Vis. Sci.* 47(8):3234-41), and non-human primate models may also be used.

IV. Methods to treat retinitis pigmentosa

[0095] In some aspects, the invention provides methods and compositions for treating retinitis pigmentosa in a mammal comprising administering to the mammal (*e.g.*, to the retina) an effective amount of rAAV viral particles comprising a vector encoding a miR-708. The methods can be used for treating a human with RP, to improve the pathologies and vision impairment associated with RP. In some embodiments, the invention includes administering an effective amount of rAAV viral particles comprising a vector comprising nucleic acid encoding rhodopsin (*e.g.*, a normal or wild-type rhodopsin). In some embodiments, the miR-708 serves to suppress activity of a mutated rhodopsin associated with RP. In some embodiments, the normal or wild-type rhodopsin serves to supplement the eye with a functional rhodopsin. In some embodiments, the viral particle comprises an AAV serotype 5 capsid (AAV5 capsid) and either AAV 2 or AAV 5 inverted terminal repeats. In some embodiments, the viral particle comprises an AAV serotype 5 tyrosine mutant capsid and either AAV 2 or AAV 5 inverted terminal repeats.

[0096] In some aspects, the invention provides methods and compositions for ameliorating a symptom of RP, comprising administration to the eye of a mammal an effective amount of rAAV viral particles comprising a vector encoding a miR-708. In other aspects, the invention provides methods and compositions for ameliorating a symptom of RP, comprising administration to the eye of a mammal an effective amount of rAAV viral particles comprising a vector encoding a miR-708 and a rhodopsin. In some embodiments the symptoms of RP include, but is not limited to, blindness, night blindness, decreased peripheral vision, and loss of high acuity vision. In some embodiments, treating retinitis pigmentosa comprises reducing or preventing symptoms associated with the retinitis pigmentosa including but not limited to methods of preventing retinal degeneration, methods for arresting progression of RP, methods for increasing photoreceptor function, and the like. Symptoms and/or pathology of RP include but are not limited to loss of sight,

loss of night vision, loss of peripheral visual fields, loss of ERG function; loss of visual acuity and contrast sensitivity; loss of visually guided behavior, reduction in rod photoreceptor function, rod photoreceptor cell death, decreased scotopic vision, reduction in retinal cell changes (loss of photoreceptor structure or function; thinning or thickening of the outer nuclear layer (ONL); thinning or thickening of the outer plexiform layer (OPL); disorganization followed by loss of rod and cone outer segments; shortening of the rod and cone inner segments; retraction of bipolar cell dendrites; thinning or thickening of the inner retinal layers including inner nuclear layer, inner plexiform layer, ganglion cell layer and nerve fiber layer; opsin mislocalization; overexpression of neurofilaments; and the like. In some embodiments, the invention provides methods to prevent deterioration of rod cell function and rod cell death and cone cell function and cone cell death.

[0097] In some aspects, the invention provides methods to prevent or delay progression of RP. Autosomal dominant RP is a genetic disease that can be genotyped. Onset and progression of RP may be determined by Optical Coherence Tomography (OCT) which allows examination of outer plexiform layer (OPL) abnormalities.

[0098] Means for determining amelioration of the symptoms of RP are known in the art. For example, measurement of visual fields (e.g., Goldmann visual fields), determination of electroretinogram (ERG), fundus photographs, optical coherence tomography, and fluorescein angiography. Improvements in visually-evoked behavior can also be used to determine amelioration of the symptoms of RP; for example, statements such as "I can find things that drop," "I can see faces during a candle-lit dinner," "I can see stripes on my shirt," "I can see stars at night," "I can read regular books and sit in the front of the classroom," "now I can play soccer and don't need someone next to me to help me find the ball," "I can ride my bicycle around my neighborhood by myself," "I achieved my dream: I saw my daughter hit a homerun," and "when can I have my other eye injected?"

[0099] In some aspects of the invention, the methods and compositions are used for the treatment of humans with RP. RP can be inherited in an autosomal dominant, autosomal recessive, or X-linked manner. X-linked RP can be either recessive, affecting primarily only males, or dominant, affecting both males and females. RP may be caused by mutations in the rho gene that encodes the rhodopsin protein. In some embodiments of the invention, the methods are used to treat humans with a mutation in the rho gene and/or in the rhodopsin protein. In some embodiments of the invention, the mutation in the

rhodopsin protein is a P23H mutation (substitution of histidine for proline at amino acid residue 23 of the rhodopsin protein). In other embodiments, the mutation in the rhodopsin protein is a T58R, P347L, or P347S, or a deletion of residue I255. Mutations associated with retinitis pigmentosa are provided by McWilliam, P, *et al*., (1989) *Genomics* 5:619–622; Dryja, TP *et al*., (1990) *Nature* 343:364–266; Farrar, GJ *et al.*, (1990) *Genomics* 8:35–40; Farrar, GJ *et al*., (2002) *EMBO J*. 21:857–864; all incorporated herein by reference.

[0100] miR-708 is a CHOP regulated micro RNA that regulated rhodopsin expression (Behrman, S., *et al.* (2011) *J. Cell Biol.* 192(6):919-27). miR-708 is an intronic micro RNA residing within the CHOP inducible gene Odz4 (*Tenurin-4*). CHOP regulates miR-708 expression during ER stress. There is a putative miR-708 sequence in the 3' UTR of the rhodopsin gene that is highly conserved (see Figure 4 of Behrman *et al.*, *ibid*)

[0101] In some embodiments, the invention provides methods for treating a human with RP. In some embodiments, the invention provides methods for treating a human with autosomal dominant RP. In some embodiments, the invention provides methods for treating a human with RP associated with a mutation in the rhodopsin gene. In some embodiments, the invention provides a method for treating a human with RP by administering an effective amount of an AAV vector encoding miR-708 to suppress the activity of a mutated rhodopsin. In some embodiments, the invention provides methods for treating a mammal (*e.g*., a dog or a cat) with RP. In some embodiments, the miR-708 nucleic acid may include without limitation nucleic acid represented by GenBank Entrez Gene IDs 100126333, 735284, or 100885899.

[0102] In some embodiments of the invention, the suppression of a mutant rhodopsin is supplemented by the delivery of an effective amount of AAV vector encoding a wild-type rhodopsin or a rhodopsin with activity essentially the same as a wild-type rhodopsin. In some embodiments, the rhodopsin is a human rhodopsin. In some embodiments, the invention provides a method for treating a human with RP by administering an effective amount of an AAV vector encoding miR-708 to suppress the activity of a mutated rhodopsin and an effective amount of an AAV vector encoding a human rhodopsin with wild-type activity. In some embodiments, the AAV vector encoding miR-708 and the AAV vector encoding the human rhodopsin are the same AAV vector. In some embodiments, the AAV vector encoding miR-708 and the AAV vector encoding the human rhodopsin are the different AAV vectors. In some embodiments, nucleic acid encoding rhodopsin may include without

limitation nucleic acid provided by identified by NCBI Reference Sequences NP_000530, NP_663358, NP_001008277, and NP_001009242.

[0103] In some aspects, the invention provides methods for treating endoplasmic reticulum (ER) stress in a cell comprising administering to the mammal a rAAV viral particle comprising a rAAV vector comprising nucleic acid encoding a miR-708. In some embodiments, the cell is an ocular cell. In further embodiments, the cell is a photoreceptor cell. In yet further embodiments, the cell is a rod photoreceptor cell. In some embodiments, the method comprises reducing one or more cellular markers of ER stress. In further embodiments, the one or more cellular marker of ER stress is spliced XBP-1, CHOP or Grp78. In some embodiments, the rAAV vector comprises nucleic acid encoding a miR-708 further comprises nucleic acid encoding rhodopsin. In other embodiments, the invention provides methods for treating endoplasmic reticulum (ER) stress in a cell comprising administering to the mammal a first rAAV vector comprising nucleic acid encoding a miR-708 and a second rAAV viral particle comprising a second rAAV vector comprising nucleic acid encoding a rhodopsin.

[0104] In some aspects, the invention provides methods to deliver miR-708 or miR-708 and rhodopsin to a mammal with RP, the method comprising administering to the retina of the mammal, an effective amount of rAAV viral particles comprising vector encoding the miR-708 and/or rhodopsin. The administration delivers the transgene product to the photoreceptor cells, where the miR-708 and/or rhodopsin mediates a beneficial effect on the photoreceptor cell and surrounding photoreceptor cells. In some embodiments, delivery of AAV viral particles to the retina is by injection of viral particles to the sub-retinal space of the retina. In some embodiments, the delivery of AAV particles to the retina is by intravitreal delivery provided the AAV particle is capable of penetrating to the back of the eye and transduces photoreceptor cells. In some embodiments, the AAV particles are administered in one or more locations in the sub-retinal space of the retina.

[0105] In some embodiments, the administration to the retina of an effective amount of rAAV viral particles comprising a vector encoding miR-708 and/or rhodopsin transduces photoreceptor cells at or near the site of administration. In some embodiments, more than about any of 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75% or 100% of photoreceptor cells are transduced. In some embodiments, about 5% to about 100%, about 10% to about 50%, about 10% to about 30%, about 25% to about 75%,

about 25% to about 50%, or about 30% to about 50% of the photoreceptor cells are transduced. Methods to identify photoreceptor cells transduced by AAV expressing miR-708 and/or rhodopsin are known in the art; for example, immunohistochemistry or the use of a marker such as enhanced green fluorescent protein can be used to detect expression of miR-708 and/or rhodopsin.

[0106] In some embodiments of the invention, the methods comprise administration to the retina (*e.g.*, the subretinal space) of a mammal an effective amount of AAV viral particles comprising a vector encoding a miR708 and/or rhodopsin for treating a mammal, *e.g.*, a human, with RP. In some embodiments, the composition is injected to one or more subretinal spaces to allow expression of miR-708 and/or rhodopsin in photoreceptor cells. In some embodiments, the composition is injected into any one of one, two, three, four, five, six, seven, eight, nine, ten or more than ten locations in the subretinal space of the retina.

[0107] In some embodiments the rAAV viral particles are administered to more than one location simultaneously or sequentially. In some embodiment, multiple injections of rAAV viral particles are no more than one hour, two hours, three hours, four hours, five hours, six hours, nine hours, twelve hours or 24 hours apart.

[0108] In some embodiments, first rAAV viral particles encoding miR-708 and second rAAV viral particles encoding rhodopsin are administered to one or more locations simultaneously or sequentially. In some embodiment, multiple injections of rAAV viral particles are no more than one hour, two hours, three hours, four hours, five hours, six hours, nine hours, twelve hours or 24 hours apart. In some embodiments the first rAAV viral particles encoding miR-708 are administered before the second rAAV viral particles encoding rhodopsin are administered. In some embodiments the first rAAV viral particles encoding miR-708 are administered after the second rAAV viral particles encoding rhodopsin are administered.

[0109] In some embodiments, the invention provides a method for treating a human with RP by administering an effective amount of a pharmaceutical composition comprising an AAV vector encoding miR-708 to suppress the activity of a mutated rhodopsin. In some embodiments, the invention provides a method for treating a human with RP by administering an effective amount of a pharmaceutical composition comprising an AAV vector encoding miR-708 to suppress the activity of a mutated rhodopsin and an effective

amount of a pharmaceutical composition comprising an AAV vector encoding rhodopsin to supplement photoreceptors with wild-type rhodopsin activity. In some embodiments, the pharmaceutical composition comprising an AAV vector encoding miR-708 and the pharmaceutical composition comprising an AAV vector encoding the human rhodopsin are the same pharmaceutical composition. In some embodiments, the pharmaceutical composition comprising an AAV vector encoding miR-708 and the pharmaceutical composition comprising an AAV vector encoding the human rhodopsin are the different pharmaceutical composition. In some embodiments, the pharmaceutical composition comprises one or more pharmaceutically acceptable excipients.

[0110] In some embodiments of the invention, the volume of the composition injected to the subretinal space of the retina or intravitreally is more than about any one of 1 µl, 2 µl, 3 µl, 4 µl, 5 µl, 6 µl, 7 µl, 8 µl, 9 µl, 10 µl, 15 µl, 20 µl, 25 µl, 50 µl, 75 µl, 100 µl, 200 µl, 300 µl, 400 µl, 500 µl, 600 µl, 700 µl, 800 µl, 900 µl, or 1 mL, or any amount therebetween.

[0111] Compositions of the invention (*e.g.*, AAV viral particles comprising a vector encoding miR-708 and/or rhodopsin) can be used either alone or in combination with one or more additional therapeutic agents for treating RP. The interval between sequential administration can be in terms of at least (or, alternatively, less than) minutes, hours, or days.

V. Expression Constructs

[0112] In some embodiments, the transgene (*e.g.*, miRNA 708 and/or rhodopsin) is operably linked to a promoter. Exemplary promoters include, but are not limited to, the cytomegalovirus (CMV) immediate early promoter, the RSV LTR, the MoMLV LTR, the phosphoglycerate kinase- 1 (PGK) promoter, a simian virus 40 (SV40) promoter and a CK6 promoter, a transthyretin promoter (TTR), a TK promoter, a tetracycline responsive promoter (TRE), an HBV promoter, an hAAT promoter, a LSP promoter, chimeric liver-specific promoters (LSPs), the E2F promoter, the telomerase (hTERT) promoter; the cytomegalovirus enhancer/chicken beta-actin/Rabbit β-globin promoter (CAG promoter; Niwa *et al*., *Gene*, 1991, 108(2):193-9) and the elongation factor 1-alpha promoter (EFl-alpha) promoter (Kim *et al*., *Gene*, 1990, 91(2):217-23 and Guo *et al*., *Gene Ther*., 1996, 3(9):802-10). In some embodiments, the promoter comprises a human β-glucuronidase

promoter or a cytomegalovirus enhancer linked to a chicken β-actin (CBA) promoter. The promoter can be a constitutive, inducible or repressible promoter. In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding miR-708 operably linked to a CBA promoter. In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding rhodopsin (*e.g.*, human rhodopsin) operably linked to a CBA promoter. In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding miR-708 and nucleic acid encoding rhodopsin (*e.g.*, human rhodopsin) operably linked to a CBA promoter.

[0113] In some embodiments, the promoter is capable of expressing the transgene in photoreceptor cells. In embodiments, the promoter is a rhodopsin kinase (RK) promoter; *e.g.*, a human RK promoter. In some embodiments, the promoter is an opsin promoter; *e.g.*, a human opsin promoter or a mouse opsin promoter.

[0114] In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding miR-708 operably linked to an RK promoter. In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding rhodopsin (*e.g.*, human rhodopsin) operably linked to an RK promoter. In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding miR-708 and rhodopsin (*e.g.*, human rhodopsin) operably linked to an RK promoter. In some embodiments, the nucleic acid encoding miR-708 is 5' to nucleic acid encoding rhodopsin. In other embodiments, the nucleic acid encoding miR-708 is 3' to nucleic acid encoding rhodopsin. In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding miR-708 operably linked to a first RK promoter and nucleic acid encoding rhodopsin operably linked to a second RK promoter. In some embodiments, the nucleic acid encoding miR-708 operably linked to a first RK promoter is 5' to nucleic acid encoding rhodopsin operably linked to a second RK promoter. In other embodiments, the nucleic acid encoding miR-708 operably linked to a first RK promoter is 3' to nucleic acid encoding rhodopsin operably linked to a second RK promoter. In some embodiments, the miR-708 comprises the sequence of SEQ ID NO:1. In some embodiments, the miR-708 comprises a nucleotide sequence that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to the sequence of SEQ ID NO:1. In some embodiments, the rhodopsin comprises the amino acid sequence of SEQ ID NO:2. In some embodiments, the rhodopsin comprises an amino acid sequence that is at least about 80%,

85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to the amino acid sequence of SEQ ID NO:2. In some embodiments, the rhodopsin is a functional equivalent of wild-type rhodopsin. In some embodiments, expression of rhodopsin from the AAV vector is refractory to suppression by miR-708. In some embodiments, nucleic acid encoding rhodopsin lacks the miR-708 target site in the 3' UTR of the rhodopsin gene. In some embodiments, nucleic acid encoding rhodopsin comprises a mutation (*e.g.*, a deletion, a substitution, an insertion, *etc.*) in the miR-708 target site in the 3' UTR of the rhodopsin gene such that it is refractory to suppression by miR-708.

[0115] In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding miR-708 operably linked to an opsin promoter. In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding rhodopsin (*e.g.*, human rhodopsin) operably linked to an opsin promoter. In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding miR-708 and nucleic acid encoding rhodopsin (*e.g.*, human rhodopsin) operably linked to an opsin promoter. In some embodiments, the nucleic acid encoding miR-708 is 5' to nucleic acid encoding rhodopsin. In other embodiments, the nucleic acid encoding miR-708 is 3' to nucleic acid encoding rhodopsin. In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding miR-708 operably linked to a first opsin promoter and nucleic acid encoding rhodopsin operably linked to a second opsin promoter. In some embodiments, the nucleic acid encoding miR-708 operably linked to a first opsin promoter is 5' to nucleic acid encoding rhodopsin operably linked to a second opsin promoter. In other embodiments, the nucleic acid encoding miR-708 operably linked to a first opsin promoter is 3' to nucleic acid encoding rhodopsin operably linked to a second opsin promoter. In some embodiments, the miR-708 comprises the sequence of SEQ ID NO:1. In some embodiments, the miR-708 comprises the sequence of SEQ ID NO:1. In some embodiments, the miR-708 comprises a nucleotide sequence that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to the sequence of SEQ ID NO:1. In some embodiments, the rhodopsin comprises the amino acid sequence of SEQ ID NO:2. In some embodiments, the rhodopsin comprises an amino acid sequence that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to the amino acid sequence of SEQ ID NO:2. In some embodiments, the rhodopsin is a functional equivalent of wild-type rhodopsin. In some embodiments, expression of rhodopsin from the AAV vector is refractory to suppression by miR-708. In

some embodiments, nucleic acid encoding rhodopsin lacks the miR-708 target site in the 3' UTR of the rhodopsin gene. In some embodiments, nucleic acid encoding rhodopsin comprises a mutation (*e.g.*, a deletion, a substitution, an insertion, *etc.*) in the miR-708 target site in the 3' UTR of the rhodopsin gene such that it is refractory to suppression by miR-708.

[0116] In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding miR-708 operably linked to an RK promoter and nucleic acid encoding rhodopsin operably linked to an opsin promoter. In some embodiments, the nucleic acid encoding miR-708 operably linked to the RK promoter is 5' to nucleic acid encoding rhodopsin operably linked to an opsin promoter. In some embodiments, the nucleic acid encoding miR-708 operably linked to the RK promoter is 3' to nucleic acid encoding rhodopsin operably linked to an opsin promoter. In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding miR-708 operably linked to an opsin promoter and nucleic acid encoding rhodopsin operably linked to an RK promoter. In some embodiments, the nucleic acid encoding miR-708 operably linked to the opsin promoter is 5' to nucleic acid encoding rhodopsin operably linked to an RK promoter. In some embodiments, the nucleic acid encoding miR-708 operably linked to the opsin promoter is 3' to nucleic acid encoding rhodopsin operably linked to an RK promoter. In some embodiments, the miR-708 comprises the sequence of SEQ ID NO:1. In some embodiments, the miR-708 comprises the sequence of SEQ ID NO:1. In some embodiments, the miR-708 comprises a nucleotide sequence that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to the sequence of SEQ ID NO:1. In some embodiments, the rhodopsin comprises the amino acid sequence of SEQ ID NO:2. In some embodiments, the rhodopsin comprises an amino acid sequence that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to the amino acid sequence of SEQ ID NO:2. In some embodiments, the rhodopsin is a functional equivalent of wild-type rhodopsin. In some embodiments, expression of rhodopsin from the AAV vector is refractory to suppression by miR-708. In some embodiments, nucleic acid encoding rhodopsin lacks the miR-708 target site in the 3' UTR of the rhodopsin gene. In some embodiments, nucleic acid encoding rhodopsin comprises a mutation (*e.g.*, a deletion, a substitution, an insertion, *etc.*) in the miR-708 target site in the 3' UTR of the rhodopsin gene such that it is refractory to suppression by miR-708.

[0117] In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding miR-708 operably linked to a CBA promoter and nucleic acid encoding rhodopsin operably linked to an RK promoter. In some embodiments, the nucleic acid encoding miR-708 operably linked to the CBA promoter is 5' to nucleic acid encoding rhodopsin operably linked to an RK promoter. In some embodiments, the nucleic acid encoding miR-708 operably linked to the CBA promoter is 3' to nucleic acid encoding rhodopsin operably linked to an RK promoter. In some embodiments, the invention provides an AAV vector comprising nucleic acid encoding miR-708 operably linked to an RK promoter and nucleic acid encoding rhodopsin operably linked to a CBA promoter. In some embodiments, the nucleic acid encoding miR-708 operably linked to the RK promoter is 5' to nucleic acid encoding rhodopsin operably linked to a CBA promoter. In some embodiments, the nucleic acid encoding miR-708 operably linked to the RK promoter is 3' to nucleic acid encoding rhodopsin operably linked to a CBA promoter. In some embodiments, the miR-708 comprises the sequence of SEQ ID NO:1. In some embodiments, the miR-708 comprises the sequence of SEQ ID NO:1. In some embodiments, the miR-708 comprises a nucleotide sequence that is at least about 80%, 85%, 90%, or 95% identical to the sequence of SEQ ID NO:1. In some embodiments, the rhodopsin comprises the amino acid sequence of SEQ ID NO:2. In some embodiments, the rhodopsin comprises an amino acid sequence that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98% identical to the amino acid sequence of SEQ ID NO:2. In some embodiments, the rhodopsin is a functional equivalent of wild-type rhodopsin. In some embodiments, expression of rhodopsin from the AAV vector is refractory to suppression by miR-708. In some embodiments, nucleic acid encoding rhodopsin lacks the miR-708 target site in the 3' UTR of the rhodopsin gene. In some embodiments, nucleic acid encoding rhodopsin comprises a mutation (*e.g.*, a deletion, a substitution, an insertion, *etc.*) in the miR-708 target site in the 3' UTR of the rhodopsin gene such that it is refractory to suppression by miR-708.

[0118] In some embodiments, nucleic acid encoding miR-708 comprises an endogenous miR-708 scaffold. In some embodiments, the miR-708 scaffold is provided by SEQ ID NO:14. In some embodiments, nucleic acid encoding miR-708 comprises a heterologous miRNA scaffold. In some embodiments, use of a heterologous miRNA scaffold is used to modulate miRNA expression; for example, to increase miRNA expression or to decrease miRNA expression. In some embodiments, nucleic acid encoding miR-708 comprises an

endogenous miR-155 scaffold. In some embodiments, the miR-155 scaffold is provided by SEQ ID NO:14.

Recombinant viral vector

[0119] The present invention contemplates the use of a recombinant viral genome for introduction of one or more nucleic acid sequences encoding for a miR-708 miRNA and/or a rhodopsin protein described herein for packaging into an AAV viral particle. The recombinant viral genome may include any element to establish the expression of a miR-708 miRNA and/or a rhodopsin protein, for example, a promoter, a miR-708 miRNA and/or a rhodopsin transgene, an ITR, a ribosome binding element, terminator, enhancer, selection marker, intron, polyA signal, and/or origin of replication.

VI. Viral particles and methods of producing viral particles

rAAV viral particles

[0120] The invention provides methods of using rAAV particles to treat retinitis pigmentosa and provides compositions comprising rAAV particles. In some embodiments, the viral particle is a recombinant AAV particle comprising a nucleic acid comprising a sequence encoding miR-708 miRNA and/or a rhodopsin protein described herein flanked by one or two ITRs. The nucleic acid is encapsidated in the AAV particle. The AAV particle also comprises capsid proteins. In some embodiments, the nucleic acid comprises the coding sequence(s) of interest (*e.g.*, nucleic acid encoding miR-708 miRNA and/or a rhodopsin protein) operatively linked components in the direction of transcription, control sequences including transcription initiation and termination sequences, thereby forming an expression cassette. In some embodiments, nucleic acid encoding the miR-708 is embedded in an intron. The expression cassette is flanked on the 5' and 3' end by at least one functional AAV ITR sequences. By "functional AAV ITR sequences" it is meant that the ITR sequences function as intended for the rescue, replication and packaging of the AAV virion. See Davidson *et al*., *PNAS*, 2000, 97(7)3428-32; Passini *et al*., *J. Virol*., 2003, 77(12):7034-40; and Pechan *et al*., *Gene Ther*., 2009, 16:10-16, all of which are incorporated herein in their entirety by reference. For practicing some aspects of the invention, the recombinant vectors comprise at least all of the sequences of AAV essential for encapsidation and the physical structures for infection by the rAAV. AAV ITRs for use in the vectors of the invention need not have a wild-type nucleotide sequence (*e.g.*, as

described in Kotin, *Hum. Gene Ther*., 1994, 5:793-801), and may be altered by the insertion, deletion or substitution of nucleotides or the AAV ITRs may be derived from any of several AAV serotypes. More than 40 serotypes of AAV are currently known, and new serotypes and variants of existing serotypes continue to be identified. See Gao *et al*., *PNAS*, 2002, 99(18): 11854-6; Gao *et al*., *PNAS*, 2003, 100(10):6081-6; and Bossis *et al*., *J. Virol*., 2003, 77(12):6799-810. Use of any AAV serotype is considered within the scope of the present invention. In some embodiments, a rAAV vector is a vector derived from an AAV serotype, including without limitation, AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV DJ, a goat AAV, bovine AAV, or mouse AAV capsid serotype ITRs or the like. In some embodiments, the nucleic acid in the AAV comprises an ITR of AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV DJ, a goat AAV, bovine AAV, or mouse AAV capsid serotype ITRs or the like. In some embodiments, the nucleic acid in the AAV further encodes miR-708, rhodopsin, or miR-708 and rhodopsin as described herein. For example, the nucleic acid in the AAV can comprise at least one ITR of any AAV serotype contemplated herein and can further encode a miR-708 comprising the nucleic acid of SEQ ID NO:1 and/or nucleic acid encoding a human rhodopsin comprising the amino acid sequence of SEQ ID NO:2. In some embodiments, the nucleic acid in the AAV comprises 5' to 3' nucleic acid encoding the following: an AAV ITR, a stuffer fragment (*e.g*., SEQ ID NO:11), a chimeric intron (*e.g*., SEQ ID NO:10), a miR-708, a bovine growth hormone polyadenylation sequence, a stuffer fragment, and an AAV ITR. In some embodiments, the nucleic acid in the AAV comprises 5' to 3' nucleic acid encoding the following: an AAV ITR, an RK promoter, a β globin intron, a miR-708 imbedded in the β globin intron, a human rhodopsin, a bovine growth hormone polyadenylation sequence, and an AAV ITR. In some embodiments, the nucleic acid in the AAV comprises 5' to 3' nucleic acid encoding the following: an AAV ITR, a stuffer fragment (*e.g*., SEQ ID NO:11), an RK promoter, a chimeric intron (*e.g*., SEQ ID NO:10), a human rhodopsin, a β-globin intron, a miR-708 embedded in a β-globin intron, a bovine growth hormone polyadenylation sequence, a stuffer fragment, and an AAV ITR. In some embodiments, the nucleic acid in the AAV comprises 5' to 3' nucleic acid encoding the following: an AAV ITR, a stuffer fragment (*e.g*., SEQ ID NO:11), an RK promoter, a chimeric intron (*e.g*., SEQ ID NO:10), a miR-708, a mouse opsin promoter, a human rhodopsin, a bovine growth

hormone polyadenylation sequence, and an AAV ITR. In some embodiments, the nucleic acid in the AAV comprises the nucleic acid of SEQ ID NO:5. In some embodiments, the nucleic acid in the AAV comprises a nucleic acid that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to SEQ ID NO:5. In some embodiments, the nucleic acid in the AAV the nucleic acid of SEQ ID NO:6. In some embodiments, the nucleic acid in the AAV comprises a nucleic acid that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to SEQ ID NO:6. In some embodiments, the nucleic acid in the AAV comprises the nucleic acid of SEQ ID NO:7. In some embodiments, the nucleic acid in the AAV comprises a nucleic acid that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to SEQ ID NO:7. In some embodiments, the nucleic acid in the AAV comprises the nucleic acid of SEQ ID NO:8. In some embodiments, the nucleic acid in the AAV comprises a nucleic acid that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to SEQ ID NO:8. In some embodiments, the nucleic acid in the AAV comprises the nucleic acid of SEQ ID NO:9. In some embodiments, the nucleic acid in the AAV comprises a nucleic acid that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to SEQ ID NO:9. In some embodiments, the nucleic acid in the AAV comprises the nucleic acid of SEQ ID NO:24. In some embodiments, the nucleic acid in the AAV comprises a nucleic acid that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to SEQ ID NO:24. In some embodiments, the nucleic acid in the AAV comprises the nucleic acid of SEQ ID NO:25. In some embodiments, the nucleic acid in the AAV comprises a nucleic acid that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to SEQ ID NO:25. In some embodiments, the nucleic acid in the AAV comprises the nucleic acid of SEQ ID NO:26. In some embodiments, the nucleic acid in the AAV comprises a nucleic acid that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to SEQ ID NO:26. In some embodiments, the nucleic acid in the AAV comprises the nucleic acid of SEQ ID NO:27. In some embodiments, the nucleic acid in the AAV comprises a nucleic acid that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to SEQ ID NO:27. In further embodiments, the rAAV particle comprises capsid proteins of AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV2/2-7m8,

AAV DJ, AAV2 N587A, AAV2 E548A, AAV2 N708A, AAV V708K, a goat AAV, AAV1/AAV2 chimeric, bovine AAV, mouse AAV capsid rAAV2/HBoV1 serotype capsid, or mutants of these capsid proteins. In some embodiments, a mutant capsid protein maintains the ability to form an AAV capsid. In some embodiments, the rAAV particle comprises AAV5 tyrosine mutant capsid (Zhong L. *et al.*, (2008) *Proc Natl Acad Sci U S A* 105(22):7827-7832. In further embodiments, the rAAV particle comprises capsid proteins of an AAV serotype from Clades A-F (Gao, *et al., J. Virol*. 2004, 78(12):6381). In some embodiments, the nucleic acid in the AAV comprises the nucleic acid sequence selected from the group consisting of SEQ ID NOs:5-8, and is flanked by at least one AAV2 ITR. In some embodiments, the nucleic acid in the AAV comprises the nucleic acid sequence that is at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to the nucleic acid selected from the group consisting of SEQ ID NOs:5-9, and is flanked by at least one AAV2 ITR.

[0121] Different AAV serotypes are used to optimize transduction of particular target cells or to target specific cell types within a particular target tissue (*e.g.*, a diseased tissue). A rAAV particle can comprise viral proteins and viral nucleic acids of the same serotype or a mixed serotype. For example, in some embodiments a rAAV particle can comprise AAV5 capsid proteins and at least one AAV2 ITR or it can comprise AAV2 capsid proteins and at least one AAV5 ITR. In other embodiments a rAAV particle can comprise AAV5 tyrosine mutant capsid proteins and at least one AAV2 ITR. In yet another example, a rAAV particle can comprise capsid proteins from both AAV5 and AAV2, and further comprise at least one AAV2 ITR. Any combination of AAV serotypes for production of a rAAV particle is provided herein as if each combination had been expressly stated herein. In some embodiments, the invention provides rAAV particles comprising AAV5 capsid proteins and a nucleic acid encoding miR-708 RNA and/or a rhodopsin transgene, flanked by at least one AAV2 ITR.

Self-complementary AAV viral genomes

[0122] In some aspects, the invention provides viral particles comprising a recombinant self-complementing genome. AAV viral particles with self-complementing genomes and methods of use of self-complementing AAV genomes are described in US Patent Nos. 6,596,535; 7,125,717; 7,765,583; 7,785,888; 7,790,154; 7,846,729; 8,093,054; and 8,361,457; and Wang Z., *et al*., (2003) *Gene Ther* 10:2105-2111, each of which are

incorporated herein by reference in its entirety. A rAAV comprising a self-complementing genome will quickly form a double stranded DNA molecule by virtue of its partially complementing sequences (*e.g.*, complementing coding and non-coding strands of a transgene). In some embodiments, the invention provides an AAV viral particle comprising an AAV genome, wherein the rAAV genome comprises a first heterologous polynucleotide sequence (*e.g.*, miR-708 and/or a rhodopsin coding strand) and a second heterologous polynucleotide sequence (*e.g.*, antisense strand of miR-708 and/or a rhodopsin noncoding or antisense strand) wherein the first heterologous polynucleotide sequence can form intrastrand base pairs with the second polynucleotide sequence along most or all of its length. In some embodiments, the first heterologous polynucleotide sequence and a second heterologous polynucleotide sequence are linked by a sequence that facilitates intrastrand basepairing; *e.g.*, a hairpin DNA structure. Hairpin structures are known in the art, for example in siRNA molecules. In some embodiments, the first heterologous polynucleotide sequence and a second heterologous polynucleotide sequence are linked by a mutated ITR (*e.g.*, the right ITR). In some embodiments, the ITR comprises the polynucleotide sequence 5'-
CACTCCCTCTCTGCGCGCTCGCTCGCTCACTGAGGCCGGGCGACCAAAGGTCGC
CCACGCCCGGGCTTTGCCCGGGCG – 3' (SEQ ID NO:20). The mutated ITR comprises a deletion of the D region comprising the terminal resolution sequence. As a result, on replicating an AAV viral genome, the rep proteins will not cleave the viral genome at the mutated ITR and as such, a recombinant viral genome comprising the following in 5' to 3' order will be packaged in a viral capsid: an AAV ITR, the first heterologous polynucleotide sequence including regulatory sequences, the mutated AAV ITR, the second heterologous polynucleotide in reverse orientation to the first heterologous polynucleotide and a third AAV ITR. In some embodiments, the invention provides AAV viral particles comprising a recombinant viral genome comprising a functional AAV2 ITR, a first polynucleotide sequence encoding miR-708 RNA and/or a rhodopsin transgene, a mutated AAV2 ITR comprising a deletion of the D region and lacking a functional terminal resolution sequence, a second polynucleotide sequence comprising the complementary sequence to the sequence encoding miR-708 RNA and/or a rhodopsin, of the first polynucleotide sequence and a functional AAV2 ITR.

Production of AAV particles

[0123] The rAAV particles can be produced using methods know in the art. See, e.g., U.S. Pat. Nos. 6,566,118; 6,989,264; and 6,995,006. In practicing the invention, host cells for producing rAAV particles include mammalian cells, insect cells, plant cells, microorganisms and yeast. Host cells can also be packaging cells in which the AAV rep and cap genes are stably maintained in the host cell or producer cells in which the AAV vector genome is stably maintained. Exemplary packaging and producer cells are derived from 293, A549 or HeLa cells. AAV vectors are purified and formulated using standard techniques known in the art.

[0124] In some aspects, a method is provided for producing any rAAV particle as disclosed herein comprising (a) culturing a host cell under a condition that rAAV particles are produced, wherein the host cell comprises (i) one or more AAV package genes, wherein each said AAV packaging gene encodes an AAV replication and/or encapsidation protein; (ii) an rAAV pro-vector comprising a nucleic acid encoding miR-708 RNA and/or any rhodopsin transgene as described herein flanked by at least one AAV ITR, and (iii) an AAV helper function; and (b) recovering the rAAV particles produced by the host cell. In some embodiments, a nucleic acid encodes miR-708 RNA of SEQ ID NO:1 and/or a transgene encoding a rhodopsin; *e.g.*, a rhodopsin with the amino acid of SEQ ID NO:2. In some embodiments, said at least one AAV ITR is selected from the group consisting of AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV DJ, a goat AAV, bovine AAV, or mouse AAV serotype ITR or the like. In some embodiments, said encapsidation protein is selected from the group consisting of AAV1, AAV2, AAV3, AAV4, AAV5, AAV6 (*e.g.*, a wild-type AAV6 capsid, or a variant AAV6 capsid such as ShH10, as described in U.S. PG Pub. 2012/0164106), AAV7, AAV8, AAVrh8, AAVrh8R, AAV9 (*e.g.*, a wild-type AAV9 capsid, or a modified AAV9 capsid as described in U.S. PG Pub. 2013/0323226), AAV10, AAVrh10, AAV11, AAV12, a tyrosine capsid mutant, a heparin binding capsid mutant, an AAV2R471A capsid, an AAVAAV2/2-7m8 capsid, an AAV DJ capsid (*e.g.*, an AAV-DJ/8 capsid, an AAV-DJ/9 capsid, or any other of the capsids described in U.S. PG Pub. 2012/0066783), AAV2 N587A capsid, AAV2 E548A capsid, AAV2 N708A capsid, AAV V708K capsid, goat AAV capsid, AAV1/AAV2 chimeric capsid, bovine AAV capsid, mouse AAV capsid, rAAV2/HBoV1 capsid, an AAV capsid described in U.S. Pat. No. 8,283,151 or International Publication No. WO/2003/042397, or mutants thereof. In some embodiments, the encapsidation protein is an AAV5 tyrosine mutant capsid protein.

In further embodiments, the rAAV particle comprises capsid proteins of an AAV serotype from Clades A-F. In some embodiments, the rAAV particles comprise an AAV5 capsid and a recombinant genome comprising AAV2 ITRs, a mutant AAV2 ITR and nucleic acid encoding miR-708 and/or rhodopsin. In some embodiments, the rAAV particles comprise an AAV5 tyrosine mutant capsid and a recombinant genome comprising AAV2 ITRs, a mutant AAV2 ITR and nucleic acid encoding miR-708 and/or rhodopsin. In a further embodiment, the rAAV particles are purified. The term "purified" as used herein includes a preparation of rAAV particles devoid of at least some of the other components that may also be present where the rAAV particles naturally occur or are initially prepared from. Thus, for example, isolated rAAV particles may be prepared using a purification technique to enrich it from a source mixture, such as a culture lysate or production culture supernatant. Enrichment can be measured in a variety of ways, such as, for example, by the proportion of DNase-resistant particles (DRPs) or genome copies (gc) present in a solution, or by infectivity, or it can be measured in relation to a second, potentially interfering substance present in the source mixture, such as contaminants, including production culture contaminants or in-process contaminants, including helper virus, media components, and the like.

[0125] Also provided herein are pharmaceutical compositions comprising a rAAV particle comprising a transgene encoding miR-708 and/or a rhodopsin transgene of the invention and a pharmaceutically acceptable carrier. In some embodiments, the composition comprises rAAV particles comprising a transgene encoding miR-708 and rAAV particles comprising a rhodopsin transgene. In some embodiments, the composition comprises rAAV particles comprising a transgene encoding miR-708 and a rhodopsin transgene. The pharmaceutical compositions may be suitable for any mode of administration described herein. A pharmaceutical composition of a rAAV comprising a nucleic acid encoding miR-708 RNA and/or a rhodopsin transgene, described herein can be introduced to the eye; for example, by subretinal administration or intravitreal administration.

[0126] In some embodiments, the pharmaceutical compositions comprising a rAAV described herein and a pharmaceutically acceptable carrier is suitable for administration to human. Such carriers are well known in the art (see, *e.g.*, Remington's Pharmaceutical Sciences, 15th Edition, pp. 1035-1038 and 1570-1580). In some embodiments, the

pharmaceutical compositions comprising a rAAV described herein and a pharmaceutically acceptable carrier is suitable for ocular injection. Such pharmaceutically acceptable carriers can be sterile liquids, such as water and oil, including those of petroleum, animal, vegetable or synthetic origin, such as peanut oil, soybean oil, mineral oil, and the like. Saline solutions and aqueous dextrose, polyethylene glycol (PEG) and glycerol solutions can also be employed as liquid carriers, particularly for injectable solutions. The pharmaceutical composition may further comprise additional ingredients, for example preservatives, buffers, tonicity agents, antioxidants and stabilizers, nonionic wetting or clarifying agents, viscosity-increasing agents, and the like. The pharmaceutical compositions described herein can be packaged in single unit dosages or in multidosage forms. The compositions are generally formulated as sterile and substantially isotonic solution.

VII. Articles of Manufacture and Kits

[0127] Also provided are kits or articles of manufacture for use in the methods described herein. In aspects, the kits comprise the compositions described herein (*e.g.*, rAAV particles comprising nucleic acid encoding miR-708 RNA and/or a rhodopsin transgene) in suitable packaging. Suitable packaging for compositions (such as ocular compositions) described herein are known in the art, and include, for example, vials (such as sealed vials), vessels, ampules, bottles, jars, flexible packaging (e.g., sealed Mylar or plastic bags), and the like. These articles of manufacture may further be sterilized and/or sealed.

[0128] The present invention also provides kits comprising compositions described herein and may further comprise instruction(s) on methods of using the composition, such as uses described herein. The kits described herein may further include other materials desirable from a commercial and user standpoint, including other buffers, diluents, filters, needles, syringes, and package inserts with instructions for performing any methods described herein. For example, in some embodiments, the kit comprises an rAAV comprising a transgene encoding miR-708 RNA and/or a rhodopsin transgene for intraocular delivery of at least 1×10^9 genome copies to a primate as described herein, a pharmaceutically acceptable carrier suitable for intraocular injection, and one or more of: a buffer, a diluent, a filter, a needle, a syringe, and a package insert with instructions for performing ocular injections. In some embodiments, the kit comprising instructions for treating retinitis pigmentosa with the rAAV particles described herein. In some embodiments, the kit comprising instructions for reducing ER stress in a cell with the rAAV particles described

herein. In some embodiments, the kit comprising instructions for using the rAAV particles described herein according to any one of the methods described herein.

EXAMPLES

[0129] The invention will be more fully understood by reference to the following examples. They should not, however, be construed as limiting the scope of the invention. It is understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application and scope of the appended claims.

Example 1: Development of a cellular model of retinitis pigmentosa

[0130] A therapeutic strategy for RHO-associated autosomal dominant RP would be to knock down both mutant and wild-type rhodopsin and alleviate ER stress. This could be achieved by co-delivering a micro-RNA (miR) that would inhibit the rhodopsin alleles and optionally co-delivering a wild-type rhodopsin sequence refractory to knockdown by the exogenously delivered miR. A CHOP-regulated miR, miR-708, regulates rhodopsin expression (Behrman, S., *et al.* (2011) *J. Cell Biol.* 192(6):919-27). miR-708 is an intronic miR residing within the CHOP-inducible gene Odz4 (Tenurin-4). CHOP regulates miR-708 expression during ER stress, and there is a putative miR-708 sequence in the 3' UTR of rhodopsin.

[0131] Described herein are methods for using an AAV vector to deliver exogenous miR-708 targeting both wild type and mutant rhodopsin through the 3' UTR miR-708 target sequence present in both alleles. In embodiments, a wild-type rhodopsin replacement sequence is also co-delivered. This replacement rhodopsin sequence may be engineered to have decreased binding to miR-708 (e.g., nucleotide substitution, deletion or addition to the 3' UTR) and thus will be refractory to knockdown by the exogenous miR-708. In embodiments, the replacement rhodopsin sequence lacks a 3' UTR miR-708 target sequence. In short, these AAV vectors would knock down expression of the rhodopsin that causes ER stress (and therefore photoreceptor cell death) and optionally supplementing expression of a wild-type, or codon-optimized, rhodopsin gene that is refractory to miR-708-induced knockdown, thereby restoring normal expression and function of rhodopsin.

Methods

Cell Culture

[0132] HEK-293 cells were engineered to express human or mouse Rhodopsin P23H using the T-Rex Tetracycline Inducible system from Invitrogen. Confluent cells in 6 well plates were transfected with 4 µg miR-708 (pcDNA) vector or a control miRNA vector using Lipofectamine 2000 (Invitrogen) per the manufacturer's instructions. 48 hours post-transfection the medium was replaced with medium containing 2 µM Tetracycline. The cells were incubated an additional 24 hours and the medium was removed from each well.

Western blotting

[0133] Cells were lysed in 400 µL RIPA buffer (Thermo Scientific) containing 1mM PMSF, and passed through a 25g syringe several times. The lysate was centrifuged at 14,000rpm for 10 min. Cells were kept at 4^{o}C throughout the process. 30 µL of supernatant was loaded onto a 4-12% Bis/Tris Gel and SDS-PAGE was performed in MOPS buffer (Invitrogen). Proteins were then transferred to a Nitrocellulose membrane using the I-Blot system from Invitrogen. The membrane was blocked for an hour at room temperature in PBS containing 0.05% Tween-20 (PBS-T) and 0.1 % I-Block (Invitrogen). The membrane was incubated overnight at 4^{o}C in PBS-T containing 1 µg/mL anti Rhodopsin mAb 1D4 (Abcam). After washing in PBS-T several times the membrane was incubated in secondary antibody solution containing a 1:1000 dilution of anti-mouse IgG HRP conjugated Ab (R&D Systems) for an hour at room temperature. The membrane was washed in PBS-T several times and developed using ECL Reagent (Thermo Scientific). mRhodopsin protein levels were quantified using the Image-J software. The membrane was stripped of proteins in PBS containing 0.1M Glycine pH 2 and then rinsed several times in PBS-T. The membrane was then probed for hGAPDH in PBS-T containing a 1:20,000 dilution of anti GAPDH pAb (Sigma) for 2 hours at Room Temperature. After washing several times in PBS-T, secondary antibody (Anti-Rabbit IgG-HRP, R&D Systems) was diluted 1:1000 in PBS-T and incubated for 1 hour at room temperature. The membrane was washed several times and developed using ECL reagent (Thermo Scientific). mRhodopsin protein levels were then normalized to hGAPDH protein levels using Image J software.

Endogenous miR-708 knockdown in HEK-293 cells

[0134] HEK-293 cells expressing mouse or human rhodopsin (described above) were transfected with 100 pmol pre-miR-708, anti-miR-708, or control miRNA (Ambion) using the Lipofectamine 2000 protocol for transfection with siRNA molecules (Invitrogen). At 48 hours post-transfection, the medium was replaced with medium containing 2 uM Tetracycline to induce Rhodopsin expression. 24 hours later each well was split into 2 samples. One was probed for mRhodopsin and hGAPDH using the western blot protocol above, and RNA was extracted from the other for TaqMan® (Life Technologies) analysis of Rhodopsin and miR-708 RNA expression. Total RNA (including small RNAs) was extracted from the cells using the miRNeasy kit from Qiagen, according to the manufacturer's instructions, including DNAse treatment of the samples. cDNA was synthesized from total RNA using the Quantitect Reverse Transcription system from Qiagen. cDNA was added to mRhodopsin, hCHOP (*Ddit3)*, hBiP (*Hspa5)* or hGAPDH TaqMan® gene expression assays (Life Technologies). Gene expression was normalized relative to hGAPDH using the $\Delta\Delta C_t$ method. miR-708 expression was quantified using the miR-708 TaqMan®expression assay (Life Technologies). miR-708 expression was displayed relative to endogenous miR-16 expression using the $\Delta\Delta C_t$ method.

Rhodopsin kinase promoter-driven expression of miR-708 in WERI Rb-1 cells

[0135] miR-708 sequence was subcloned downstream of the Rhodopsin Kinase (RK) promoter after excision from pcDNA 6.2 GW vector (Block-iT system, Invitrogen) into vector pRK-MVM, which contains the native hRK promoter and MVM intron sequences. WERI Rb-1 cells (ATCC) were transfected with 2 µg pRK-miR-708 or pRK-miR-Control vector using Fugene-HD (Promega), according to the manufacturer's instructions. At 48 hours post-transfection, the cells were collected, and total RNA (including small RNAs) was extracted using the miRNeasy kit protocol (Qiagen). miR-708 was quantified in each sample using the miR-708 TaqMan® gene expression assay as described earlier (Life Technologies). To quantify mRhodopsin knockdown in miR-708 expressing WERI Rb-1 cells, cells were co-transfected with 2 µg each of pRK-miR-708 (or control) and pSport6 mRhodopsin P23H using Fugene-HD according to the manufacturer's instructions (Promega). RNA was extracted as described and mRhodopsin RNA levels were quantified as described above using the ΔΔCt method relative to hGAPDH RNA levels.

Extraction of RNA from mouse retinas injected with AAV vectors

[0136] RNA was extracted from mouse retinas using the miRNeasy kit according to the manufacturer's instructions (Qiagen). Individual mouse retinas were homogenized in Qiazol Lysis Buffer using 1 mm Zirconia/Silica beads (Biospec) for 10 min. After homogenization RNA was extracted according to the manufacturer's instructions. miR-708 levels in each retina were quantified using the qStar microRNA quantification system (Origene). cDNA was synthesized using the first strand cDNA synthesis kit (Origene), followed by miR-708 specific amplification and quantification using miR-708 specific primers and a miR-708 copy standard (Origene). For quantification of Rhodopsin levels in injected mouse eyes, mRhodopsin was amplified using specific primers (Life Technologies) and quantified against a Rhodopsin cDNA standard. RdCVF levels were qualitatively analyzed against GAPDH expression using the ΔΔCt method.

Rhodopsin suppression/replacement vector

[0137] hRhodopsin cDNA (with no flanking UTR sequences) was cloned into the pRK vector by excision from the pcDNA vector and performing a blunt ended ligation into pRK-MCS. cDNA was synthesized (Biobasic) containing the hRhodopsin Kinase promoter sequence and the hβ-globin Intron with a hmiR-708 sequence insertion (sequence taken from Genbank/NCBI) located between the intron's splice acceptor/donor sites. This sequence was subcloned from pUC57 vector, ligated into pcDNA hRhodopsin vector, and renamed pRK-miR-708 hRho/wt. miRNA-708 and hRhodopsin protein levels were assayed as described above in transfected WERI Rb-1 cells.

Quantification of XBP-1 splicing in P23H mRhodopsin-transfected WERI Rb-1 cells

[0138] hWERI Rb-1 cells were co-transfected with pcDNA vector encoding a non-glycosylated P23H mutated mRhodopsin and pRK-miR-708 vector. This P23H Rhodopsin cDNA was mutated using site-directed PCR mutagenesis (Agilent Technologies) to change two Asparagine codons (at positions 2 and 5) to Alanine. The cells were transfected as described with 2 µg of each vector and incubated for 72 hrs. Total RNA was collected from the cells as described previously. cDNA was synthesized using the High Capacity cDNA synthesis kit (Invitrogen). XBP-1 spicing was assessed using primers specific for XBP-1 and High Fidelity PCR MasterMix (Roche). Amplified sequences were analyzed on a 2% agarose gel and the relative amounts of spliced (~280 nt) vs. unspliced (~300nt) XBP-1 transcript was quantified using Image-J software.

Additional methods

[0139] Methods for immunofluorescence, Western blotting with and without Endo-glycosidase H treatment, UPR marker expression, and TUNEL staining of cells expressing wild-type or P23H mutant rhodopsin were performed as described in Adamowicz, M., *et al.* (2012) *Adv. Exp. Med. Biol.* 723:573-9.

Results

[0140] Human retinal pigmented epithelial (RPE) cells were transiently transfected with a gene encoding either human wild-type (WT) or human P23H mutant rhodopsin (a mutation linked to RP). The localization of rhodopsin was investigated by confocal immunofluorescence microscopy using anti-rhodopsin antibody. In the case of the wild type protein, the majority of the protein was processed to the plasma membrane (**FIG. 1A**), indicating normal biogenesis. By contrast, the mutant P23H showed a perinuclear/reticular distribution characteristic of endoplasmic reticulum (ER) retention, with almost no expression at the cell surface (**FIG. 1B**). These results demonstrate that P23H mutant rhodopsin fails to be trafficked properly to the plasma membrane and is instead retained in the ER.

[0141] Aggregation of rhodopsin was assessed by SDS-PAGE immunoblot analysis of detergent soluble extracts from RPE cells transiently expressing wild type or P23H mutant protein (**FIG. 2A**). Wild-type rhodopsin migrated predominantly as a diffuse band at a molecular mass of ~ 40 kDa. This species corresponds to monomeric, mature rhodopsin containing N-linked glycans. The mobility of P23H mutant rhodopsin differed markedly from wild-type rhodopsin, with the majority of P23H migrating as higher-weight dimers and oligomers (**FIG. 2A**). P23H was also sensitive to Endoglycosidase H—note that treatment with Endoglycosidase H affects the migration of P23H rhodopsin, but not wild-type, as shown in **FIG. 2B**. Endoglycosidase H is specific for core glycosylated, high mannose N-linked oligosaccharide structures typical of proteins that have not matured beyond the ER.

[0142] Together, these data suggest that in RPE cells wild type rhodopsin is able to fold and mature beyond the ER, whereas the P23H mutant is more prone to forming non-native oligomers and is retained within the ER, perhaps due to an inability to fold productively.

[0143] Next, P23H rhodopsin's ability to induce ER stress in transfected RPE cells was assessed by measuring the levels of two markers of the UPR, BiP and CHOP. Increased BiP mRNA levels were detected in cells transiently expressing both WT and P23H rhodopsin (**FIG. 3A**), suggesting that increasing the folding load of the ER *per se* induced the UPR. However, BiP mRNA expression was significantly higher in cells expressing P23H rhodopsin (43-fold over untransfected cells) as compared with cells expressing WT rhodopsin (14-fold over untransfected cells) (**FIG. 3A**). The rhodopsin mRNA levels were identical in cells expressing WT or mutant forms of the protein (**FIG. 3A**). Thus, P23H rhodopsin is a more potent inducer of BiP than WT rhodopsin. Without wishing to be bound to theory, this discrepancy may be due to the folding defect of the mutant protein.

[0144] CHOP expression was examined next. Cells expressing the WT rhodopsin protein showed a 15-fold induction of CHOP compared to untransfected cells, while cells expressing P23H mutant showed an even greater 23-fold induction (**FIG. 3A**). As CHOP is a UPR–induced transcription factor that mediates apoptosis (Lee, E.S., *et al.* (2007) *FEBS Lett.* 581(22):4325-32), the relative levels of apoptosis between WT and P23H mutant expressing cells was measured. In agreement with the mRNA levels of CHOP, TUNEL assay results further suggested that RPE cells transiently expressing the P23H mutant are more prone to apoptosis than those expressing the wild type rhodopsin (**FIG. 3B**).

Example 2: Modulation of miR-708 levels regulates rhodopsin expression and the UPR in HEK-293 cells

[0145] A consensus sequence corresponding to a putative miR-708 target site has been found in the 3' UTR of several mammalian rhodopsin genes (Behrman, S., *et al.* (2011) *J. Cell Biol.* 192(6):919-27). This Example demonstrates that miR-708 regulation of rhodopsin may be used as a tool to modulate rhodopsin expression in cultured cells.

[0146] HEK-293 cells expressing a P23H mutant mRhodopsin gene encoding a 3'UTR miR-708 target sequence were transfected with a plasmid expressing miR-708 or miR-Control as depicted in **FIG. 4**. After 72 hrs, the cells were collected, and mP23H Rhodopsin protein expression was analyzed using a Western blot (**FIG. 5**). P23H mRhodopsin protein expression was reduced to ~30% in cells transfected with CBA-miR-708, compared to cells transfected with a CBA-miR-Control vector.

[0147] Expression of UPR target genes (CHOP/BIP) was also analyzed by TaqMan® gene expression analysis. HEK-293 cells expressing miR-708 also showed reduced expression of CHOP and BiP RNA compared to control cells (**FIG. 6**). These results suggest that reducing the level of misfolded P23H mRhodopsin results in a concomitant reduction in expression of UPR genes BiP and CHOP.

[0148] In the converse experiment, HEK-293 cells expressing either mouse P23H Rhodopsin (including a 3' UTR miR-708 target sequence) or human P23H Rhodopsin (lacking the 3' UTR miR-708 target sequence) were transfected with anti-miR-708 pre-miRNA or negative control pre-miRNA (**FIG. 7**). In this experiment, exogenous anti-miR-708 was used to inhibit endogenous HEK293 miR-708. If endogenous miR-708 regulated rhodopsin expression through the putative miR-708 target sequence, then changes in levels of the P23H rhodopsin would be observed only if there was a miR-708 target sequence in the 3' UTR of the rhodopsin gene. Cells were transfected with 100 pmol of each RNA. Cell lysates were generated, and rhodopsin protein was quantified on a Western blot while mRNA levels were analyzed by TaqMan® analysis (**FIG. 7**). Inhibition of endogenous miR-708 resulted in an increase of both mouse Rhodopsin mRNA and protein (**FIG. 7A**), whereas the levels of both human rhodopsin mRNA and protein remained unaffected (**FIG. 7B**), despite lower levels of endogenous miR-708. These results demonstrate that the regulation of rhodopsin by miR-708 requires the miR-708 target sequence in the rhodopsin 3' UTR.

[0149] Together, these results show that rhodopsin is a functional target of miR-708, and that modulation of miR-708 activity may be used as a tool to affect rhodopsin expression.

Example 3: Design of an AAV ITR plasmid expressing miR-708 under the control of the photoreceptor-specific rhodopsin kinase promoter

[0150] It is thought that buildup of mutant rhodopsin protein in the ER contributes to the ER stress underlying photoreceptor cell death in RP. The previous Example demonstrates that miR-708 expression is able to regulate overall rhodopsin levels. An adeno-associated virus (AAV)-based vector was constructed for specific expression of miR-708 in the photoreceptor cells of the retina to determine if lowering total rhodopsin levels (including wild-type and mutant forms) may alleviate ER stress independent of the rhodopsin mutation.

[0151] **FIG. 8** depicts an AAV inverted terminal repeat (ITR) plasmid designed to express miR-708 specifically in retinal photoreceptor cells. miR-708 expression was driven by the rhodopsin kinase promoter (pRK), which is specifically expressed in rod photoreceptor cells. In this vector, miR-708 was expressed from the miR-155 scaffold shown in **FIG. 4**.

[0152] Next, this AAV ITR plasmid was validated in cultured cells. WERI or RPE cells were transfected with the pre-viral plasmid described in **FIG. 8**, and the levels of miR-708 were quantitated by TaqMan® analysis. **FIG. 9A** shows that WERI cells transfected with the pRK-driven miR-708 plasmid had over a 2000-fold increase in miR-708 levels compared to WERI cells transfected with a plasmid expressing miR-Scramble (control). In contrast, RPE cells, in which the RK promoter is not significantly expressed, did not show a significant increase in miR-708 levels (**FIG. 9A**).

[0153] The function of miR-708 in regulating rhodopsin expression was confirmed by co-transfecting the pRK-miR-708 plasmid (or a miR-Control plasmid) and a plasmid with the P23H mouse rhodopsin gene harboring a 3'miR708 target sequence into WERI cells. **FIG. 9B** shows that the P23H mRhodopsin mRNA was reduced in the presence of the miR-708, compared to a miR-Control. These results demonstrate that expression of miR-708 using an AAV ITR vector is effective in reducing the expression of rhodopsin in photoreceptor cells.

Example 4: Knockdown of rhodopsin in mouse retinas using a miR-708 AAV5 vector

[0154] To test whether an AAV vector could be used to reduce rhodopsin expression in the retina *in vivo*, the pRK-miR-708 plasmid described in **FIG. 8** was packaged into an AAV5 capsid to generate AAV5-RK miR-708. In addition, an AAV5 miR-Control vector was generated. Wild-type C57bl mice received a subretinal injection of $1x10^8$ vgs of AAV5-RK miR-708 or AAV5 miR-Control in the contralateral eye. At 1 month post-injection, the mice were euthanized, and the neuro retina was extracted and flash-frozen for qPCR analysis of gene expression.

[0155] **FIG. 10A** shows that mouse eyes that had been injected with an AAV5 vector expressing miR-708 had reduced rhodopsin expression, compared to mouse eyes injected with an AAV5 miR-Control vector. In contrast, the expression of another rod-specific gene, Rod Derived Cone Viability Factor (RdCVF), was not affected (**FIG. 10B**). **FIG. 10C** confirms that eyes injected with AAV5miR708 vector showed a significant increase in miR-708 copy number, compared to eyes that received AAV5miR control. These results suggest that AAV-based vectors expressing miR-708 in rod photoreceptors are effective in reducing endogenous rhodopsin expression *in vivo*.

[0156] To demonstrate the functional relevance of rhodopsin knockdown, mouse eyes treated with AAV5 miR-708 or AAV5 miR-Control were analyzed by electroretinogram (ERG) to assess retinal function. Eyes that received the AAV5 miR-708 vector showed a decreased scotopic response, as expected if levels of rhodopsin are reduced (**FIG. 11A**). Scotopic ERG responses are an assessment of rod function, and this measurement can be correlated to rhodopsin levels. However, cone function in the same animals, as assessed by photopic ERG, was unchanged following AAV5 miR-708 delivery (**FIG. 11B**), confirming that miR-708 had a biological effect on rod photoreceptor cells while sparing the cone cells. These data demonstrate that AAV5 miR-708 delivery results in a biological effect that is restricted to the rod target cell.

Example 5: Construction of a hRhodopsin suppression/replacement vector with an intron-embedded miR-708 expression cassette

[0157] miR-708 is normally expressed *in vivo* from the first intron in the *ODZ4* gene. Therefore, a novel construct was designed based on the sequence of miR-708 and its endogenous scaffold/flanking sequence. The miR-708 sequence was embedded into a

synthetic intron and cloned downstream of the photoreceptor specific promoter Rhodopsin Kinase (RK), but upstream of the hRhodopsin cDNA. The endogenous miR-708 sequence including its flanking regulatory and processing sequences were cloned into the β-globin intron sequence upstream of the hRhodopsin cDNA sequence but downstream of the RK promoter. As such, the miR-708 sequence is 5' relative to the rhodopsin coding sequence.

[0158] **FIG. 12** provides a diagram of this 5' suppression/replacement vector. hRhodopsin (lacking a 3' UTR mir708 target sequence) was controlled by the RK promoter. The endogenous miR-708 sequence including endogenous scaffold (*e.g.*, including any Drosha/Dicer recognition motifs) was embedded within the β-globin intron. hRhodopsin cDNA (with no 3' miR-708 UTR target sequence) was included downstream of the splice junction site. miR-708 was embedded within the β-globin, which is located downstream of the RK promoter, and therefore the miR-708 was processed after splicing of the β-globin intronic sequence. In addition vector with a similar structure harboring a control miR was generated.

[0159] The vector described in **FIG. 12**, or a vector with a control miRNA, was used to transfect WERI cells. WERI cells were used because they express little, if any, endogenous miR-708, and they are permissive to the RK promoter. WERI cells were co-transfected with a cDNA encoding P23H mRhodopsin (with a 3'UTR miR-708 sequence). Both rhodopsin knockdown (RNA levels) and levels of the UPR genes CHOP and BIP were examined in transfected cells.

[0160] **FIG. 13** shows that cells co-transfected with mRhodopsin (P23H) and the miR-708 vector had reduced mRhodopsin levels compared to cells co-transfected with mRhodopsin and control miRNA vector. Additionally, the UPR genes CHOP and BiP were also down regulated in the miR-708 transfected cells compared to control. This data suggests that using the endogenous miR708 scaffold with intronic expression of miR708 provides an alternative scaffold that supports miR708 processing and expression.

Example 6: Comparison of different miR-708 scaffolds

[0161] Lower levels of miR-708 expression may be beneficial in reducing any potential off-target effects of the miRNA in a clinical setting. Therefore, different miR scaffolds were tested for strength of expression in the WERI human retinoblastoma cell line.

[0162] **FIG. 14** depicts quantified miR-708 levels in WERI cells transfected with CBA-driven miR-708, RK-driven miR708 using the miR-155 scaffold shown in **FIG. 4**, or the RK intron-embedded miR-708 hRhodopsin vector shown in **FIG. 12**. miR-708 expression in the RK intronic system was not as robust as the CBA driven system. However, miR-708 expression was still well above background and about 5 fold lower than pRKmiR708 using the miR-155 scaffold. Note that hRhodopsin was co-expressed from the intron-embedded vectors, but not in the CBA or RK miR-155 scaffold vectors.

[0163] Next, the levels of hRhodopsin mRNA were compared in WERI cells expressing the miR-708 intron-embedded, suppression/replacement vector or a miR-Control vector. **FIG. 15** shows that WERI cells transfected with the miR-708 intron-embedded, suppression/replacement vector had a similar level of hRhodopsin compared to cells transfected with the control vector. These results indicate that hRhodopsin expression from the suppression/replacement vector, which lacks the 3' UTR miR-708 target sequence, is refractory to inhibition by miR-708 expression. Both cells showed higher hRhodopsin expression than untransfected WERI cells.

Example 7: Knockdown of mutant rhodopsin by the miR-708 suppression/replacement vector reduces a marker of ER stress

[0164] The ability of the miR-708 suppression/replacement vector to reduce ER stress in cells expressing mutant rhodopsin was examined. WERI cells expressing a non-glycosylated, P23H mutant rhodopsin (N2K/N15K/P23H), with or without a 3'UTR miR708 target sequence, were transfected with the suppression replacement vector described in **FIG. 12**. Cells were harvested and RNA extracted to measure X-box binding protein 1 (XBP-1) splicing. XBP-1 is a transcription factor important in regulating ER stress genes. Its splicing is a known marker of cellular ER stress/UPR; cells undergoing UPR show increased levels of spliced XBP-1.

[0165] As shown in **FIG. 16**, cells expressing mutant Rhodopsin with a 3' UTR target sequence had decreased XBP-1 splicing when transfected with the miR-708 suppression/replacement vector. In contrast, cells expressing the mutant P23H Rhodopsin lacking the 3'UTR miR-708 target sequence had equivalent levels of XBP-1 splicing compared to cells transfected with the miR-Control sequence. These results demonstrate that knockdown of mutant rhodopsin using the miR-708 suppression/replacement vector is effective in reducing ER stress.

Example 8: Expression of miR-708 in the β-globin intron scaffold placed in the rhodopsin 3' UTR increases the expression of rhodopsin and miR-708

[0166] In order to test whether the position of the miR-708 scaffold affects its expression, a vector was constructed where the miR-708 sequence (including its flanking regulatory/processing sequences) was cloned into the β-globin intron sequence downstream of the Rhodopsin cDNA, *i.e.,* within the 3' UTR. **FIG. 17** shows a diagram of this 3' suppression/replacement vector, which is similar to that shown in **FIG. 12**, except that the miR-708 human β-globin intron scaffold is in the 3' UTR of the rhodopsin cDNA, rather than the 5' UTR.

[0167] To determine if the position of the miR-708 human β-globin intron scaffold in the vector affected miR-708 or hRhodopsin expression from the vector, WERI cells were transfected with the 5' UTR vector of **FIG. 12** or the 3' UTR vector of **FIG. 17**. **FIG. 18** shows the expression of hRhodopsin and miR-708 in these cells. The vector with the miR-708 scaffold in the 3' UTR was found to produce higher levels of both hRhodopsin and miR-708 RNA than the vector using the 5' UTR configuration.

Example 9: Evaluation of the suppression/replacement vector in a P23H mouse model of retinal degeneration

[0168] Suppression/replacement constructs are evaluated in a P23H mouse model of retinal degeneration. In this model, the mutant P23H protein expressed in rod photoreceptor cells induces ER stress/UPR, causing apoptosis and ultimate rod cell death (Lee, E.S., *et al.* (2007) *FEBS Lett.* 581(22):4325-32). Following rod cell death there is a non-cell-autonomous death of cone cells.

[0169] The P23H mouse is treated with a suppression/replacement AAV vector expressing miR-708 and a human rhodopsin gene refractory to knockdown by miR708 (because it lacks a miR-708 target sequence). The suppression/replacement vector results in knockdown of both WT and P23H mouse rhodopsin, but the replacement rhodopsin gene compensates for the reduction in WT levels of rhodopsin. Therefore, the vector provides the necessary rod rhodopsin to maintain rod cell function and integrity.

[0170] An alternate suppression/replacement construct design is also tested. As shown in **FIG. 19**, this alternate vector drives expression of miR-708 from the RK promoter and co-express hRhodopsin (refractory to miR-708 knockdown) using the mouse opsin promoter.

[0171] These suppression/replacement vectors are also tested as described above in a P23H mouse model in which the endogenous mRhodopsin gene harbors a single copy loss-of-function allele (*e.g.*, the mouse is heterozygous with respect to a mRhodopsin knockout allele). This heterozygous mouse model may be constructed using standard mouse genetic techniques from a $mRho^{-/-}$ mouse and the P23H model described above. Without wishing to be bound to theory, it is thought that this $mRho^{+/-}$ P23H mouse model, which contains one copy of the mutant hRhodopsin P23H allele and one copy of the wild-type mouse gene, may resemble a human ADRP genotype in which patients have equal copies of the mutant and wild-type rhodopsin alleles.

Example 10: Evaluation of additional suppression/replacement vectors

[0172] Several vectors were cloned that express both miR-708 (or a control miRNA sequence) and hRhodopsin from a single vector. The vectors differ from each other in that the flanking sequences of the miRNA sequence are derived from either miR-155 (taken from Invitrogen "Block-It" system) or endogenous miR-708 5' and 3' flanking sequences. The miRNA sequences are embedded in the hβ-globin intron downstream of the Rhodopsin Kinase promoter and upstream of the hRhodopsin ORF. The goal was to test if expression and miRNA processing are similar from each construct. An additional pair of vectors contained the miRNA sequences (control or miR-708) downstream of the hRhodopsin ORF, also embedded in the β-globin intron. Only the vectors containing the miR-708 endogenous flanking 5' and 3' sequences located downstream of the hRhodopsin ORF were tested in this experiment, both endogenous miR-708 and miR-155 flanking sequences were tested in the vectors where the β-globin intron is located upstream of the hRhodopsin ORF.

WERI cells were transfected with each construct and both miR-708 expression and hRhodopsin expression were determined.

[0173] The results in **Fig. 20** indicate that the miR-155 flanking sequences generate better expression (or miRNA processing) of miR-708 compared to endogenous miR-708 flanking sequences. miR-708 expression was about 10 fold higher in those cells transfected with vectors containing the miR-155 flanking sequences compared to miR-708 flanking sequences. The vectors containing miR-708 flanking sequences had lower expression of miR-708 regardless of whether the sequences were upstream or downstream relative to the hRhodopsin ORF. hRhodopsin expression was unaffected by miR-708 overexpression, as its expression levels are approximately equal regardless of the miRNA sequence co-expressed in the vector. miR-708 expression was not detected in vectors containing control miRNA sequences, as expected.

Example 11: Evaluation of additional suppression/replacement vectors with a mutated miR-708 target sequence

[0174] As described above, a consensus sequence corresponding to a putative miR-708 target site has been found in the 3' UTR of several mammalian rhodopsin genes (Behrman, S., *et al.* (2011) *J. Cell Biol.* 192(6):919-27). This Example demonstrates that a rhodopsin with a mutated miR-708 target sequence can be used in a suppression/replacement vector.

[0175] An rAAV vector is constructed comprising nucleic acid encoding miR-708 and a human rhodopsin gene. The human rhodopsin gene is mutated in the miR-708 target sequence (SEQ ID NO:19) by nucleotide substitution, deletion or insertion to reduce or prevent recognition by miR-708. In some examples, the entire miR-708 target sequence is deleted. In some examples, reduction or prevention by miR-708 is measured in reference to miR-708 recognition of a wild-type rhodopsin 3'UTR comprising the miR-708 target sequence.

[0176] To test for suppression of autosomal dominant rhodopsin by miR-708 with concomitant expression of wild-type rhodopsin, HEK-293 cells expressing a P23H mutant mRhodopsin gene encoding a 3'UTR miR-708 target sequence are transfected with a plasmid expressing miR-708 and human rhodopsin with (CBA-miR-708-hRho-3'UTR^{-}) or without (CBA-miR-708-hRho-3'UTR^{+}) a mutated miR-708 target sequence. A miR-Control as described in Example 2 is also used. After 72 hrs, the cells are collected, and

mP23H Rhodopsin and human rhodopsin protein expression are analyzed using a Western blot. Reduction of P23H mRhodopsin protein expression in cells transfected with the CBA-miR-708-hRho-3'UTR$^-$ or CBA-miR-708-hRho-3'UTR$^+$ compared to cells transfected with a CBA-miR-Control vector indicates miR-708 activity. Expression of human rhodopsin in cells transfected with CBA-miR-708-hRho-3'UTR$^-$ but not CBA-miR-708-hRho-3'UTR$^+$ indicates that the rhodopsin encoded by CBA-miR-708-hRho-3'UTR$^-$ is refractory to suppression by miR-708.

Example 12: AAV-mediated suppression of endogenous rhodopsin and expression of human rhodopsin in the mouse retina

[0177] Based on the experiments described above, further experiments were performed to test the rhodopsin suppression/replacement strategy in an intact eye. This Example demonstrates the efficacy of a suppression/replacement AAV vector built using a miR-708 scaffold in the mouse retina.

[0178] An AAV5 capsid with a vector bearing the rod-specific opsin promoter, the miR-708 scaffold (*e.g.*, the miR-708 endogenous scaffold/flanking sequences), and a human rhodopsin replacement gene was constructed. In one version of this vector, the miR-708 sequence (*e.g.*, the miR-708 sequence that binds the miR-708 target sequence) was inserted to drive expression of miR-708 in the context of the miR708 scaffold and the human rhodopsin replacement gene (AAV5OPSmiR708$_{708}$hRHO). In another version of this vector, a control vector was generated that harbored a miR control sequence (AAV5OPSmiRcontrol$_{708}$hRHO). In both vectors, the replacement human rhodopsin gene was refractory to miR-708 knockdown because it lacks a miR-708 target sequence. Both vectors were injected subretinally into the retinas of wild type mice. For each mouse, the contralateral naïve eye was uninjected, and expression in each injected retina was normalized as fold expression compared to the contralateral uninjected retina. Three weeks post injection, the retinas were harvested and assayed for miR-708 levels (**FIG. 21A**), mouse rhodopsin mRNA levels (**FIG. 21B**), and human rhodopsin (**FIG. 21C**).

[0179] **FIG. 21A** shows an increase in miR-708 levels in the mouse retina following injection with the AAV5OPSmiR708$_{708}$hRHO vector, as compared to the contralateral naive eye. A significant reduction in mouse rhodopsin was measured in the eye that received AAV5OPSmiR708$_{708}$hRHO, and no reduction in mouse rhodopsin was measured

in eyes that received the control vector, AAV5OPSmiRcontrol$_{708}$hRHO (**FIG. 21B**). In addition, human rhodopsin levels were increased up to 100 fold by both vectors, compared to the contralateral uninjected naïve eye (**FIG. 21C**). These data demonstrate that the AAV5OPSmiR708$_{708}$hRHO vector was efficacious *in vivo*.

[0180] In summary, the optimized suppression/replacement vector AAV5OPSmiR708$_{708}$hRHO achieved knockdown of mouse rhodopsin by miR-708 (endogenous mouse rhodopsin has a 3'UTR target sequence) with concomitant expression of the replacement human rhodopsin, which was refractory to miR708 knockdown (the human rhodopsin replacement gene lacks a 3'UTR miR708 target sequence). These results show the efficacy of the suppression/replacement strategy in the intact mammalian eye.

Example 13: Validation of candidate vectors in human cells

[0181] Candidate AAV5-based vectors were next assayed for the ability to promote miR-708 and human rhodopsin expression in human cells (HeLa).

[0182] Two different promoters were tested: rhodopsin kinase (GRK1) and the opsin promoter. The rhodopsin kinase promoter is described above. The opsin promoter (shown in SEQ ID NO:22) contains a 676bp fragment encoding a 400bp CMV enhancer upstream of the opsin promoter sequence (-500bp - +15bp). In addition 65bp NRL sequence is included; this encodes a neural retinal basic zipper factor (a Rod photoreceptor specific transcription factor). Downstream of the promoter construct is a hybrid intron sequence from CBA exon1 and minute virus of mouse (MVM) – called MVM intron sequence (shown in SEQ ID NO:23). A diagram of this promoter construct is depicted in **FIG. 22**.

[0183] Two different scaffolds were used: the miR-155 scaffold or the miR-708 scaffold. Both were embedded in a beta globin intron. In total, 4 candidate vectors were tested: AAV5GRK1miR708_155hRho (AAV5 vector with rhodopsin kinase promoter driving expression of miR-708 in a miR-155 scaffold and human rhodopsin minus the miR-708 target sequence; SEQ ID NO:24), AAV5GRK1miR708_708hRho (AAV5 vector with rhodopsin kinase promoter driving expression of miR-708 in a miR-708 scaffold and human rhodopsin minus the miR-708 target sequence; SEQ ID NO:25), AAV5OPSmiR708_155hRho (AAV5 vector with opsin promoter driving expression of miR-708 in a miR-155 scaffold and human rhodopsin minus the miR-708 target sequence; SEQ ID NO:26), and AAV5OPSmiR708_708hRho (AAV5 vector with opsin promoter

driving expression of miR-708 in a miR-708 scaffold and human rhodopsin minus the miR-708 target sequence; SEQ ID NO:27). **FIG. 23A** shows the miR-708 sequence embedded in the beta globin intron. The miR-708 and miR-155 scaffolds are shown in **FIGS. 23B** and **23C**, respectively.

[0184] Each of the 4 candidate AAV5 vectors was used to infect HeLa cells (using the AdTs149 helper virus), and levels of miR-708 and hRhodopsin were measured. As shown in **FIG. 24**, all four vectors resulted in miR-708 and hRhodopsin expression in human cells *in vivo*, as compared to vectors driving expression of a control miR from either the opsin or the rhodopsin kinase promoter (Ops miR-Cont and RK miR-Cont, respectively). These results demonstrate the successful validation of several vectors that may be used for suppression/replacement strategies (such as those described above) in human cells.

SEQUENCES

miR-708 nucleotide sequence

AACTGCCCTCAAGGAGCTTACAATCTAGCTGGGGGTAAATGACTTGCACATGAACACAACTAGACTG
TGAGCTTCTAGAGGGCAGGGA (SEQ ID NO:1)

Human rhodopsin amino acid sequence

MNGTEGPNFYVPFSNATGVVRSPFEYPQYYLAEPWQFSMLAAYMFLLIVLGFPINFLTLYVTVQHKK
LRTPLNYILLNLAVADLFMVLGGFTSTLYTSLHGYFVFGPTGCNLEGFFATLGGEIALWSLVVLAIE
RYVVVCKPMSNFRFGENHAIMGVAFTWVMALACAAPPLAGWSRYIPEGLQCSCGIDYYTLKPEVNNE
SFVIYMFVVHFTIPMIIIFFCYGQLVFTVKEAAAQQQESATTQKAEKEVTRMVIIMVIAFLICWVPY
ASVAFYIFTHQGSNFGPIFMTIPAFFAKSAAIYNPVIYIMMNKQFRNCMLTTICCGKNPLGDDEASA
TVSKTETSQVAPA (SEQ ID NO:2)

Human rhodopsin cDNA-UTR deleted

ATGAATGGCACAGAAGGCCCTAACTTCTACGTGCCCTTCTCCAATGCGACGGGTGTGGTACGCAGCC
CCTTCGAGTACCCACAGTACTACCTGGCTGAGCCATGGCAGTTCTCCATGCTGGCCGCCTACATGTT
TCTGCTGATCGTGCTGGGCTTCCCCATCAACTTCCTCACGCTCTACGTCACCGTCCAGCACAAGAAG
CTGCGCACGCCTCTCAACTACATCCTGCTCAACCTAGCCGTGGCTGACCTCTTCATGGTCCTAGGTG
GCTTCACCAGCACCCTCTACACCTCTCTGCATGGATACTTCGTCTTCGGGCCCACAGGATGCAATTT
GGAGGGCTTCTTTGCCACCCTGGGCGGTGAAATTGCCCTGTGGTCCTTGGTGGTCCTGGCCATCGAG
CGGTACGTGGTGGTGTGTAAGCCCATGAGCAACTTCCGCTTCGGGGAGAACCATGCCATCATGGGCG
TTGCCTTCACCTGGGTCATGGCGCTGGCCTGCGCCGCACCCCCACTCGCCGGCTGGTCCAGGTACAT
CCCCGAGGGCCTGCAGTGCTCGTGTGGAATCGACTACTACACGCTCAAGCCGGAGGTCAACAACGAG
TCTTTTGTCATCTACATGTTCGTGGTCCACTTCACCATCCCCATGATTATCATCTTTTTCTGCTATG
GGCAGCTCGTCTTCACCGTCAAGGAGGCCGCTGCCCAGCAGCAGGAGTCAGCCACCACACAGAAGGC
AGAGAAGGAGGTCACCCGCATGGTCATCATCATGGTCATCGCTTTCCTGATCTGCTGGGTGCCCTAC
GCCAGCGTGGCATTCTACATCTTCACCCACCAGGGCTCCAACTTCGGTCCCATCTTCATGACCATCC
CAGCGTTCTTTGCCAAGAGCGCCGCCATCTACAACCCTGTCATCTATATCATGATGAACAAGCAGTT
CCGGAACTGCATGCTCACCACCATCTGCTGCGGCAAGAACCCACTGGGTGACGATGAGGCCTCTGCT
ACCGTGTCCAAGACGGAGACGAGCCAGGTGGCCCCGGCC (SEQ ID NO:3)

Human rhodopsin cDNA-includes 3'UTR

AGAGTCATCCAGCTGGAGCCCTGAGTGGCTGAGCTCAGGCCTTCGCAGCATTCTTGGGTGGGAGCAG
CCACGGGTCAGCCACAAGGGCCACAGCCATGAATGGCACAGAAGGCCCTAACTTCTACGTGCCCTTC
TCCAATGCGACGGGTGTGGTACGCAGCCCCTTCGAGTACCCACAGTACTACCTGGCTGAGCCATGGC
AGTTCTCCATGCTGGCCGCCTACATGTTTCTGCTGATCGTGCTGGGCTTCCCCATCAACTTCCTCAC
GCTCTACGTCACCGTCCAGCACAAGAAGCTGCGCACGCCTCTCAACTACATCCTGCTCAACCTAGCC
GTGGCTGACCTCTTCATGGTCCTAGGTGGCTTCACCAGCACCCTCTACACCTCTCTGCATGGATACT
TCGTCTTCGGGCCCACAGGATGCAATTTGGAGGGCTTCTTTGCCACCCTGGGCGGTGAAATTGCCCT
GTGGTCCTTGGTGGTCCTGGCCATCGAGCGGTACGTGGTGGTGTGTAAGCCCATGAGCAACTTCCGC
TTCGGGGAGAACCATGCCATCATGGGCGTTGCCTTCACCTGGGTCATGGCGCTGGCCTGCGCCGCAC
CCCCACTCGCCGGCTGGTCCAGGTACATCCCCGAGGGCCTGCAGTGCTCGTGTGGAATCGACTACTA
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RK-miR-708-intron hRho wt

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RK-intron-miR-708-op-hRho wt

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Chimeric Intron

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Stuffer sequence

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GAGGTGCTGGCATGGAACAGAGAAATTCCAGCCTCGATTCCTATTATGAACCCGACACCTTTTGTAT
TTTCATCTTGGTTTTACAGTGTACAAAACGAACTAGATCAGCAGGGCATGGGCATAATCACGAATGC
ACACACATACACTAATGTGTGGCTCATGTTTAAGTATCACTTACTACAGGACACCCAATCTAACAGC
ACCGATAAAGTGACAGAGAAACGCAAGCCTTCTGCGAACATGGCCTGGCTGTTCCAATTCCGAACCT
TGCTTTTCTGGGCCTTGCCACACAGGCTCTTCCCCCGTCCCCCCAGGGACATTCTACCCTTGAACTC
CACACTCCACTGCTGCCTTTGCCAGGAAGCCCATCTGTTCCTTTTTGGTTCTGCCAGAACGTGTGGT
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TGCCTGAACTCAGTGGTGGCCTCATTCTGGAAGCCAAGTTTATACAGAGTAGCAGTGACCCAGGGAT
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TGTGGGCAGCTTCTTGGTCACCCTCAGGTTGGGGAATCACCTTCTGTCTTCATTTTCCAGGAACTTG
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TGGCGGTGGCATTGCCCAGGTATTTCATCAGCAGCACCCAGCTGGACAGCTTCTTACAGTGCTGGAT
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CCCTATGCTGTTTTCCTGGGACAGTGGGAGCTGGCTTAGAATGCCCTGGGGCCCCCAGGACCCTGGC
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CACACCATCCCCACAGTTACGTACTAGT (SEQ ID NO:11)

pCBA-hRhodopsin-miR708 (miR-155 scaffold)

GAATTCGGACCGTCGACATTGATTATTGACTAGTTATTAATAGTAATCAATTACGGGGTCATTAGTT
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GACACAAGGCCTGTTACTAGCACTCACATGGAACAAATGGCCCAGATCTGGCCGCACTCGAGATGCT
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AGAAAATACCGCATCAGGCGCCATTCGCCATTCAGGCTGCGCAACTGTTGGGAAGGGCGATCGGTGC
GGGCCTCTTCGCTATTACGCCAGCTGGCGAAAGGGGGATGTGCTGCAAGGCGATTAAGTTGGGTAAC
GCCAGGGTTTTCCCAGTCACGACGTTGTAAAACGACGGCCAGT (SEQ ID NO:12)

MIR155 scaffold

GATCCTGGAGGCTTGCTGAAGGCTGTATGCTGAAGGAGCTTACAATCTAGCTGGGGTTTTGGCCACT
GACTGACCCCAGCTAGTGTAAGCTCCTTCAGGACACAAGGCCTGTTACTAGCACTCACATGGAACAA
ATGGCCCAGATCTGGCCGCAC(SEQ ID NO:13)

Endogenous MIR708 scaffold

AACCTAACCCCCATGGTTGGCGAGGGACTGCTGTGTGTGAAATGGTAACTGCCCTCAAGGAGCTTAC
AATCTAGCTGGGGGTAAATGACTTGCACATGAACACAACTAGACTGTGAGCTTCTAGAGGGCAGGGA

CCTTACCCTAGTCATCTCTCTTCTCACCCTGCACACCCTCCCTGAGGGATCTCAT (SEQ ID NO:14)

pRK-hRhodopsin-miR-708 (mir708 in the miR708 endogenous scaffold, located in the 3' UTR of hRhodopsin)

TATGCGGTGTGAAATACCGCACAGATGCGTAAGGAGAAAATACCGCATCAGGCGCCATTCGCCATTC
AGGCTGCGCAACTGTTGGGAAGGGCGATCGGTGCGGGCCTCTTCGCTATTACGCCAGCTGGCGAAAG
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GTGCACCA (SEQ ID NO:15)

β-globin intron sequence

ACTAGAAGCTTTATTGCGGTAGTTTATCACAGTTAAATTGCTAACGCAGTCAGTGCTTCTGACACAA
CAGTCTCGAACTTAAGCTGCAGTGACTCTCTTAAGGTAGCCTTGCAGAAGTTGGTCGTGAGGCACTG
GGCAGGTAAGTATCAAGGTTACAAGACAGGTTTAAGGAGACCAATAGAAACTGGGCTTGTCGAGACA
GAGAATGGATCCTGGAGGCTTGCTGAAGGCTGTATGCTGAAGGAGCTTACAATCTAGCTGGGGTTTT
GGCCACTGACTGACCCCAGCTAGTGTAAGCTCCTTCAGGACACAAGGCCTGTTACTAGCACTCACAT
GGAACAAATGGCCCAGATCTGAGACTCTTGCGTTTCTGATAGGCACCTATTGGTCTTACTGACATCC
ACTTTGCCTTTCTCTCCACAGGTGTCCACTCCCAGTTCA (SEQ ID NO:16)

MIR708 sequence in a MIR155 scaffold

TGGATCCTGGAGGCTTGCTGAAGGCTGTATGCTGAAGGAGCTTACAATCTAGCTGGGGTTTTGGCCA
CTGACTGACCCCAGCTAGTGTAAGCTCCTTCAGGACACAAGGCCTGTTACTAGCACTCACATGGAAC
AAATGGCCCAGATCTG (SEQ ID NO:17)

MIR708 sequence in a native scaffold

AAACCTAACCCCCATGGTTGGCGAGGGACTGCTGTGTGTGAAATGGTAACTGCCCTCAAGGAGCTTA
CAATCTAGCTGGGGGTAAATGACTTGCACATGAACACAACTAGACTGTGAGCTTCTAGAGGGCAGGG
ACCTTACCCTAGTCATCTCTCTTCTCACCCTGCACACCCTCCCTGAGGGATCTCAT (SEQ ID
NO:18)

Human rhodopsin miR-708 target from 3'UTR

CUCUGCCUGGAGACUAAGGCAAAUUGGGCCAUUAAAAGCUCAGCUCCUAUGUUGGUAUUAACGGUGGU
GGGUUUUGUUG (SEQ ID NO:19)

Mutated AAV ITR

CCACTCCCTCTCTGCGCGCTCGCTCGCTCACTGAGGCCGGGCGACCAAAGGTCGCCCGACGCCCGGGC
TTTGCCCGGGCGGCCTCAGTGAGCGAGCGAGCGCGCAGAGAGGGA (SEQ ID NO:20)

Wild Type ITR sequence

GGCCACTCCCTCTCTGCGCGCTCGCTCGCTCACTGAGGCCGGGCGACCAAAGGTCGCCCGACGCCCGG
GCTTTGCCCGGGCGGCCTCAGTGAGCGAGCGAGCGCGCAGAGAGGGAGTGGCCAACTCCATCACTAGG
GGTTCCT (SEQ ID NO:21)

Opsin promoter

TGCTGATTCAGCCAGGAACTAGTTATTAATAGTAATCAATTACGGGGTCATTAGTTCATAGCCCATAT
ATGGAGTTCCGCGTTACATAACTTACGGTAAATGGCCCGCCTGGCTGACCGCCCAACGACCCCCGCCC
ATTGACGTCAATAATGACGTATGTTCCCATAGTAACGCCAATAGGGACTTTCCATTGACGTCAATGGG
TGGAGTATTTACGGTAAACTGCCCACTTGGCAGTACATCAAGTGTATCATATGCCAAGTACGCCCCCT
ATTGACGTCAATGACGGTAAATGGCCCGCCTGGCATTATGCCCAGTACATGACCTTATGGGACTTTCC
TACTTGGCAGTACATCTACGTATTAGTCATCGCTATTACCACAAATAGTTATCGAGCCGCTGAGCCGG
GGGGCGGGGGGTGTGAGACTGGAGGCGATGGACGGAGCTGACGGCACACACAGCTCAGATCTGTCAAG
TGAGCCATTGTCAGGGCTTGGGGACTGGATAAGTCAGGGGGTCTCCTGGGAAGAGATGGGATAGGTGA
GTTCAGGAGGAGACATTGTCAACTGGAGCCATGTGGAGAAGTGAATTTAGGGCCCAAAGGTTCCAGTC
GCAGCCTGAGGCCACCAGACTGACATGGGGAGGAATTCCCAGAGGACTCTGGGGCAGACAAGATGAGA
CACCCTTTCCTTTCTTTACCTAAGGGCCTCCACCCGATGTCACCTTGGCCCCTCTGCAAGCCAATTAG
GCCCCGGTGGCAGCAGTGGGATTAGCGTTAGTATGATATCTCGCGGA (SEQ ID NO:22)

MVM intron

GGAGTCGCTGCGACGCTGCCTTCGCCCCGTGCCCCGCTCCGCCGCCGCCTCGCGCCGCCCGCCCCGGC
TCTGACTGACCGCGTTACTCCCACAGGTGAGCGGGCGGGACGGCCCTTCTCCTCCGGGCTGTAATTAG
CAAGAGGTAAGGGTTTAAGGGATGGTTGGTTGGTGGGGTATTAATGTTTAATTACCTGTTTTACAGGC
CTGAAATCACTTGGTTTTAGGTTGGGGATCCGGTACCCAATTGCCATGGGCTAGCATGCATGAGCTCC
CTGCAGGGTTTTAATGCCAACTTTGTACAAAAAAGCAGGCACC (SEQ ID NO:23)

AAV5GRK1miR708_155hRho (AAV5 vector with rhodopsin kinase promoter driving expression of miR-708 in a miR-155 scaffold and human rhodopsin minus the miR-708 target sequence)

TGACTAGTTAGGGCCCCAGAAGCCTGGTGGTTGTTTGTCCTTCTCAGGGGAAAAGTGAGGCGGCCCCT
TGGAGGAAGGGGCCGGGCAGAATGATCTAATCGGATTCCAAGCAGCTCAGGGGATTGTCTTTTTCTAG
CACCTTCTTGCCACTCCTAAGCGTCCTCCGTGACCCCGGCTGGGATTTAGCCTGGTGCTGTGTCAGCC
CCGGTCTCCCAGGGGCTTCCCAGTGGTCCCCAGGAACCCTCGACAGGGCCCGGTCTCTCTCGTCCAGC

AAGGGCAGGGACGGGCCACAGGCCAAGGGCACTAGAAGCTTTATTGCGGTAGTTTATCACAGTTAAAT
TGCTAACGCAGTCAGTGCTTCTGACACAACAGTCTCGAACTTAAGCTGCAGTGACTCTCTTAAGGTAG
CCTTGCAGAAGTTGGTCGTGAGGCACTGGGCAGGTAAGTATCAAGGTTACAAGACAGGTTTAAGGAGA
CCAATAGAAACTGGGCTTGTCGAGACAGAGAATGGATCCTGGAGGCTTGCTGAAGGCTGTATGCTGAA
GGAGCTTACAATCTAGCTGGGGTTTTGGCCACTGACTGACCCCAGCTAGTGTAAGCTCCTTCAGGACA
CAAGGCCTGTTACTAGCACTCACATGGAACAAATGGCCCAGATCTGAGACTCTTGCGTTTCTGATAGG
CACCTATTGGTCTTACTGACATCCACTTTGCCTTTCTCTCCACAGGTGTCCACTCCCAGTTCACACCG
GCACAATGAATGGCACAGAAGGCCCTAACTTCTACGTGCCCTTCTCCAATGCGACGGGTGTGGTACGC
AGCCCCTTCGAGTACCCACAGTACTACCTGGCTGAGCCATGGCAGTTCTCCATGCTGGCCGCCTACAT
GTTTCTGCTGATCGTGCTGGGCTTCCCCATCAACTTCCTCACGCTCTACGTCACCGTCCAGCACAAGA
AGCTGCGCACGCCTCTCAACTACATCCTGCTCAACCTAGCCGTGGCTGACCTCTTCATGGTCCTAGGT
GGCTTCACCAGCACCCTCTACACCTCTCTGCATGGATACTTCGTCTTCGGGCCCACAGGATGCAATTT
GGAGGGCTTCTTTGCCACCCTGGGCGGTGAAATTGCCCTGTGGTCCTTGGTGGTCCTGGCCATCGAGC
GGTACGTGGTGGTGTGTAAGCCCATGAGCAACTTCCGCTTCGGGGAGAACCATGCCATCATGGGCGTT
GCCTTCACCTGGGTCATGGCGCTGGCCTGCGCCGCACCCCCACTCGCCGGCTGGTCCAGGTACATCCC
CGAGGGCCTGCAGTGCTCGTGTGGAATCGACTACTACACGCTCAAGCCGGAGGTCAACAACGAGTCTT
TTGTCATCTACATGTTCGTGGTCCACTTCACCATCCCCATGATTATCATCTTTTTCTGCTATGGGCAG
CTCGTCTTCACCGTCAAGGAGGCCGCTGCCCAGCAGCAGGAGTCAGCCACCACACAGAAGGCAGAGAA
GGAGGTCACCCGCATGGTCATCATCATGGTCATCGCTTTCCTGATCTGCTGGGTGCCCTACGCCAGCG
TGGCATTCTACATCTTCACCCACCAGGGCTCCAACTTCGGTCCCATCTTCATGACCATCCCAGCGTTC
TTTGCCAAGAGCGCCGCCATCTACAACCCTGTCATCTATATCATGATGAACAAGCAGTTCCGGAACTG
CATGCTCACCACCATCTGCTGCGGCAAGAACCCACTGGGTGACGATGAGGCCTCTGCTACCGTGTCCA
AGACGGAGACGAGCCAGGTGGCCCCGGCCTAACCAAGAAAGCTTAAGTTTAAACCGCTGATCAGCCTC
GACTGTGCCTTCTAGTTGCCAGCCATCTGTTGTTTGCCCCTCCCCCGTGCCTTCCTTGACCCTGGAAG
GTGCCACTCCCACTGTCCTTTCCTAATAAAATGAGGAAATTGCATCGCATTGTCTGAGTAGGTGTCAT
TCTATTCTGGGGGGTGGGGTGGGGCAGGACAGCAAGGGGGAGGATTGGGAAGACAATAGCAGGCATGC
TGGGGATGCGGTGGGCTCTATGGC (SEQ ID NO:24)

AAV5GRK1miR708_708hRho (AAV5 vector with rhodopsin kinase promoter driving expression of miR-708 in a miR-708 scaffold and human rhodopsin minus the miR-708 target sequence)

GGGCCCCAGAAGCCTGGTGGTTGTTTGTCCTTCTCAGGGGAAAAGTGAGGCGGCCCCTTGGAGGAAGG
GGCCGGGCAGAATGATCTAATCGGATTCCAAGCAGCTCAGGGGATTGTCTTTTTCTAGCACCTTCTTG
CCACTCCTAAGCGTCCTCCGTGACCCCGGCTGGGATTTAGCCTGGTGCTGTGTCAGCCCCGGTCTCCC
AGGGGCTTCCCAGTGGTCCCCAGGAACCCTCGACAGGGCCCGGTCTCTCTCGTCCAGCAAGGGCAGGG
ACGGGCCACAGGCCAAGGGCACTAGAAGCTTTATTGCGGTAGTTTATCACAGTTAAATTGCTAACGCA
GTCAGTGCTTCTGACACAACAGTCTCGAACTTAAGCTGCAGTGACTCTCTTAAGGTAGCCTTGCAGAA
GTTGGTCGTGAGGCACTGGGCAGGTAAGTATCAAGGTTACAAGACAGGTTTAAGGAGACCAATAGAAA
CTGGGCTTGTCGAGACAGAGAAAAACCTAACCCCCATGGTTGGCGAGGGACTGCTGTGTGTGAAATGG
TAACTGCCCTCAAGGAGCTTACAATCTAGCTGGGGGTAAATGACTTGCACATGAACACAACTAGACTG
TGAGCTTCTAGAGGGCAGGGACCTTACCCTAGTCATCTCTCTTCTCACCCTGCACACCCTCCCTGAGG
GATCTCATGACTCTTGCGTTTCTGATAGGCACCTATTGGTCTTACTGACATCCACTTTGCCTTTCTCT
CCACAGGTGTCCACTCCCAGTTCACACCGGCACAATGAATGGCACAGAAGGCCCTAACTTCTACGTGC
CCTTCTCCAATGCGACGGGTGTGGTACGCAGCCCCTTCGAGTACCCACAGTACTACCTGGCTGAGCCA
TGGCAGTTCTCCATGCTGGCCGCCTACATGTTTCTGCTGATCGTGCTGGGCTTCCCCATCAACTTCCT
CACGCTCTACGTCACCGTCCAGCACAAGAAGCTGCGCACGCCTCTCAACTACATCCTGCTCAACCTAG
CCGTGGCTGACCTCTTCATGGTCCTAGGTGGCTTCACCAGCACCCTCTACACCTCTCTGCATGGATAC
TTCGTCTTCGGGCCCACAGGATGCAATTTGGAGGGCTTCTTTGCCACCCTGGGCGGTGAAATTGCCCT
GTGGTCCTTGGTGGTCCTGGCCATCGAGCGGTACGTGGTGGTGTGTAAGCCCATGAGCAACTTCCGCT
TCGGGGAGAACCATGCCATCATGGGCGTTGCCTTCACCTGGGTCATGGCGCTGGCCTGCGCCGCACCC
CCACTCGCCGGCTGGTCCAGGTACATCCCCGAGGGCCTGCAGTGCTCGTGTGGAATCGACTACTACAC
GCTCAAGCCGGAGGTCAACAACGAGTCTTTTGTCATCTACATGTTCGTGGTCCACTTCACCATCCCCA
TGATTATCATCTTTTTCTGCTATGGGCAGCTCGTCTTCACCGTCAAGGAGGCCGCTGCCCAGCAGCAG
GAGTCAGCCACCACACAGAAGGCAGAGAAGGAGGTCACCCGCATGGTCATCATCATGGTCATCGCTTT
CCTGATCTGCTGGGTGCCCTACGCCAGCGTGGCATTCTACATCTTCACCCACCAGGGCTCCAACTTCG

GTCCCATCTTCATGACCATCCCAGCGTTCTTTGCCAAGAGCGCCGCCATCTACAACCCTGTCATCTAT
ATCATGATGAACAAGCAGTTCCGGAACTGCATGCTCACCACCATCTGCTGCGGCAAGAACCCACTGGG
TGACGATGAGGCCTCTGCTACCGTGTCCAAGACGGAGACGAGCCAGGTGGCCCCGGCCTAACCAAGAA
AGCTTAAGTTTAAACCGCTGATCAGCCTCGACTGTGCCTTCTAGTTGCCAGCCATCTGTTGTTTGCCC
CTCCCCCGTGCCTTCCTTGACCCTGGAAGGTGCCACTCCCACTGTCCTTTCCTAATAAAATGAGGAAA
TTGCATCGCATTGTCTGAGTAGGTGTCATTCTATTCTGGGGGGTGGGGTGGGGCAGGACAGCAAGGGG
GAGGATTGGGAAGACAATAGCAGGCATGCTGGGGATGCGGTGGGCTCTATGGC (SEQ ID NO:25)

AAV5OPSmiR708_155hRho (AAV5 vector with opsin promoter driving expression of miR-708 in a miR-155 scaffold and human rhodopsin minus the miR-708 target sequence)

ACGCGTTTTCTGCAGCGGGGATTAATATGATTATGAACACCCCCAATCTCCCAGATGCTGATTCAGCC
AGGAACTAGTTATTAATAGTAATCAATTACGGGGTCATTAGTTCATAGCCCATATATGGAGTTCCGCG
TTACATAACTTACGGTAAATGGCCCGCCTGGCTGACCGCCCAACGACCCCCGCCCATTGACGTCAATA
ATGACGTATGTTCCCATAGTAACGCCAATAGGGACTTTCCATTGACGTCAATGGGTGGAGTATTTACG
GTAAACTGCCCACTTGGCAGTACATCAAGTGTATCATATGCCAAGTACGCCCCCTATTGACGTCAATG
ACGGTAAATGGCCCGCCTGGCATTATGCCCAGTACATGACCTTATGGGACTTTCCTACTTGGCAGTAC
ATCTACGTATTAGTCATCGCTATTACCACAAATAGTTATCGAGCCGCTGAGCCGGGGGGCGGGGGGTG
TGAGACTGGAGGCGATGGACGGAGCTGACGGCACACACAGCTCAGATCTGTCAAGTGAGCCATTGTCA
GGGCTTGGGGACTGGATAAGTCAGGGGGTCTCCTGGGAAGAGATGGGATAGGTGAGTTCAGGAGGAGA
CATTGTCAACTGGAGCCATGTGGAGAAGTGAATTTAGGGCCCAAAGGTTCCAGTCGCAGCCTGAGGCC
ACCAGACTGACATGGGGAGGAATTCCCAGAGGACTCTGGGGCAGACAAGATGAGACACCCTTTCCTTT
CTTTACCTAAGGGCCTCCACCCGATGTCACCTTGGCCCCTCTGCAAGCCAATTAGGCCCCGGTGGCAG
CAGTGGGATTAGCGTTAGTATGATATCTCGCGGATGCTGAATCAGCCTCTGGCTTAGGGAGAGAAGGT
CACTTTATAAGGGTCTGGGGGGGGTCAGTGCCTGGAGTTGCGCTGTGGGAGCCGTCAGTGGCTGAGCT
CAACTAGAAGCTTTATTGCGGTAGTTTATCACAGTTAAATTGCTAACGCAGTCAGTGCTTCTGACACA
ACAGTCTCGAACTTAAGCTGCAGTGACTCTCTTAAGGTAGCCTTGCAGAAGTTGGTCGTGAGGCACTG
GGCAGGTAAGTATCAAGGTTACAAGACAGGTTTAAGGAGACCAATAGAAACTGGGCTTGTCGAGACAG
AGAATGGATCCTGGAGGCTTGCTGAAGGCTGTATGCTGAAGGAGCTTACAATCTAGCTGGGGTTTTGG
CCACTGACTGACCCCAGCTAGTGTAAGCTCCTTCAGGACACAAGGCCTGTTACTAGCACTCACATGGA
ACAAATGGCCCAGATCTGAGACTCTTGCGTTTCTGATAGGCACCTATTGGTCTTACTGACATCCACTT
TGCCTTTCTCTCCACAGGTGTCCACTCCCAGTTCACACCGGCACAATGAATGGCACAGAAGGCCCTAA
CTTCTACGTGCCCTTCTCCAATGCGACGGGTGTGGTACGCAGCCCCTTCGAGTACCCACAGTACTACC
TGGCTGAGCCATGGCAGTTCTCCATGCTGGCCGCCTACATGTTTCTGCTGATCGTGCTGGGCTTCCCC
ATCAACTTCCTCACGCTCTACGTCACCGTCCAGCACAAGAAGCTGCGCACGCCTCTCAACTACATCCT
GCTCAACCTAGCCGTGGCTGACCTCTTCATGGTCCTAGGTGGCTTCACCAGCACCCTCTACACCTCTC
TGCATGGATACTTCGTCTTCGGGCCCACAGGATGCAATTTGGAGGGCTTCTTTGCCACCCTGGGCGGT
GAAATTGCCCTGTGGTCCTTGGTGGTCCTGGCCATCGAGCGGTACGTGGTGGTGTGTAAGCCCATGAG
CAACTTCCGCTTCGGGGAGAACCATGCCATCATGGGCGTTGCCTTCACCTGGGTCATGGCGCTGGCCT
GCGCCGCACCCCCACTCGCCGGCTGGTCCAGGTACATCCCCGAGGGCCTGCAGTGCTCGTGTGGAATC
GACTACTACACGCTCAAGCCGGAGGTCAACAACGAGTCTTTTGTCATCTACATGTTCGTGGTCCACTT
CACCATCCCCATGATTATCATCTTTTTCTGCTATGGGCAGCTCGTCTTCACCGTCAAGGAGGCCGCTG
CCCAGCAGCAGGAGTCAGCCACCACACAGAAGGCAGAGAAGGAGGTCACCCGCATGGTCATCATCATG
GTCATCGCTTTCCTGATCTGCTGGGTGCCCTACGCCAGCGTGGCATTCTACATCTTCACCCACCAGGG
CTCCAACTTCGGTCCCATCTTCATGACCATCCCAGCGTTCTTTGCCAAGAGCGCCGCCATCTACAACC
CTGTCATCTATATCATGATGAACAAGCAGTTCCGGAACTGCATGCTCACCACCATCTGCTGCGGCAAG
AACCCACTGGGTGACGATGAGGCCTCTGCTACCGTGTCCAAGACGGAGACGAGCCAGGTGGCCCCGGC
CTAACCAAGAAAGCTTAAGTTTAAACCGCTGATCAGCCTCGACTGTGCCTTCTAGTTGCCAGCCATCT
GTTGTTTGCCCCTCCCCCGTGCCTTCCTTGACCCTGGAAGGTGCCACTCCCACTGTCCTTTCCTAATA
AAATGAGGAAATTGCATCGCATTGTCTGAGTAGGTGTCATTCTATTCTGGGGGGTGGGGTGGGGCAGG
ACAGCAAGGGGGAGGATTGGGAAGACAATAGCAGGCATGCTGGGGATGCGGTGGGCTCTATGGC
(SEQ ID NO:26)

AAV5OPSmiR708_708hRho (AAV5 vector with opsin promoter driving expression of miR-708 in a miR-708 scaffold and human rhodopsin minus the miR-708 target sequence)

ACGCGTTTTCTGCAGCGGGGATTAATATGATTATGAACACCCCCAATCTCCCAGATGCTGATTCAGCC
AGGAACTAGTTATTAATAGTAATCAATTACGGGGTCATTAGTTCATAGCCCATATATGGAGTTCCGCG
TTACATAACTTACGGTAAATGGCCCGCCTGGCTGACCGCCCAACGACCCCCGCCCATTGACGTCAATA
ATGACGTATGTTCCCATAGTAACGCCAATAGGGACTTTCCATTGACGTCAATGGGTGGAGTATTTACG
GTAAACTGCCCACTTGGCAGTACATCAAGTGTATCATATGCCAAGTACGCCCCCTATTGACGTCAATG
ACGGTAAATGGCCCGCCTGGCATTATGCCCAGTACATGACCTTATGGGACTTTCCTACTTGGCAGTAC
ATCTACGTATTAGTCATCGCTATTACCACAAATAGTTATCGAGCCGCTGAGCCGGGGGGCGGGGGGTG
TGAGACTGGAGGCGATGGACGGAGCTGACGGCACACACAGCTCAGATCTGTCAAGTGAGCCATTGTCA
GGGCTTGGGGACTGGATAAGTCAGGGGGTCTCCTGGGAAGAGATGGGATAGGTGAGTTCAGGAGGAGA
CATTGTCAACTGGAGCCATGTGGAGAAGTGAATTTAGGGCCCAAAGGTTCCAGTCGCAGCCTGAGGCC
ACCAGACTGACATGGGGAGGAATTCCCAGAGGACTCTGGGGCAGACAAGATGAGACACCCTTTCCTTT
CTTTACCTAAGGGCCTCCACCCGATGTCACCTTGGCCCCTCTGCAAGCCAATTAGGCCCCGGTGGCAG
CAGTGGGATTAGCGTTAGTATGATATCTCGCGGATGCTGAATCAGCCTCTGGCTTAGGGAGAGAAGGT
CACTTTATAAGGGTCTGGGGGGGGTCAGTGCCTGGAGTTGCGCTGTGGGAGCCGTCAGTGGCTGAGCT
CAACTAGAAGCTTTATTGCGGTAGTTTATCACAGTTAAATTGCTAACGCAGTCAGTGCTTCTGACACA
ACAGTCTCGAACTTAAGCTGCAGTGACTCTCTTAAGGTAGCCTTGCAGAAGTTGGTCGTGAGGCACTG
GGCAGGTAAGTATCAAGGTTACAAGACAGGTTTAAGGAGACCAATAGAAACTGGGCTTGTCGAGACAG
AGAAAAACCTAACCCCCATGGTTGGCGAGGGACTGCTGTGTGTGAAATGGTAACTGCCCTCAAGGAGC
TTACAATCTAGCTGGGGGTAAATGACTTGCACATGAACACAACTAGACTGTGAGCTTCTAGAGGGCAG
GGACCTTACCCTAGTCATCTCTCTTCTCACCCTGCACACCCTCCCTGAGGGATCTCATGACTCTTGCG
TTTCTGATAGGCACCTATTGGTCTTACTGACATCCACTTTGCCTTTCTCTCCACAGGTGTCCACTCCC
AGTTCACACCGGCACAATGAATGGCACAGAAGGCCCTAACTTCTACGTGCCCTTCTCCAATGCGACGG
GTGTGGTACGCAGCCCCTTCGAGTACCCACAGTACTACCTGGCTGAGCCATGGCAGTTCTCCATGCTG
GCCGCCTACATGTTTCTGCTGATCGTGCTGGGCTTCCCCATCAACTTCCTCACGCTCTACGTCACCGT
CCAGCACAAGAAGCTGCGCACGCCTCTCAACTACATCCTGCTCAACCTAGCCGTGGCTGACCTCTTCA
TGGTCCTAGGTGGCTTCACCAGCACCCTCTACACCTCTCTGCATGGATACTTCGTCTTCGGGCCCACA
GGATGCAATTTGGAGGGCTTCTTTGCCACCCTGGGCGGTGAAATTGCCCTGTGGTCCTTGGTGGTCCT
GGCCATCGAGCGGTACGTGGTGGTGTGTAAGCCCATGAGCAACTTCCGCTTCGGGGAGAACCATGCCA
TCATGGGCGTTGCCTTCACCTGGGTCATGGCGCTGGCCTGCGCCGCACCCCCACTCGCCGGCTGGTCC
AGGTACATCCCCGAGGGCCTGCAGTGCTCGTGTGGAATCGACTACTACACGCTCAAGCCGGAGGTCAA
CAACGAGTCTTTTGTCATCTACATGTTCGTGGTCCACTTCACCATCCCCATGATTATCATCTTTTTCT
GCTATGGGCAGCTCGTCTTCACCGTCAAGGAGGCCGCTGCCCAGCAGCAGGAGTCAGCCACCACACAG
AAGGCAGAGAAGGAGGTCACCCGCATGGTCATCATCATGGTCATCGCTTTCCTGATCTGCTGGGTGCC
CTACGCCAGCGTGGCATTCTACATCTTCACCCACCAGGGCTCCAACTTCGGTCCCATCTTCATGACCA
TCCCAGCGTTCTTTGCCAAGAGCGCCGCCATCTACAACCCTGTCATCTATATCATGATGAACAAGCAG
TTCCGGAACTGCATGCTCACCACCATCTGCTGCGGCAAGAACCCACTGGGTGACGATGAGGCCTCTGC
TACCGTGTCCAAGACGGAGACGAGCCAGGTGGCCCCGGCCTAACCAAGAAAGCTTAAGTTTAAACCGC
TGATCAGCCTCGACTGTGCCTTCTAGTTGCCAGCCATCTGTTGTTTGCCCCTCCCCCGTGCCTTCCTT
GACCCTGGAAGGTGCCACTCCCACTGTCCTTTCCTAATAAAATGAGGAAATTGCATCGCATTGTCTGA
GTAGGTGTCATTCTATTCTGGGGGGTGGGGTGGGGCAGGACAGCAAGGGGGAGGATTGGGAAGACAAT
AGCAGGCATGCTGGGGATGCGGTGGGCTCTATGGC (SEQ ID NO:27)

Cone Rod Homeobox Containing Transcription Factor

AGAGGACTAAGCCACAGGTGAGGAGAAAGGGGGGGGGGGGTCTGCTGACCCAGCAACACTCTTTCCTT
CTGAGGCTTAAGAGCTATTAGCGTAGGTGACTCAGTCCCTAATCCTCCATTCAATGCCCTGTGACTGC
CCCTGCTTC (SEQ ID NO:28)

CMV Enhancer

ACTAGTTATTAATAGTAATCAATTACGGGGTCATTAGTTCATAGCCCATATATGGAGTTCCGCGTTAC
ATAACTTACGGTAAATGGCCCGCCTGGCTGACCGCCCAACGACCCCCGCCCATTGACGTCAATAATGA
CGTATGTTCCCATAGTAACGCCAATAGGGACTTTCCATTGACGTCAATGGGTGGAGTATTTACGGTAA
ACTGCCCACTTGGCAGTACATCAAGTGTATCATATGCCAAGTACGCCCCCTATTGACGTCAATGACGG
TAAATGGCCCGCCTGGCATTATGCCCAGTACATGACCTTATGGGACTTTCCTACTTGGCAGTACATCT
ACGTATTAGTCATCGCTATTACCA (SEQ ID NO:29)

Neural retinal basic leucine zipper factor

TTTCTGCAGCGGGGATTAATATGATTATGAACACCCCCAATCTCCCAGATGCTGATTCAGCCAGGA
(SEQ ID NO:30)

CLAIMS

What is claimed is:

1. A method for treating retinitis pigmentosa in a mammal, comprising administering to the eye of the mammal a recombinant adeno-associated virus (rAAV) viral particle comprising a rAAV vector comprising nucleic acid encoding a miR-708.

2. A method for treating endoplasmic reticulum (ER) stress in a cell of a mammal, comprising administering to the mammal a rAAV viral particle comprising a rAAV vector comprising nucleic acid encoding a miR-708.

3. The method of claim 2, wherein the rAAV particle is administered to an eye of the mammal, optionally wherein the mammal has or is at risk of having retinitis pigmentosa.

4. The method claim 2 or 3, wherein the cell is an ocular cell.

5. The method of claim 4, wherein the cell is a photoreceptor cell.

6. The method of claim 5, wherein the cell is a rod photoreceptor cell.

7. The method of any one of claims 1-6, wherein the method comprises reducing one or more cellular markers of ER stress.

8. The method of claim 7, wherein the one or more cellular marker of ER stress is spliced XBP-1, CHOP or Grp78.

9. The method of any one of claims 1-8, wherein the rAAV vector comprises nucleic acid encodes miR-708 and rhodopsin.

10. The method of any one of claims 1-8, further comprising administering to the eye of the mammal a second rAAV viral particle comprising a second rAAV vector comprising nucleic acid encoding rhodopsin.

11. A method for treating retinitis pigmentosa in a mammal, comprising administering to the eye of the mammal or the cell a rAAV viral particle comprising a rAAV vector comprising nucleic acid encoding a miR-708 and rhodopsin.

12. The method of any one of claims 1-11, wherein the nucleic acid encoding miR-708 is operably linked to a promoter.

13. The method of claim 12, wherein the promoter is capable of expressing the miR-708 in photoreceptor cells.

14. The method of claim 12 or 13, wherein the promoter comprises a rhodopsin kinase (RK) promoter or an opsin promoter.

15. The method of any one of claims 9-11, wherein the nucleic acid encoding rhodopsin is operably linked to a promoter.

16. The method of claim 15, wherein the promoter is capable of expressing the rhodopsin in photoreceptor cells.

17. The method of claim 15 or 16, wherein the promoter comprises a RK promoter or an opsin promoter.

18. The method of claim 9, wherein i) the nucleic acid encoding miR-708 and the nucleic acid encoding rhodopsin are operably linked to one RK promoter; or ii) the nucleic acid encoding miR-708 is operably linked to a first RK promoter or a first opsin promoter and the nucleic acid encoding rhodopsin is operably linked to a second RK promoter or a second opsin promoter.

19. The method of claim 18, wherein the nucleic acid encoding miR-708 is 5' to the nucleic acid encoding rhodopsin.

20. The method of claim 18, wherein the nucleic acid encoding miR-708 is 3' to the nucleic acid encoding rhodopsin.

21. The method of claim 12 or 15, wherein the promoter is the chicken β-actin (CBA) promoter.

22. The method of any one of claims 12-21, wherein a sequence derived from a minute virus of mouse (MVM) intron is located 3' to the promoter , wherein optionally the MMV intron comprises the nucleotide sequence of SEQ ID NO:23.

23. The method of any one of claims 12-22, wherein the promoter further comprises

i) a CMV enhancer;

ii) a sequence derived from a photoreceptor specific transcription factor;

iii) a sequence derived from a rod photoreceptor specific transcription factor;

iv) a sequence derived from a neural retinal basic zipper factor;

v) a sequence derived from a cone rod homeobox-containing transcription factor sequence;

vi) a CMV enhancer and at least one or more of a sequence derived from a photoreceptor specific transcription factor, a sequence derived from a rod photoreceptor specific transcription factor, a sequence derived from a neural retinal basic zipper factor; a sequence derived from a cone rod homeobox-containing transcription factor sequence,;

vii) a neural retinal basic leucine zipper factor, a CMV enhancer and an Opsin promoter (-500 to +17);

viii) a neural retinal basic leucine zipper factor, a CMV enhancer, an Opsin promoter (-500 to +17), and an MVM intron;

ix) a CMV enhancer comprising SEQ ID NO:29;

x) a neural retinal basic leucine zipper factor sequence comprising SEQ ID NO:30;

xi) a sequence derived from a cone rod homeobox-containing transcription factor sequence comprising SEQ ID NO:28;;

xii) a CMV enhancer comprising SEQ ID NO:29 and at least one or more of a sequence derived from a photoreceptor specific transcription factor, a sequence derived from a rod photoreceptor specific transcription factor, a sequence derived from a neural retinal basic zipper factor comprising SEQ ID NO:30; a sequence derived from a cone rod homeobox-containing transcription factor sequence comprising SEQ ID NO:28;

xiii) a neural retinal basic leucine zipper factor comprising SEQ ID NO:30, a CMV enhancer comprising SEQ ID NO:29 and an Opsin promoter (-500 to +17) comprising SEQ ID NO:22; or

xiv) a neural retinal basic leucine zipper factor comprising SEQ ID NO:30, a CMV enhancer comprising SEQ ID NO:29, an Opsin promoter (-500 to +17) comprising SEQ ID NO:22, and an MVM intron comprising SEQ ID NO:23.

24. The method of any one of claims 1-23, wherein the nucleic acid encoding miR-708 is embedded in an intron.

25. The method of any one of claims 1-24, wherein the nucleic acid encoding miR-708 comprises an endogenous miR-708 scaffold or a miR-155 scaffold.

26. The method of any one of claims 9-25 wherein the rhodopsin is human rhodopsin.

27. The method of any one of claims 9-26, wherein the nucleic acid encoding rhodopsin comprises a substitution, insertion or deletion of nucleic acid in the miR-708 target sequence.

28. The method of claim 27, wherein the substitution, insertion or deletion reduces or prevents recognition by miR-708.

29. The method of any one of claims 9-28, wherein the rhodopsin lacks the 3' untranslated region (UTR) miR-708 target sequence.

30. The method of any one of claims 9-29, wherein the nucleic acid encoding rhodopsin comprises a substitution, insertion or deletion of nucleic acid in the miR-708 target sequence wherein the miR-708 target sequence is SEQ ID NO:19.

31. The method of any one of claims 9-30, wherein expression of the rhodopsin is refractory to suppression by miR-708.

32. The method of any one of claims 1-31, wherein the nucleic acid encoding miR-708 comprises the nucleic acid of SEQ ID NO:1.

33. The method of any one of claims 1-31, wherein the nucleic acid encoding miR-708 comprises a nucleic acid having about at least 85% identity to SEQ ID NO:1.

34. The method of any one of claims 9-33, wherein the rhodopsin comprises the amino acid sequence of SEQ ID NO:2.

35. The method of any one of claims 9-33, wherein the rhodopsin comprises an amino acid sequence having about at least 85% identity to SEQ ID NO:2.

36. The method of any one of claims 9-34, wherein the nucleic acid encoding the rhodopsin comprises nucleic acid of SEQ ID NO:3.

37. The method of any one of claims 9-34, wherein the nucleic acid encoding the rhodopsin comprises a nucleic acid having about 85% identity to SEQ ID NO:3.

38. The method of any one of claims 1-8 or 10, wherein the AAV viral particle comprises a recombinant viral genome comprising a polynucleotide of SEQ ID NO:5.

39. The method of any one of claims 1-9 or 11, wherein the AAV viral particle comprises a recombinant viral genome comprising a polynucleotide of SEQ ID NO:6 SEQ ID NO:7, SEQ ID NO:24, SEQ ID NO:25, SEQ ID NO:26, or SEQ ID NO:27.

40. The method of any one of claims 1-8 or 10, wherein the AAV viral particle comprises a recombinant viral genome comprising a polynucleotide having about at least 85% identity to SEQ ID NO:5.

41. The method of any one of claims 1-9 or 11, wherein the AAV viral particle comprises a recombinant viral genome comprising a polynucleotide having about at least 85% identity to SEQ ID NO:6, SEQ ID NO:7, SEQ ID NO:24, SEQ ID NO:25, SEQ ID NO:26, or SEQ ID NO:27.

42. The method of any one of claims 1-41, wherein the AAV viral particle and/or the second AAV viral particle comprises an AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV2/2-7m8, AAV DJ, AAV2 N587A, AAV2 E548A, AAV2 N708A, AAV V708K, a goat AAV, AAV1/AAV2 chimeric, bovine AAV, or mouse AAV capsid rAAV2/HBoV1 serotype capsid.

43. The method of any one of claims 1-42, wherein the rAAV viral particle and/or the second rAAV viral particle comprise an AAV serotype 5 capsid.

44. The method of claim 43, wherein the rAAV viral particle and/or the second rAAV viral particle comprise an AAV serotype 5 tyrosine mutant capsid.

45. The method of any one of claims 1-44, wherein the rAAV vector and/or the second rAAV vector comprise AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV DJ, a goat AAV, bovine AAV, or mouse AAV serotype inverted terminal repeats (ITRs).

46. The method claim 45, wherein the rAAV vector and/or the second rAAV vector comprise AAV serotype 2 ITRs.

47. The method of any one of claims 1-46, wherein the ITR and the capsid of the rAAV viral particle are derived from the same AAV serotype.

48. The method of any one of claims 1-46, wherein the ITR and the capsid of the rAAV viral particles are derived from different AAV serotypes.

49. The method of claim 48, wherein the rAAV viral particle comprises an AAV-5 capsid, and wherein the vector comprises AAV2 ITRs.

50. The method of claim 48 or 49, wherein the rAAV viral particle comprises an AAV-5 tyrosine mutant capsid, and wherein the vector comprises AAV2 ITRs.

51. The method of any one of claims 1-50, wherein the rAAV particles are injected into the subretinal space of the retina of the mammal.

52. The method of claim 51, wherein the rAAV is administered to more than one location of the subretinal space of the retina of the mammal.

53. The method of any one of claims 1-51, wherein the rAAV particles are injected intravitreally to the mammal.

54. The method of any one of claims 1-53, wherein at least 10-30% of the photoreceptor cells are transduced by the AAV.

55. The method of any one of claims 1-54, wherein the mammal has a mutation in the endogenous rhodopsin gene.

56. The method of claim 55, wherein the mutation in the endogenous rhodopsin gene is an autosomal dominant mutation.

57. The method of any one of claims 1 or 3-56, wherein the retinitis pigmentosa is autosomal dominant retinitis pigmentosa or autosomal recessive retinitis pigmentosa.

58. The method of any one of claims 1-59, wherein the mammal is a human.

59. The method of claim 58, wherein the human has a P23H mutation in the endogenous rhodopsin gene.

60. The method of claim 10, wherein the rAAV viral particle encoding the miR-708 and the second rAAV viral particle encoding the rhodopsin are administered to the mammal at the same time or the rAAV viral particle encoding the miR-708 and the rAAV viral particle encoding the rhodopsin are administered to the mammal sequentially.

61. The method of claim 60, wherein the rAAV viral particle encoding the miR-708 is administered to the mammal first and the rAAV viral particle encoding the rhodopsin is administered to the mammal second or the rAAV viral particle encoding the rhodopsin is administered to the mammal first and the rAAV viral particle encoding the miR-708 is administered to the mammal second.

62. The method of any one of claims 1-60, wherein the rAAV viral particles are in a pharmaceutical composition, wherein optionally the pharmaceutical composition further comprises a pharmaceutically acceptable carrier.

63. A rAAV particle, and optionally a second rAAV particle according to any one of claims 1-62.

64. The rAAV particle, and optionally the second rAAV particle of claim 63 for use in the methods of any one of claims 1-62.

65. A rAAV particle comprising nucleic acid encoding a miR-708.

66. The rAAV particle of claim 65, wherein the rAAV vector comprising nucleic acid encoding a miR-708 further encodes rhodopsin.

67. The rAAV particle of claim 65, further comprising a second rAAV viral particle comprising a second rAAV vector comprising nucleic acid encoding a rhodopsin.

68. The rAAV particle of any one of claims 65-67, wherein the nucleic acid encoding miR-708 is operably linked to a promoter.

69. The rAAV particle of claim 68, wherein the promoter is capable of expressing the miR-708 in photoreceptor cells.

70. The rAAV particle of claim 68 or 69, wherein the promoter comprises a RK promoter or an opsin promoter.

71. The rAAV particle of any one of claims 66 or 67, wherein the nucleic acid encoding rhodopsin is operably linked to a promoter.

72. The rAAV particle of claim 71, wherein the promoter is capable of expressing the rhodopsin in photoreceptor cells.

73. The rAAV particle of claim 71 or 72, wherein the promoter comprises a RK promoter or an opsin promoter.

74. The rAAV particle of any one of claim 73, wherein i) the nucleic acid encoding miR-708 and the nucleic acid encoding rhodopsin are operably linked to one RK promoter or opsin promoter; or ii) the nucleic acid encoding miR-708 is operably linked to a first RK

promoter or a first opsin promoter and the nucleic acid encoding rhodopsin is operably linked to a second RK promoter or a second opsin promoter.

75. The rAAV particle of claim 74, wherein the nucleic acid encoding miR-708 is 5' to the nucleic acid encoding rhodopsin.

76. The rAAV particle of claim 74, wherein the nucleic acid encoding miR-708 is 3' to the nucleic acid encoding rhodopsin.

77. The rAAV particle of claim 68 or 71, wherein the promoter is the chicken β-actin (CBA) promoter.

78. The rAAV particle of any one of claims 68-77, wherein a sequence derived from a minute virus of mouse (MVM) intron is located 3' to the promoter, wherein optionally the MMV intron comprises the nucleotide sequence of SEQ ID NO:23.

79. The method of any one of claims 68-78, wherein the promoter further comprises

i) a CMV enhancer;

ii) a sequence derived from a photoreceptor specific transcription factor;

iii) a sequence derived from a rod photoreceptor specific transcription factor;

iv) a sequence derived from a neural retinal basic zipper factor;

v) a sequence derived from a cone rod homeobox-containing transcription factor sequence;

vi) a CMV enhancer and at least one or more of a sequence derived from a photoreceptor specific transcription factor, a sequence derived from a rod photoreceptor specific transcription factor, a sequence derived from a neural retinal basic zipper factor; a sequence derived from a cone rod homeobox-containing transcription factor sequence;

vii) a neural retinal basic leucine zipper factor, a CMV enhancer and an Opsin promoter (-500 to +17);

viii) a neural retinal basic leucine zipper factor, a CMV enhancer, an Opsin promoter (-500 to +17), and an MVM intron;

ix) a CMV enhancer comprising SEQ ID NO:29;

x) a neural retinal basic leucine zipper factor sequence comprising SEQ ID NO:30;

xi) a sequence derived from a cone rod homeobox-containing transcription factor sequence comprising SEQ ID NO:28;;

xii) a CMV enhancer comprising SEQ ID NO:29 and at least one or more of a sequence derived from a photoreceptor specific transcription factor, a sequence derived from a rod photoreceptor specific transcription factor, a sequence derived from a neural retinal basic zipper factor comprising SEQ ID NO:30; a sequence derived from a cone rod homeobox-containing transcription factor sequence comprising SEQ ID NO:28;

xiii) a neural retinal basic leucine zipper factor comprising SEQ ID NO:30, a CMV enhancer comprising SEQ ID NO:29 and an Opsin promoter (-500 to +17) comprising SEQ ID NO:22; or

xiv) a neural retinal basic leucine zipper factor comprising SEQ ID NO:30, a CMV enhancer comprising SEQ ID NO:29, an Opsin promoter (-500 to +17) comprising SEQ ID NO:22, and an MVM intron comprising SEQ ID NO:23.

80. The rAAV particle of any one of claims 65-79, wherein the nucleic acid encoding miR-708 is embedded in an intron.

81. The rAAV particle of any one of claims 65-80, wherein the nucleic acid encoding miR-708 comprises an endogenous miR-708 scaffold or a miR-155 scaffold.

82. The rAAV particle of any one of claims 66-81, wherein the rhodopsin is human rhodopsin.

83. The method of any one of claims 66-82, wherein the nucleic acid encoding rhodopsin comprises a substitution, insertion or deletion of nucleic acid in the miR-708 target sequence.

84. The method of claim 83, wherein the substitution, insertion or deletion reduces or prevents recognition by miR-708.

85. The rAAV particle of any one of claims 66-84, wherein the rhodopsin lacks the 3' UTR miR-708 target sequence.

86. The rAAV particle of any one of claims 66-85, wherein the nucleic acid encoding rhodopsin comprises a substitution, insertion or deletion of nucleic acid in the miR-708 target sequence wherein the miR-708 target sequence is SEQ ID NO:19.

87. The rAAV particle of any one of claims 65-86, wherein expression of the rhodopsin is refractory to suppression by miR-708.

88. The rAAV particle of any one of claims 65-87, wherein the nucleic acid encoding miR-708 comprises the nucleic acid of SEQ ID NO:1.

89. The rAAV particle of any one of claims 65-88, wherein the nucleic acid encoding miR-708 comprises a nucleic acid having about at least 85% identity to SEQ ID NO:1.

90. The rAAV particle of any one of claims 66-89, wherein the rhodopsin comprises the amino acid sequence of SEQ ID NO:2.

91. The rAAV particle of any one of claims 66-90, wherein the rhodopsin comprises an amino acid sequence having about at least 85% identity to SEQ ID NO:2.

92. The rAAV particle of any one of claims 66-90, wherein the nucleic acid encoding the rhodopsin comprises nucleic acid of SEQ ID NO:3.

93. The rAAV particle of any one of claims 66-90, wherein the nucleic acid encoding the rhodopsin comprises a nucleic acid having about 85% identity to SEQ ID NO:3.

94. The rAAV particle of claim 65 or 66, wherein the AAV viral particle comprises a recombinant viral genome comprising a polynucleotide of SEQ ID NO:5.

95. The rAAV particle of any one of claims 66 or 68-73, wherein the AAV viral particle comprises a recombinant viral genome comprising a polynucleotide of SEQ ID NO:6, SEQ ID NO:7, SEQ ID NO:24, SEQ ID NO:25, SEQ ID NO:26, or SEQ ID NO:27.

96. The rAAV particle of claim 65 or 67, wherein the AAV viral particle comprises a recombinant viral genome comprises a polynucleotide having about at least 85% identity to SEQ ID NO:5.

97. The rAAV particle of any one of claims 66 or 68-73, wherein the AAV viral particle comprises a recombinant viral genome comprises a polynucleotide having about at least 85% identity to SEQ ID NO:6 SEQ ID NO:7, SEQ ID NO:24, SEQ ID NO:25, SEQ ID NO:26, or SEQ ID NO:27.

98. The rAAV particle of any one of claims 65-97, wherein the AAV viral particle comprises an AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV2/2-7m8, AAV DJ, AAV2 N587A, AAV2 E548A, AAV2 N708A, AAV V708K, a goat AAV, AAV1/AAV2 chimeric, bovine AAV, or mouse AAV capsid rAAV2/HBoV1 serotype capsid.

99. The rAAV particle of any one of claims 65-98, wherein the rAAV viral particle comprises an AAV serotype 5 capsid.

100. The rAAV particle of claim 98 or 99, wherein the rAAV viral particle comprises an AAV serotype 5 tyrosine mutant capsid.

101. The rAAV particle of any one of claims 65-100, wherein the rAAV vector comprises AAV1, AAV2, AAV3, AAV4, AAV5, AAV6, AAV7, AAV8, AAVrh8, AAVrh8R, AAV9, AAV10, AAVrh10, AAV11, AAV12, AAV2R471A, AAV DJ, a goat AAV, bovine AAV, or mouse AAV serotype inverted terminal repeats (ITRs).

102. The rAAV particle of any one of claims 65-101, wherein the vector comprises AAV serotype 2 ITRs.

103. The rAAV particle of any one of claims 65-102, wherein the ITR and the capsid of the rAAV viral particle are derived from the same AAV serotype.

104. The rAAV particle of any one of claims 65-102, wherein the ITR and the capsid of the rAAV viral particles are derived from different AAV serotypes.

105. The rAAV particle of claim 104, wherein the rAAV viral particle comprises an AAV-5 capsid, and wherein the vector comprises AAV2 ITRs.

106. The rAAV particle of claim 105, wherein the rAAV viral particle comprises an AAV-5 tyrosine mutant capsid, and wherein the vector comprises AAV2 ITRs.

107. A composition comprising the rAAV particle of any one of claims 65-106.

108. A composition comprising a rAAV particle comprising a rAAV vector comprising nucleic acid encoding miR-708 according to any one of claims 1-62, and optionally a second rAAV particle comprising a rAAV vector comprising nucleic acid encoding rhodopsin, used in the methods of any one of claims 1-62.

109. The composition of claim 107 or 108 for use in the method of any one of claims 1-62.

110. The composition of any one of claims 107-108, wherein the composition is a pharmaceutical composition, wherein optionally the pharmaceutical composition further comprises a pharmaceutically acceptable carrier.

111. A kit comprising an effective amount of rAAV particles according to the methods of any one of claims 1-62.

112. A kit comprising an effective amount of rAAV particles according to any one of claims 63-106.

113. A kit comprising an effective amount of the composition of any one of claims 107-110.

114. A kit comprising an effective amount of rAAV particles comprising a rAAV vector comprising nucleic acid encoding miR-708.

115. A kit comprising an effective amount of rAAV particles comprising a rAAV vector comprising nucleic acid encoding miR-708 and rhodopsin.

116. A kit comprising an effective amount of rAAV particles comprising a rAAV vector comprising nucleic acid encoding miR-708 and an effective amount of second rAAV particles comprising a second rAAV vector comprising nucleic acid encoding rhodopsin.

117. The kit of any one of claims 118-122, further comprising instructions for use of the rAAV particles in the treatment of retinitis pigmentosa and/or treatment of ER stress.

118. An article of manufacture comprising an effective amount of rAAV particles according to the methods of any one of claims 1-62.

119. An article of manufacture comprising an effective amount of rAAV particles according to any one of claims 63-106.

120. An article of manufacture comprising an effective amount of the composition of any one of claims 107-110.

121. An article of manufacture comprising an effective amount of rAAV particles comprising a rAAV vector comprising nucleic acid encoding miR-708.

122. An article of manufacture comprising an effective amount of rAAV particles comprising a rAAV vector comprising nucleic acid encoding miR-708 rhodopsin.

123. An article of manufacture comprising an effective amount of rAAV particles comprising a rAAV vector comprising nucleic acid encoding miR-708 and an effective

amount of second rAAV particles comprising a second rAAV vector comprising nucleic acid encoding rhodopsin.

124. A nucleic acid comprising an intron derived from an MVM.

125. The nucleic acid of claim 124 wherein the MVM intron comprises SEQ ID NO:23.

126. The nucleic acid of claim 124 or 125, further comprising a promoter and optionally an enhancer.

127. The nucleic acid of claim 126, wherein the promoter is located 5' to the MVM intron.

128. An expression construct comprising the nucleic acid of any one of claims 124-127.

129. A vector comprising the nucleic acid of any one of claims 124-127 or the expression construct of claim 128.

130. A cell comprising the nucleic acid of any one of claims 124-127, the expression construct of claim 128 or the vector of claim 129.