Claims:

1. A composition comprising: a first water-soluble polymer having a molecular weight of about 10 kDa to 10,000 kDa, wherein the first water-soluble polymer includes a plurality of backbone units and at least one first type of a mucin-binding unit, wherein the backbone units comprise greater than 50% of the first water-soluble polymer based on molecular weight, wherein the first type of mucin-binding unit comprises of 1 unit up to 50% of the first water-soluble polymer based on molecular weight, wherein the first type of mucin-binding unit comprises monomer units having one or more pyridyl disulfide group, copolymers that include the monomer units, or both, wherein the first type of mucin-binding unit is functionalized so the water-soluble polymer has the characteristic of altering the hydration, rheology, or both of a mucin polymer, a second water-soluble polymer, or a combination thereof, wherein altering the hydration, rheology, or both is achieved through mucoadhesion, mucolability, mucointegration, or a combination thereof.

2. The composition of claim 1, wherein the backbone unit comprises monomer units, copolymers including the monomer units, or both the monomer units and the copolymers, wherein the monomer unit is selected from the group consisting of: an acrylamide monomer, a methacrylamide monomer, an acrylate monomer, a methacrylate monomer, a styrenic monomer, a vinyl pyridine monomer, a maleimide monomer, a maleic anhydride-derived monomer, a vinyl ester monomer, a vinyl ether monomer, a vinyl amide monomer, a vinyl amine monomer, a vinyl halide monomer, or a derivative of anyone of these.

3. The composition of claim 1, wherein the backbone unit comprises a monomer unit, a copolymer including the monomer unit or both, wherein the monomer unit is selected from the group consisting of: acrylamide, *N,N*-dimethylacrylamide, *N*,*N*-dialkylacrylamides, *N*-alkylacrylamides, *N,N*-dialkyl methacrylamides, *N*-alkyl methacrylamides, poly(ethlylene glycol) acrylate, poly(ethylene glycol) methacrylate, poly(ethylene glycol) acrylamide, and poly(ethylene glycol) methacrylamide.

4. The composition of any one of claims 1 to 3, wherein the monomer units having one or more pyridyl disulfide group is selected from the group consisting of: 2-(pyridin-2-yldisulfaneyl)ethyl methacrylate, pyridyl disulfide ethyl acrylate, pyridyl disulfide ethyl acrylamido, pyridyl disulfide alkyl (e.g. ethyl) methacrylamido, 2-(pyridin-2-yldisulfaneyl)ethyl acrylate, 2-(pyridin-2-yldisulfaneyl)ethyl acrylamido, 2-(pyridin-2-yldisulfaneyl)ethyl

methacrylate, or 2-(pyridin-2-yldisulfaneyl)ethyl methacrylate, a halogenated versions of each of these, or a derivative of any one of these or copolymer of anyone of these.

5. The composition of any one of claims 1 to 4, wherein the mucin-binding unit further comprises monomer units, copolymers that include the monomer units, or both, wherein the monomer unit is selected from the group consisting of: acrylic acid, methacrylic acid, 4-vinylbenzoic acid, 4-(acrylamido)phenylboronic acid, 3-(acrylamido)phenylboronic acid, (2-(3-acrylamidopropanamido)phenyl)boronic acid (APAPBA), 2-(acrylamido)phenylboronic acid, 4-vinylphenylboronic acid, 3-vinylphenylboronic acid, 2-vinylphenylboronic acid, N-(2-(tritylthio)ethyl)acrylamide, a monomer including one or more boronic acid groups, a monomer containing one or more disulfide-forming groups, a halogenated versions of each of these, or a derivative of any one of these or copolymer of anyone of these.

6. The composition of any one of claims 1 to 4, wherein the mucin-binding unit further comprises monomer units, copolymers that include the monomer units, or both, wherein the monomer unit includes a functional group selected from the group consisting of: a boronic acid group, a carboxylate group, a carboxylic acid group, a hydrogen-bonding group, a hydrophobic group, a 1,2-diol group, a 1,3-diol group, a group capable of forming disulfide linkages or a derivative of any one of these.

7. The composition of any one of claims 1 to 6, wherein the first water-soluble polymer includes a second type of mucin-binding unit, wherein the second type of mucin-binding unit comprises monomer units, copolymers that include the monomer units, or both, wherein the monomer unit is selected from the group consisting of: acrylic acid, methacrylic acid, 4-vinylbenzoic acid, 4-(acrylamido)phenylboronic acid, 3-(acrylamido)phenylboronic acid, (2-(3-acrylamidopropanamido)phenyl)boronic acid (APAPBA), 2-(acrylamido)phenylboronic acid, 4-vinylphenylboronic acid, 3-vinylphenylboronic acid, 2-vinylphenylboronic acid, 2-(pyridin-2-yldisulfaneyl)ethyl methacrylate, pyridyl disulfide ethyl acrylate, pyridyl disulfide ethyl acrylamido, pyridyl disulfide alkyl (e.g. ethyl) methacrylamido, 2-(pyridin-2-yldisulfaneyl)ethyl acrylate, 2-(pyridin-2-yldisulfaneyl)ethyl acrylamido, 2-(pyridin-2-yldisulfaneyl)ethyl methacrylate, or 2-(pyridin-2-yldisulfaneyl)ethyl methacrylate, N-(2-(tritylthio)ethyl)acrylamide, a monomer including one or more boronic acid groups, a monomer containing one or more disulfide-forming groups, a halogenated versions of each of these, or a derivative of any one of

these or copolymer of anyone of these, wherein the first type of mucin-binding unit is different than the second type of mucin-binding unit.

8. The composition of claim 7, wherein the first water-soluble polymer includes a third type of mucin-binding unit, wherein the third type of mucin-binding unit comprises monomer units, copolymers that include the monomer units, or both, wherein the monomer unit is selected from the group consisting of: acrylic acid, methacrylic acid, 4-vinylbenzoic acid, 4-(acrylamido)phenylboronic acid, 3-(acrylamido)phenylboronic acid, (2-(3-acrylamidopropanamido)phenyl)boronic acid (APAPBA), 2-(acrylamido)phenylboronic acid, 4-vinylphenylboronic acid, 3-vinylphenylboronic acid, 2-vinylphenylboronic acid, 2-(pyridin-2-yldisulfaneyl)ethyl methacrylate, pyridyl disulfide ethyl acrylate, pyridyl disulfide ethyl acrylamido, pyridyl disulfide alkyl (e.g. ethyl) methacrylamido, 2-(pyridin-2-yldisulfaneyl)ethyl acrylate, 2-(pyridin-2-yldisulfaneyl)ethyl acrylamido, 2-(pyridin-2-yldisulfaneyl)ethyl methacrylate, or 2-(pyridin-2-yldisulfaneyl)ethyl methacrylate, N-(2-(tritylthio)ethyl)acrylamide, a monomer including one or more boronic acid groups, a monomer containing one or more disulfide-forming groups, a halogenated versions of each of these, or a derivative of any one of these or copolymer of anyone of these, wherein the first type of mucin-binding unit is different than the second type of mucin-binding unit, wherein the second type of mucin-binding unit is different than the third type of mucin-binding unit monomer.

9. The composition of claim 8, wherein the first type of mucin binding unit comprises 1 functional unit to about 5% of the first water-soluble polymer based on molecular weight; wherein the second type of mucin binding unit comprises 1 functional unit to about 5% of the first water-soluble polymer based on molecular weight; wherein the third type of mucin binding unit comprises 1 functional unit to about 5% of the first water-soluble polymer based on molecular weight.

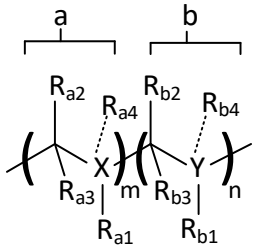
10. The composition of any one of claims 1 to 9, wherein the first water-soluble polymer has a structure that is linear or non-linear, wherein the non-linear structure is selected from the group consisting of star-like, branched, hyperbranched, cyclic, graph copolymer, or bottle brush-like.

11. The composition of any one of claims 1 to 10, wherein the first type of mucin binding unit is located solely at one or both terminal ends of the first water-soluble polymer.

12. The composition of any one of claims 1 to 11, wherein the first water-soluble polymer is a block copolymer selected from an AB diblock copolymer or an ABA triblock copolymer, optionally wherein the mucin-binding units are isolated on the A block of the AB diblock copolymer or A block of the ABA triblock copolymer.

13. The composition of any one of claims 1 to 11, wherein the first water-soluble polymer is a random copolymer or a statistical copolymer.

14. The composition of any one of claims 1 to 11, wherein the first water-soluble polymer is an alternative copolymer or a gradient copolymer.

15. The composition of claim 1, wherein the first water-soluble polymer has the following chemical structure: 

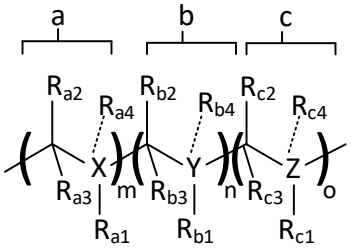
, wherein unit a is the backbone unit and m is greater than 50% of the first water-soluble polymer based on molecular weight, wherein unit b is the first type of mucin binding unit and n is 1 unit to about 50% of the first water-soluble polymer based on molecular weight,

wherein unit a and unit b are different from one another,

R_{a1}, R_{a2}, R_{a3}, R_{a4}, R_{b1}, R_{b2}, R_{b3}, and R_{b4}, independently of one another, are selected from: H, $-OR_1$, $-NR_1R_2$, $-N^+(R_1)_3$, $-N^+(R_1)_2(R_2)$, $-N^+(R_1)(R_2)(R_3)$, $-S(O)_2R_1$, $-S(O)_2OR_1$, $-S(O)_2NR_1R_2$, $-NR_1S(O)_2R_2$, $-NR_1C(O)\ R_2$, $-C(O)R_1$, $-C(O)OR_1$, $-C(O)NR_1R_2$, $-NR_1C(O)OR_2$, $-NR_1C(O)NR_1R_2$, $-OC(O)NR_1R_2$, $-NR_1S(O)_2NR_1R_2$, $-C(O)NR_1S(O)_2NR_1R_2$, catechol, a boronic acid group, and a pyridyl disulfide group, where each R_1, R_2, and R_3 is independently H or a linear or branched $C_{1\text{-}18}$ alkyl as well as $-C(O)OCH_2CH_2-OH$, $-C(O)OCH_2CH_2-N(CH_3)_2$, $-C(O)OCH_2CH_2-N^+(CH_3)_3$, $-C(O)OCH_2CH_2-OSO_3^-$, $-C(O)OCH_2CH_2-OSO_3H$, $-C(O)OCH_2CH_2-SO_3^-$, $-C(O)OCH_2CH_2-SO_3H$, and $-C(O)N(H)C((CH_3)_2)CH_2SO_3^-$, $-C(O)N(H)C((CH_3)_2)CH_2SO_3H$,

wherein one of R_{b1}, R_{b2}, R_{b3}, and R_{b4} is a pyridyl disulfide group, and

wherein X is C, and wherein Y is C.

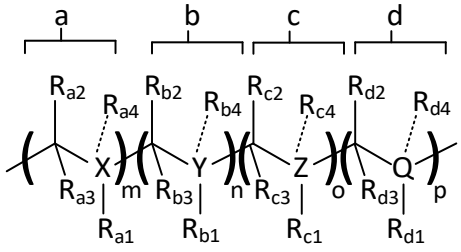
16. The composition of claim 1, wherein the first water-soluble polymer has the following chemical structure: 

, wherein unit a is the backbone unit and m is greater than 50% of the first water-soluble polymer based on molecular weight, wherein unit b is the first type of mucin binding unit and n is 1 unit to about 50% of the first water-soluble polymer based on molecular weight, wherein unit c is the second type of mucin binding unit and o is 1 unit to about 50% of the first water-soluble polymer based on molecular weight, wherein unit a, unit b and unit c are different from one another,

R_{a1}, R_{a2}, R_{a3}, R_{a4}, R_{b1}, R_{b2}, R_{b3}, R_{b4}, R_{c1}, R_{c2}, R_{c3}, and R_{c4}, independently of one another, can be H, $-OR_1$, $-NR_1R_2$, $-N^+(R_1)_3$, $-N^+(R_1)_2(R_2)$, $-N^+(R_1)(R_2)(R_3)$, $-S(O)_2R_1$, $-S(O)_2OR_1$, $-S(O)_2NR_1R_2$, $-NR_1S(O)_2R_2$, $-NR_1C(O)\ R_2$, $-C(O)R_1$, $-C(O)OR_1$, $-C(O)NR_1R_2$, $-NR_1C(O)OR_2$, $-NR_1C(O)NR_1R_2$, $-OC(O)NR_1R_2$, $-NR_1S(O)_2NR_1R_2$, $-C(O)NR_1S(O)_2NR_1R_2$, catechol, a boronic acid group, and a pyridyl disulfide group, where each R_1, R_2, and R_3 is independently H or linear or branched $C_{1\text{-}18}$ alkyl as well as $-C(O)OCH_2CH_2-OH$, $-C(O)OCH_2CH_2-N(CH_3)_2$, $-C(O)OCH_2CH_2-N^+(CH_3)_3$, $-C(O)OCH_2CH_2-OSO_3^-$, $-C(O)OCH_2CH_2-OSO_3H$, $-C(O)OCH_2CH_2-SO_3^-$, $-C(O)OCH_2CH_2-SO_3H$, and $-C(O)N(H)C((CH_3)_2)CH_2SO_3^-$, $-C(O)N(H)C((CH_3)_2)CH_2SO_3H$,,

wherein one of R_{b1}, R_{b2}, R_{b3}, and R_{b4} is a pyridyl disulfide group, and

wherein X is C, wherein Y is C, and wherein Z is C.

17. The composition of claim 1, wherein the first water-soluble polymer has chemical structure as shown below: 

, wherein unit a is the backbone unit and m is greater than 50% of the first water-soluble polymer based on molecular weight, wherein unit b is the first type of mucin binding unit and n is 1 unit to about 50% of the first water-soluble polymer based on molecular weight, wherein unit c is the second type of mucin binding unit and o is 1 unit to about 50% of the first water-soluble polymer based on molecular

weight, wherein unit d is the second type of mucin binding unit and o is 1 unit to about 50% of the first water-soluble polymer based on molecular weight, wherein unit a,unit b, unit c and unit d are different from one another,

R_{a1}, R_{a2}, R_{a3}, R_{a4}, R_{b1}, R_{b2}, R_{b3}, R_{b4}, R_{c1}, R_{c2}, R_{c3}, R_{c4}, R_{d1}, R_{d2}, R_{d3}, and R_{d4}, independently of one another, can be H, $-OR_1$, $-NR_1R_2$, $-N^+(R_1)_3$, $-N^+(R_1)_2(R_2)$, $-N^+(R_1)(R_2)(R_3)$, $-S(O)_2R_1$, $-S(O)_2OR_1$, $-S(O)_2NR_1R_2$, $-NR_1S(O)_2R_2$, $-NR_1C(O)\ R_2$, $-C(O)R_1$, $-C(O)OR_1$, $-C(O)NR_1R_2$, $-NR_1C(O)OR_2$, $-NR_1C(O)NR_1R_2$, $-OC(O)NR_1R_2$, $-NR_1S(O)_2NR_1R_2$, $-C(O)NR_1S(O)_2NR_1R_2$, catechol, a boronic acid group, and a pyridyl disulfide group, where each R_1, R_2, and R_3 is independently H or linear or branched $C_{1\text{-}18}$ alkyl as well as $-C(O)OCH_2CH_2-OH$, $-C(O)OCH_2CH_2-N(CH_3)_2$, $-C(O)OCH_2CH_2-N^+(CH_3)_3$, $-C(O)OCH_2CH_2-OSO_3^-$, $-C(O)OCH_2CH_2-OSO_3H$, $-C(O)OCH_2CH_2-SO_3^-$, $-C(O)OCH_2CH_2-SO_3H$, and $-C(O)N(H)C((CH_3)_2)CH_2SO_3^-$, $-C(O)N(H)C((CH_3)_2)CH_2SO_3H$,

wherein one of R_{b1}, R_{b2}, R_{b3}, and R_{b4} is a pyridyl disulfide group, and

wherein X is C, wherein Y is C, wherein Z is C, and wherein Q is C.

18. A synthetic method of making the first water-soluble polymer of claims 1 to 17, comprising: polymerizing a backbone unit of claims 2 or 3 and at least one mucin-binding unit of any one of claims 4 to 6 to form the first water-soluble polymer of claims 1 to 17.

19. The method of claim 18, wherein the polymerization is cationic polymerization, anionic polymerization, ring-opening polymerization, or coordination polymerization, and is selected from the group consisting of a radical polymerization, conventional radical polymerization, reversible-deactivation radical polymerization, reversible addition-fragmentation chain transfer (RAFT) polymerization, macromolecular design by interchange of xanthate (MADIX) polymerization, photoiniferter polymerization, atom transfer radical polymerization (ATRP), or stable free radical polymerization (SFRP) or optionally the polymerization is a reversible addition-fragmentation chain transfer (RAFT) polymerization, photoiniferter polymerization, or macromolecular design by interchange of xanthate (MADIX) polymerization.

20. The method of any one of the claims 18 or 19, wherein the mucin-binding unit or combination of mucin binding units is incorporated into the copolymer by a post-polymerization reaction of copolymer units.