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(54) Title: OLIGONUCLEOTIDE THERAPY FOR WILSON DISEASE

(57) Abstract: The present disclosure provides antisense oligonucleotides, compositions, and methods that target ATP7B exon 6 or a flanking intron, thereby modulating splicing of ATP7B pre-mRNA to increase the level of ATP7B mRNA molecules having exon 6, e.g., to provide a therapy for Wilson disease. The present disclosure provides an antisense oligonucleotide including a nucleobase sequence at least 70% complementary to an ATP7B target sequence in exon 6, a 5'-flanking intron, a 3'-flanking intron, or a combination of exon 6 and the 5'-flanking or 3'-flanking intron.



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OLIGONUCLEOTIDE THERAPY FOR WILSON DISEASE

FIELD OF THE INVENTION

[0001] The present invention relates to the field of oligonucleotides and their use for the treatment of disease. In particular, the invention pertains to antisense oligonucleotides that may be used in the treatment of Wilson disease.

BACKGROUND

[0002] Wilson disease is a fatal copper homeostasis disorder, typically diagnosed in patients between the ages of 5 and 35, leading to hepatic and neurologic symptoms due to free copper accumulation. The prevalence of Wilson disease is estimated to be 1 in 30,000 individuals. Impaired hepato-biliary excretion of copper may be caused by defects in the trans Golgi copper transporter ATP7B in liver hepatocytes. ATP7B is required for transport of copper from the cytoplasm to the endomembrane compartment, which is followed by the release of copper into the bile via vesicular transport from the Golgi and/or loading of copper onto apoceruloplasmin (CP) for bloodstream transport. Free copper accumulation causes direct oxidative damage to biomolecules (DNA, lipids, mitochondria) and oxidative damage/stress triggering apoptosis.

[0003] Present treatment guidelines for Wilson disease recommend an initial treatment with chelating agents, which sequester free copper and lead to its excretion, followed by maintenance treatment with chelating agents or zinc salts, which block intestinal absorption. Initial treatment with chelating agents (2-12 months) is traditionally required to remove excess copper from patients. Worsening liver condition can cause increased copper release from dead hepatocytes, as such, maintenance treatment may only be started when a stable liver condition is achieved. Maintenance treatment with zinc salts, however, is complicated by adherence difficulties and gastrointestinal side effects. Adverse effects due to chelation therapy further causes discontinuation in 20-30% patients. Chelation therapy is associated with immune reactions, reduced wound healing, neutropenia or thrombocytopenia, lymphadenopathy, proteinuria and nephrotoxicity, long-term liver iron accumulation, and spikes in free copper resulting in neurological damage.

[0004] An ATP7B mutation associated with Wilson disease is a single base pair change in exon 6 from adenosine to cytosine causing a corresponding change in amino acid 645 from methionine to arginine (M645R): chr13:52535985:A:C [hg19/b37]; NCBI Reference Sequence NG_008806.1 (SEQ ID NO: 1):g.54646T>G; NM_0053.3(ATP7B):c.1934T>G (p.Met645Arg). The M645R mutation is presumed to result in partial to complete loss-of-function based on genetic evidence and compound heterozygotes with a truncating variant typically have Wilson disease onset between ages 4-15.

[0005] Recent analysis of the M645R mutated ATP7B protein, expressed using a cDNA-encoding plasmid, indicated that the mutant protein has similar capability to uptake copper in microsomal fractions of sf9 insect cells expressing only the mutant protein, whereas all other pathogenic mutations tested showed a decrease in capability. Further research found a similar result, with the M645R mutated ATP7B protein having no biochemical defect in numerous cellular assays.

[0006] Previous analysis of the M645R and associated mutations may have failed, however, to consider the effect of such a mutation on splicing. Splicing is a natural biological mechanism that occurs within human cells. Splicing may be used to process the primary messenger ribonucleic acid (mRNA) that is transcribed from deoxyribonucleic acid (DNA), before the mRNA is translated into protein. Splicing may

involve removing one or more contiguous segments of mRNA (introns) to conjoin the remaining segments (exons), delimited by pairs of 5' splice sites and 3' splice sites. Alternative splicing, which may be the splicing together of different combinations of exons, may result in multiple mRNA transcripts from a single gene.

- 5 **[0007]** Certain human genetic diseases (e.g., caused by genetic aberrations, such as point mutations), may be caused by aberrant splicing. As such, there is a need for a splicing mediator to treat diseases that are caused by aberrant splicing.

SUMMARY OF THE INVENTION

- 10 **[0008]** In general, the invention provides an oligonucleotide including a nucleobase sequence complementary to a sequence within ATP7B exon6, a flanking intron, or a combination thereof.
- [0009]** In one aspect, the invention provides an antisense oligonucleotide including a nucleobase sequence at least 70% complementary to an ATP7B target sequence in exon 6, a 5'-flanking intron, a 3'-flanking intron, or a combination of exon 6 and the 5'-flanking or 3'-flanking intron.
- 15 **[0010]** In some embodiments, the ATP7B target sequence reduces the binding of a splicing factor to an intronic splicing silencer in the 5'-flanking or 3'-flanking intron.
- [0011]** In some embodiments, the ATP7B target sequence includes at least one nucleotide located among positions 54672-54680 in SEQ ID NO: 1. In some embodiments, the ATP7B target sequence includes at least one nucleotide located among positions 54691-54701 in SEQ ID NO: 1. In some
- 20 **[0012]** In some embodiments, the ATP7B target sequence includes at least one nucleotide located among positions 54492-54506 in SEQ ID NO: 1.
- [0012]** In some embodiments, the ATP7B target sequence includes at least one nucleotide located among positions 54472-54516 in SEQ ID NO: 1. In some embodiments, the ATP7B target sequence includes at least one nucleotide located among positions 54522-54593 in SEQ ID NO: 1. In some
- 25 **[0013]** In some embodiments, the nucleobase sequence is complementary to a sequence within the 5'-flanking intron. In some embodiments, the ATP7B target sequence is located within the 5'-flanking intron among positions up to 54517 in SEQ ID NO: 1. In some embodiments, the nucleobase sequence has at least 70% sequence identity to SEQ ID NO: 119, 120, 121, 122, 123, or 124. In some
- 30 **[0014]** In some embodiments, the ATP7B target sequence is located within the combination of the 5'-flanking intron and exon 6. In some embodiments, the ATP7B target sequence is located within the combination of the 5'-flanking intron and exon 6 among positions 54562 to 54593 in SEQ ID NO: 1. In some embodiments, nucleobase sequence has at least 70% sequence identity to SEQ ID NO: 11.
- [0015]** In some embodiments, the ATP7B target sequence is located within exon 6 or the
- 40 **[0015]** combination of the 3'-flanking intron and exon 6. In some embodiments, the ATP7B target sequence is

located among positions 54631 to 54677 in SEQ ID NO: 1. In some embodiments, the nucleobase sequence has at least 70% sequence identity to SEQ ID NO: 22, 23, 24, or 25.

[0016] In some embodiments, the ATP7B target sequence is located within the 3'-flanking intron. In some embodiments, the ATP7B target sequence is located among positions 54655 to 54738 in SEQ ID NO: 1. In some embodiments, the 5'-terminal nucleotide of the oligonucleotide is complementary to neither position 54695 nor position 54696 of SEQ ID NO: 1. In some embodiments, the nucleobase sequence has at least 70% sequence identity to SEQ ID NO: 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, or 155. In some embodiments, the nucleobase sequence has at least 70% sequence identity to SEQ ID NOs: 39, 48, 49, 50, 61, 63, 64, 65, 66, 67, 76, 77, 78, 79, 80, 81, 90, 91, 92, 93, 94, 95, 100, 103, 104, 121, and 149.

[0017] In some embodiments, the sequence identity of any nucleobase sequence is at least 80%, 85%, 90%, or 95%, e.g., at least 90%. In some embodiments, the sequence identity is 100%.

[0018] In some embodiments, the antisense oligonucleotide includes at least one modified nucleobase.

[0019] In some embodiments, the antisense oligonucleotide includes at least one modified internucleoside linkage. In some embodiments, the modified internucleoside linkage is a phosphorothioate linkage. In some embodiments, the phosphorothioate linkage is a stereochemically enriched phosphorothioate linkage. In some embodiments, at least 50% of internucleoside linkages in the antisense oligonucleotide are independently the modified internucleoside linkage. In some embodiments, at least 70% of the internucleoside linkages in the antisense oligonucleotide are independently the modified internucleoside linkage. In some embodiments, all internucleoside linkages in the antisense oligonucleotide are independently the modified internucleoside linkage.

[0020] In some embodiments, the antisense oligonucleotide includes at least one modified sugar nucleoside. In some embodiments, at least one modified sugar nucleoside is a 2'-modified sugar nucleoside. In some embodiments, at least one 2'-modified sugar nucleoside includes a 2'-modification selected from the group consisting of 2'-fluoro, 2'-methoxy, and 2'-methoxyethoxy. In some embodiments, the 2'-modified sugar nucleoside includes the 2'-methoxyethoxy modification.

[0021] In some embodiments, all nucleosides in the antisense oligonucleotide are independently the modified sugar nucleosides.

[0022] In certain embodiments of the invention, all internucleoside linkages in the antisense oligonucleotide are phosphorothioate diester linkages, and all nucleosides in the antisense oligonucleotide are 2'-methoxyethoxy modified ribose nucleosides. Such antisense oligonucleotides may also further include a targeting moiety, such as N-acetylgalactosamine or a cluster thereof.

[0023] In some embodiments, at least one modified sugar nucleoside is a bridged nucleic acid. In some embodiments, the bridged nucleic acid is a locked nucleic acid (LNA), ethylene-bridged nucleic acid (ENA), or cEt nucleic acid.

[0024] In some embodiments, the antisense oligonucleotide is a morpholino oligomer.

[0025] In some embodiments, the antisense oligonucleotide further includes a targeting moiety. In some embodiments, the targeting moiety is covalently conjugated at the 5'-terminus of the antisense oligonucleotide. In some embodiments, the targeting moiety is covalently conjugated at the 3'-terminus of the antisense oligonucleotide. In some embodiments, the targeting moiety is covalently conjugated at an internucleoside linkage of the antisense oligonucleotide.

[0026] In some embodiments, the targeting moiety is covalently conjugated through a linker. In some embodiments, the linker is a cleavable linker (e.g., a linker including $-S-S-$, $-C(O)O-$, $-C(O)S-$, $-OC(O)-$, $-SC(O)-$).

[0027] Examples of targeting moieties include N-acetylgalactosamine, glycyrrhetic acid, glycyrrhizin, lactobionic acid, lactoferrin, IgA, a bile acid (e.g., lithocholyltaurine or taurocholic acid), and clusters thereof. In some embodiments, the targeting moiety includes N-acetylgalactosamine. In some embodiments, the targeting moiety is an N-acetylgalactosamine cluster.

[0028] In some embodiments, the antisense oligonucleotide includes at least 12 nucleosides. In some embodiments, the antisense oligonucleotide includes at least 16 nucleosides. In some embodiments, the antisense oligonucleotide includes a total of 50 nucleosides or fewer. In some embodiments, the antisense oligonucleotide includes a total of 30 nucleosides or fewer. In some embodiments, the antisense oligonucleotide includes a total of 20 nucleosides or fewer. In some embodiments, the antisense oligonucleotide includes a total of 16 to 20 nucleosides. In some embodiments, the antisense oligonucleotide includes a total of 16 to 19 nucleosides.

[0029] In another aspect, the invention provides a pharmaceutical composition including the antisense oligonucleotide of the invention and a pharmaceutically acceptable excipient.

[0030] In yet another aspect, the invention provides a method of increasing the level of exon 6-containing ATP7B mRNA molecules in a cell expressing an aberrant ATP7B gene by contacting the cell with the antisense oligonucleotide of the invention. In some embodiments, the cell is in a subject.

[0031] In still another aspect, the invention provides a method of treating Wilson disease in a subject having an aberrant ATP7B gene by administering a therapeutically effective amount of the antisense oligonucleotide of the invention or the pharmaceutical composition of the invention to the subject in need thereof. In some embodiments, the administering step is performed parenterally. In some embodiments, the aberrant ATP7B gene is ATP7B having a g.54646T>G mutation in SEQ ID NO: 1.

[0032] Recognized herein is the need for compositions and methods for treating diseases that may be caused by abnormal splicing resulting from an underlying genetic aberration. In some cases, antisense nucleic acid molecules, such as oligonucleotides, may be used to effectively modulate the splicing of targeted genes in genetic diseases, in order to alter the gene products produced. This approach can be applied in therapeutics to selectively modulate the expression and gene product composition for genes involved in genetic diseases.

[0033] The present disclosure provides compositions and methods that may advantageously use antisense oligonucleotides targeted to and hybridizable with nucleic acid molecules that encode for ATP7B. Such antisense oligonucleotides may target one or more splicing regulatory elements in one or more exons or introns of ATP7B. These splicing regulatory elements modulate splicing of ATP7B ribonucleic acid (RNA).

[0034] In one aspect, the present disclosure provides an ATP7B RNA splice-modulating antisense oligonucleotide having a sequence targeted to one or more splicing regulatory elements adjacent to an

exon of ATP7B. In some embodiments, a genetic aberration of ATP7B includes the M645R mutation. In some embodiments, the M645R mutation results from ATP7B chr13:52535985:A:C [hg19/b37] (g.54646T>G in SEQ ID NO: 1). In some embodiments, the one or more splicing regulatory elements include an exonic splicing silencer element or an intronic splicing silencer element. In some
5 embodiments, the sequence is targeted to an abnormally spliced exon. In some embodiments, the sequence is targeted to an intron adjacent to an abnormally spliced exon. In some embodiments, the antisense oligonucleotide modulates variant splicing to yield an increase in exon inclusion. In some
10 embodiments, the antisense oligonucleotide has a length of 12 to 20 nucleotides. In some embodiments, the antisense oligonucleotide has a length of 12 to 30 nucleotides. In some embodiments, the antisense oligonucleotide has a length of 12 to 50 nucleotides.

[0035] In another aspect, the present disclosure provides a method for modulating splicing of ATP7B RNA in a cell, tissue, or organ of a subject, including bringing the cell, tissue, or organ in contact with an antisense oligonucleotide including one or more sequences targeted to one or more splicing regulatory elements of an abnormally spliced exon or an intron adjacent to the abnormally spliced exon. In some
15 embodiments, the genetic aberration of ATP7B includes M645R. In some embodiments, the M645R results from ATP7B chr13:52535985:A:C [hg19/b37] (g.54646T>G in SEQ ID NO: 1). In some embodiments, the splicing regulatory element is an exonic splicing silencer element or an intronic splicing silencer element. In some embodiments, the sequence is targeted to an abnormally spliced exon. In
20 some embodiments, the sequence is targeted to an intron adjacent to an abnormally spliced exon. In some embodiments, the antisense oligonucleotide modulates variant splicing to yield an increase in exon inclusion (e.g., exon 6 inclusion, e.g., increase by at least 5%, at least 10%, at least 15%, at least 20%, at least 25%, at least 30%, at least 35%, at least 40%, at least 45%, or at least 50%; e.g., up to 100%, up to 90%, up to 80%, up to 70%, up to 60%, up to 50%, as compared to the ratio of exon 6-including ATP7B transcripts to the total number of ATP7B transcript molecules in a cell including ATP7B gene having an
25 exon 6-skipping mutation in the absence of a treatment with an antisense oligonucleotide). In some embodiments, the antisense oligonucleotide has a length of 12 to 20 nucleotides. In some embodiments, the antisense oligonucleotide has a length of 12 to 30 nucleotides. In some embodiments, the antisense oligonucleotide has a length of 12 to 50 nucleotides. In some embodiments, the subject has or is suspected of having a disease, e.g., Wilson disease, and the subject is monitored for a progression or
30 regression of the disease in response to bringing the cell, tissue, or organ in contact with the composition.

[0036] In another aspect, the present disclosure provides a method for treating Wilson disease in a subject, including administering to the subject a therapeutically effective amount of an antisense oligonucleotide including a sequence targeted to a splicing regulatory element of an abnormally spliced exon or an intron adjacent to the abnormally spliced exon. The antisense oligonucleotide modulates
35 splicing of ATP7B RNA. In some embodiments, the genetic aberration of ATP7B includes the M645R mutation. In some embodiments, the M645R mutation results from ATP7B chr13:52535985:A:C [hg19/b37] (g.54646T>G mutant of SEQ ID NO: 1). In some embodiments, the splicing regulatory element includes an exonic splicing silencer element or an intronic splicing silencer element. In some
40 embodiments, the sequence is targeted to an abnormally spliced exon of ATP7B. In some embodiments, the sequence is targeted to an intron adjacent to an abnormally spliced exon of the genetic aberration of ATP7B that modulates variant splicing of ATP7B RNA. In some embodiments, the antisense oligonucleotide modulates splicing to yield an increase in exon inclusion (e.g., increase by at least 5%, at

least 10%, at least 15%, at least 20%, at least 25%, at least 30%, at least 35%, at least 40%, at least 45%, or at least 50%; e.g., up to 100%, up to 90%, up to 80%, up to 70%, up to 60%, up to 50%, as compared to the ratio of exon 6-including ATP7B transcripts to the total number of ATP7B transcript molecules in a cell including ATP7B gene having an exon 6-skipping mutation in the absence of a treatment with an antisense oligonucleotide). In some embodiments, the antisense oligonucleotide has a length of 12 to 20 nucleotides. In some embodiments, the antisense oligonucleotide has a length of 12 to 30 nucleotides. In some embodiments, the antisense oligonucleotide has a length of 12 to 50 nucleotides. In some embodiments, the subject is monitored for a progression or regression of Wilson disease in response to administering to the subject the therapeutically effective amount of the antisense oligonucleotide. In some embodiments, the antisense oligonucleotide reduces 24-hour urinary copper level in the subject, e.g., by at least 5%, at least 10%, at least 15%, at least 20%, at least 25%, at least 30%, at least 35%, at least 40%, at least 45%, or at least 50%; e.g., up to 90%, up to 80%, up to 70%, up to 60%, up to 50%, as compared to a control subject. In some embodiments, the control subject is the subject prior to therapy with an antisense oligonucleotide of the invention or is a subject suffering from Wilson disease and not receiving an antisense oligonucleotide of the invention. In some embodiments, the antisense oligonucleotide reduces 24-hour urinary copper level in the subject to <100 µg/24 hours (<1.6 µmol/24 hours) (e.g., to ≤40 µg/24 hours (≤0.6 µmol/24 hours)).

[0037] In another aspect, the present disclosure provides a pharmaceutical composition for treatment of Wilson disease including an antisense oligonucleotide and a pharmaceutically acceptable carrier. The antisense oligonucleotide includes a sequence targeted to a splicing regulatory element of an abnormally spliced exon or an intron adjacent to the abnormally spliced exon. The antisense oligonucleotide modulates splicing of ATP7B RNA. In some embodiments, the genetic aberration of ATP7B includes M645R. In some embodiments, the M645R mutation results from ATP7B chr13:52535985:A:C [hg19/b37] (g.54646T>G mutant of SEQ ID NO: 1).

Definitions

[0038] Various terms used throughout the present description may be read and understood as follows, unless the context indicates otherwise: “or” as used throughout is inclusive, as though written “and/or”; singular articles and pronouns as used throughout include their plural forms, and vice versa; similarly, gendered pronouns include their counterpart pronouns so that pronouns should not be understood as limiting anything described herein to use, implementation, performance, etc. by a single gender; “exemplary” should be understood as “illustrative” or “exemplifying” and not necessarily as “preferred” over other embodiments. Further definitions for terms may be set out herein; these may apply to prior and subsequent instances of those terms, as will be understood from a reading of the present description.

[0039] The term “acyl,” as used herein, represents a chemical substituent of formula $-C(O)-R$, where R is alkyl, aryl, arylalkyl, cycloalkyl, heterocyclyl, heterocyclyl alkyl, heteroaryl, or heteroaryl alkyl. An optionally substituted acyl is an acyl that is optionally substituted as described herein for each group R.

[0040] The term “acyloxy,” as used herein, represents a chemical substituent of formula $-OR$, where R is acyl. An optionally substituted acyloxy is an acyloxy that is optionally substituted as described herein for acyl.

[0041] The term "alkane-tetrayl," as used herein, represents a tetravalent, acyclic, straight or branched chain, saturated hydrocarbon group having from 1 to 16 carbons, unless otherwise specified. Alkane-tetrayl may be optionally substituted as described for alkyl.

[0042] The term "alkane-triyl," as used herein, represents a trivalent, acyclic, straight or branched chain, saturated hydrocarbon group having from 1 to 16 carbons, unless otherwise specified. Alkane-triyl may be optionally substituted as described for alkyl.

[0043] The term "alkanoyl," as used herein, represents a chemical substituent of formula $-C(O)-R$, where R is alkyl. An optionally substituted alkanoyl is an alkanoyl that is optionally substituted as described herein for alkyl.

[0044] The term "alkoxy," as used herein, represents a chemical substituent of formula $-OR$, where R is a C_{1-6} alkyl group, unless otherwise specified. An optionally substituted alkoxy is an alkoxy group that is optionally substituted as defined herein for alkyl.

[0045] The term "alkyl," as used herein, refers to an acyclic straight or branched chain saturated hydrocarbon group, which, when unsubstituted, has from 1 to 12 carbons, unless otherwise specified. In certain preferred embodiments, unsubstituted alkyl has from 1 to 6 carbons. Alkyl groups are exemplified by methyl; ethyl; n- and iso-propyl; n-, sec-, iso- and tert-butyl; neopentyl, and the like, and may be optionally substituted, valency permitting, with one, two, three, or, in the case of alkyl groups of two carbons or more, four or more substituents independently selected from the group consisting of: alkoxy; acyloxy; amino; aryl; aryloxy; azido; cycloalkyl; cycloalkoxy; halo; heterocyclyl; heteroaryl; heterocyclylalkyl; heteroarylalkyl; heterocycloxy; heteroaryloxy; hydroxy; nitro; thiol; silyl; cyano; $=O$; $=S$; and $=NR'$, where R' is H, alkyl, aryl, or heterocyclyl. In some embodiments, a substituted alkyl includes two substituents (oxo and hydroxy, or oxo and alkoxy) to form a group $-L-CO-R$, where L is a bond or optionally substituted C_{1-11} alkylene, and R is hydroxyl or alkoxy. Each of the substituents may itself be unsubstituted or, valency permitting, substituted with unsubstituted substituent(s) defined herein for each respective group.

[0046] The term "alkylene," as used herein, represents a divalent substituent that is a monovalent alkyl having one hydrogen atom replaced with a valency. An optionally substituted alkylene is an alkylene that is optionally substituted as described herein for alkyl.

[0047] The term "aryl," as used herein, represents a mono-, bicyclic, or multicyclic carbocyclic ring system having one or two aromatic rings. Aryl group may include from 6 to 10 carbon atoms. All atoms within an unsubstituted carbocyclic aryl group are carbon atoms. Non-limiting examples of carbocyclic aryl groups include phenyl, naphthyl, 1,2-dihydronaphthyl, 1,2,3,4-tetrahydronaphthyl, fluorenyl, indanyl, indenyl, etc. The aryl group may be unsubstituted or substituted with one, two, three, four, or five substituents independently selected from the group consisting of: alkyl; alkoxy; acyloxy; amino; aryl; aryloxy; azido; cycloalkyl; cycloalkoxy; halo; heterocyclyl; heteroaryl; heterocyclylalkyl; heteroarylalkyl; heterocycloxy; heteroaryloxy; hydroxy; nitro; thiol; silyl; and cyano. Each of the substituents may itself be unsubstituted or substituted with unsubstituted substituent(s) defined herein for each respective group.

[0048] The term "aryl alkyl," as used herein, represents an alkyl group substituted with an aryl group. The aryl and alkyl portions may be optionally substituted as the individual groups as described herein.

[0049] The term "arylene," as used herein, represents a divalent substituent that is an aryl having one hydrogen atom replaced with a valency. An optionally substituted arylene is an arylene that is optionally substituted as described herein for aryl.

[0050] The term "aryloxy," as used herein, represents a group –OR, where R is aryl. Aryloxy may be an optionally substituted aryloxy. An optionally substituted aryloxy is aryloxy that is optionally substituted as described herein for aryl.

[0051] The term "ATP7B," as used herein, represents a nucleic acid (e.g., genomic DNA, pre-mRNA, or mRNA) that is translated and, if genomic DNA, first transcribed, *in vivo* to ATPase copper transporting beta protein. An exemplary genomic DNA sequence comprising the human ATP7B gene is given by SEQ ID NO: 1 (NCBI Reference Sequence: NG_008806.1). SEQ ID NO: 1 provides the sequence for the antisense strand of the genomic DNA of ATP7B (positions 5001-83826 in SEQ ID NO: 1) and other nearby genes. One of skill in the art will recognize that an RNA sequence typically includes uridines instead of thymidines. The term "ATP7B," as used herein, represents wild-type and mutant versions. An exemplary mutant nucleic acid (e.g., genomic DNA, pre-mRNA, or mRNA) results in ATPase copper transporting beta protein lacking exon 6.

[0052] The term "bicyclic sugar moiety," as used herein, represents a modified sugar moiety including two fused rings. In certain embodiments, the bicyclic sugar moiety includes a furanosyl ring.

[0053] The expression " C_{x-y} ," as used herein, indicates that the group, the name of which immediately follows the expression, when unsubstituted, contains a total of from x to y carbon atoms. If the group is a composite group (e.g., aryl alkyl), C_{x-y} indicates that the portion, the name of which immediately follows the expression, when unsubstituted, contains a total of from x to y carbon atoms. For example, (C_{6-10} -aryl)- C_{1-6} -alkyl is a group, in which the aryl portion, when unsubstituted, contains a total of from 6 to 10 carbon atoms, and the alkyl portion, when unsubstituted, contains a total of from 1 to 6 carbon atoms.

[0054] The term "complementary," as used herein in reference to a nucleobase sequence, refers to the nucleobase sequence having a pattern of contiguous nucleobases that permits an oligonucleotide having the nucleobase sequence to hybridize to another oligonucleotide or nucleic acid to form a duplex structure under physiological conditions. Complementary sequences include Watson-Crick base pairs formed from natural and/or modified nucleobases. Complementary sequences can also include non-Watson-Crick base pairs, such as wobble base pairs (guanosine-uracil, hypoxanthine-uracil, hypoxanthine-adenine, and hypoxanthine-cytosine) and Hoogsteen base pairs.

[0055] The term "contiguous," as used herein in the context of an oligonucleotide, refers to nucleosides, nucleobases, sugar moieties, or internucleoside linkages that are immediately adjacent to each other. For example, "contiguous nucleobases" means nucleobases that are immediately adjacent to each other in a sequence.

[0056] The term "cycloalkyl," as used herein, refers to a cyclic alkyl group having from three to ten carbons (e.g., a C_3 - C_{10} cycloalkyl), unless otherwise specified. Cycloalkyl groups may be monocyclic or bicyclic. Bicyclic cycloalkyl groups may be of bicyclo[p.q.0]alkyl type, in which each of p and q is, independently, 1, 2, 3, 4, 5, 6, or 7, provided that the sum of p and q is 2, 3, 4, 5, 6, 7, or 8. Alternatively, bicyclic cycloalkyl groups may include bridged cycloalkyl structures, e.g., bicyclo[p.q.r]alkyl, in which r is 1, 2, or 3, each of p and q is, independently, 1, 2, 3, 4, 5, or 6, provided that the sum of p, q, and r is 3, 4, 5, 6, 7, or 8. The cycloalkyl group may be a spirocyclic group, e.g., spiro[p.q]alkyl, in which each of p and q is, independently, 2, 3, 4, 5, 6, or 7, provided that the sum of p and q is 4, 5, 6, 7, 8, or 9. Non-limiting examples of cycloalkyl include cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, cycloheptyl, 1-bicyclo[2.2.1]heptyl, 2-bicyclo[2.2.1]heptyl, 5-bicyclo[2.2.1]heptyl, 7-bicyclo[2.2.1]heptyl, and decaliny.

The cycloalkyl group may be unsubstituted or substituted (e.g., optionally substituted cycloalkyl) with one, two, three, four, or five substituents independently selected from the group consisting of: alkyl; alkoxy; acyloxy; amino; aryl; aryloxy; azido; cycloalkyl; cycloalkoxy; halo; heterocyclyl; heteroaryl; heterocyclylalkyl; heteroarylalkyl; heterocyclyloxy; heteroaryloxy; hydroxy; nitro; thiol; silyl; cyano; =O; =S; =NR', where R' is H, alkyl, aryl, or heterocyclyl. Each of the substituents may itself be unsubstituted or substituted with unsubstituted substituent(s) defined herein for each respective group.

[0057] The term "cycloalkylene," as used herein, represents a divalent substituent that is a cycloalkyl having one hydrogen atom replaced with a valency. An optionally substituted cycloalkylene is a cycloalkylene that is optionally substituted as described herein for cycloalkyl.

[0058] The term "cycloalkoxy," as used herein, represents a group -OR, where R is cycloalkyl. Cycloalkoxy may be an optionally substituted cycloalkoxy. An optionally substituted cycloalkoxy is cycloalkoxy that is optionally substituted as described herein for cycloalkyl.

[0059] The term "duplex," as used herein, represents two oligonucleotides that are paired through hybridization of complementary nucleobases.

[0060] The term "exon 6," as used herein, refers to exon 6 of ATP7B pre-mRNA or genomic DNA, e.g., SEQ ID NO: 2, which corresponds to positions 54582 to 54658 in SEQ ID NO: 1 (hg19/b37 coordinates chr13:52535973-52536049), or a mutant version thereof (e.g., g.54646T>G in SEQ ID NO: 1).

[0061] The term "flanking intron," as used herein, refers to an intron that is adjacent to the 5'- or 3'-end of exon 6 or a mutant thereof. The flanking intron is a 5'-flanking intron or a 3'-flanking intron. The 5'-flanking intron corresponds to the flanking intron that is adjacent to the 5'-end of exon 6 (e.g., intron positions between exon 5 and exon 6 in SEQ ID NO: 1). The 3'-flanking intron corresponds to the flanking intron that is adjacent to the 3'-end of exon 6 (e.g., intron positions between exon 6 and exon 7 in SEQ ID NO: 1).

[0062] The term "genetic aberration," as used herein, generally refers to a mutation or variant in a gene. Examples of genetic aberration may include, but are not limited to, a point mutation (single nucleotide variant or single base substitution), an insertion or deletion (indel), a transversion, a translocation, an inversion, or a truncation. An aberrant ATP7B gene includes one or more mutations causing the splicing of pre-mRNA to skip exon 6.

[0063] The term "halo," as used herein, represents a halogen selected from bromine, chlorine, iodine, and fluorine.

[0064] The term "heteroalkane-tetrayl," as used herein refers to an alkane-tetrayl group interrupted once by one heteroatom; twice, each time, independently, by one heteroatom; three times, each time, independently, by one heteroatom; or four times, each time, independently, by one heteroatom. Each heteroatom is, independently, O, N, or S. In some embodiments, the heteroatom is O or N. An unsubstituted C_{x-y} heteroalkane-tetrayl contains from X to Y carbon atoms as well as the heteroatoms as defined herein. The heteroalkane-tetrayl group may be unsubstituted or substituted (e.g., optionally substituted heteroalkane-tetrayl), as described for heteroalkyl.

[0065] The term "heteroalkane-triyl," as used herein refers to an alkane-triyl group interrupted once by one heteroatom; twice, each time, independently, by one heteroatom; three times, each time, independently, by one heteroatom; or four times, each time, independently, by one heteroatom. Each heteroatom is, independently, O, N, or S. In some embodiments, the heteroatom is O or N. An

unsubstituted C_{x-y} heteroalkane-triyl contains from X to Y carbon atoms as well as the heteroatoms as defined herein. The heteroalkane-triyl group may be unsubstituted or substituted (e.g., optionally substituted heteroalkane-triyl), as described for heteroalkyl.

[0066] The term "heteroalkyl," as used herein, refers to an alkyl group interrupted one or more times by one or two heteroatoms each time. Each heteroatom is independently O, N, or S. None of the heteroalkyl groups includes two contiguous oxygen atoms. The heteroalkyl group may be unsubstituted or substituted (e.g., optionally substituted heteroalkyl). When heteroalkyl is substituted and the substituent is bonded to the heteroatom, the substituent is selected according to the nature and valency of the heteroatom. Thus, the substituent bonded to the heteroatom, valency permitting, is selected from the group consisting of =O, -N(R^{N2})₂, -SO₂OR^{N3}, -SO₂R^{N2}, -SOR^{N3}, -COOR^{N3}, an N protecting group, alkyl, aryl, cycloalkyl, heterocyclyl, or cyano, where each R^{N2} is independently H, alkyl, cycloalkyl, aryl, or heterocyclyl, and each R^{N3} is independently alkyl, cycloalkyl, aryl, or heterocyclyl. Each of these substituents may itself be unsubstituted or substituted with unsubstituted substituent(s) defined herein for each respective group. When heteroalkyl is substituted and the substituent is bonded to carbon, the substituent is selected from those described for alkyl, provided that the substituent on the carbon atom bonded to the heteroatom is not Cl, Br, or I. In some embodiments, carbon atoms are found at the termini of a heteroalkyl group. In some embodiments, heteroalkyl is PEG.

[0067] The term "heteroalkylene," as used herein, represents a divalent substituent that is a heteroalkyl having one hydrogen atom replaced with a valency. An optionally substituted heteroalkylene is a heteroalkylene that is optionally substituted as described herein for heteroalkyl.

[0068] The term "heteroaryl," as used herein, represents a monocyclic 5-, 6-, 7-, or 8-membered ring system, or a fused or bridging bicyclic, tricyclic, or tetracyclic ring system; the ring system contains one, two, three, or four heteroatoms independently selected from the group consisting of nitrogen, oxygen, and sulfur; and at least one of the rings is an aromatic ring. Non-limiting examples of heteroaryl groups include benzimidazolyl, benzofuryl, benzothiazolyl, benzothieryl, benzoxazolyl, furyl, imidazolyl, indolyl, isoindazolyl, isoquinolinyl, isothiazolyl, isothiazolyl, isoxazolyl, oxadiazolyl, oxazolyl, purinyl, pyrrolyl, pyridinyl, pyrazinyl, pyrimidinyl, qunazolynyl, quinolinyl, thiadiazolyl (e.g., 1,3,4-thiadiazole), thiazolyl, thienyl, triazolyl, tetrazolyl, dihydroindolyl, tetrahydroquinolyl, tetrahydroisoquinolyl, etc. The term bicyclic, tricyclic, and tetracyclic heteroaryls include at least one ring having at least one heteroatom as described above and at least one aromatic ring. For example, a ring having at least one heteroatom may be fused to one, two, or three carbocyclic rings, e.g., an aryl ring, a cyclohexane ring, a cyclohexene ring, a cyclopentane ring, a cyclopentene ring, or another monocyclic heterocyclic ring. Examples of fused heteroaryls include 1,2,3,5,8,8a-hexahydroindolizine; 2,3-dihydrobenzofuran; 2,3-dihydroindole; and 2,3-dihydrobenzothiophene. Heteroaryl may be optionally substituted with one, two, three, four, or five substituents independently selected from the group consisting of: alkyl; alkoxy; acyloxy; aryloxy; amino; arylalkoxy; cycloalkyl; cycloalkoxy; halogen; heterocyclyl; heterocyclyl alkyl; heteroaryl; heteroaryl alkyl; heterocycloxy; heteroaryloxy; hydroxyl; nitro; thiol; cyano; =O; -NR₂, where each R is independently hydrogen, alkyl, acyl, aryl, arylalkyl, cycloalkyl, heterocyclyl, or heteroaryl; -COOR^A, where R^A is hydrogen, alkyl, aryl, arylalkyl, cycloalkyl, heterocyclyl, or heteroaryl; and -CON(R^B)₂, where each R^B is independently hydrogen, alkyl, aryl, arylalkyl, cycloalkyl, heterocyclyl, or heteroaryl. Each of the substituents may itself be unsubstituted or substituted with unsubstituted substituent(s) defined herein for each respective group.

[0069] The term "heteroarylene," as used herein, represents a divalent substituent that is a heteroaryl having one hydrogen atom replaced with a valency. An optionally substituted heteroarylene is a heteroarylene that is optionally substituted as described herein for heteroaryl.

[0070] The term "heteroaryloxy," as used herein, refers to a structure –OR, in which R is heteroaryl.

5 Heteroaryloxy can be optionally substituted as defined for heteroaryl.

[0071] The term "heterocyclyl," as used herein, represents a monocyclic, bicyclic, tricyclic, or tetracyclic ring system having fused or bridging 4-, 5-, 6-, 7-, or 8-membered rings, unless otherwise specified, the ring system containing one, two, three, or four heteroatoms independently selected from the group consisting of nitrogen, oxygen, and sulfur. Heterocyclyl may be aromatic or non-aromatic. An

10 aromatic heterocyclyl is heteroaryl as described herein. Non-aromatic 5-membered heterocyclyl has zero or one double bonds, non-aromatic 6- and 7-membered heterocyclyl groups have zero to two double bonds, and non-aromatic 8-membered heterocyclyl groups have zero to two double bonds and/or zero or one carbon-carbon triple bond. Heterocyclyl groups have a carbon count of 1 to 16 carbon atoms unless otherwise specified. Certain heterocyclyl groups may have a carbon count up to 9 carbon atoms. Non-

15 aromatic heterocyclyl groups include pyrrolinyl, pyrrolidinyl, pyrazolinyl, pyrazolidinyl, imidazolinyl, imidazolidinyl, piperidinyl, homopiperidinyl, piperazinyl, pyridazinyl, oxazolidinyl, isoxazolidinyl, morpholinyl, thiomorpholinyl, thiazolidinyl, isothiazolidinyl, thiazolidinyl, tetrahydrofuranyl, dihydrofuranyl, tetrahydrothienyl, dihydrothienyl, pyranyl, dihydropyranyl, dithiazolyl, etc. The term "heterocyclyl" also represents a heterocyclic compound having a bridged multicyclic structure in which one or more carbons

20 and/or heteroatoms bridges two non-adjacent members of a monocyclic ring, e.g., quinuclidine, tropanes, or diaza-bicyclo[2.2.2]octane. The term "heterocyclyl" includes bicyclic, tricyclic, and tetracyclic groups in which any of the above heterocyclic rings is fused to one, two, or three carbocyclic rings, e.g., a cyclohexane ring, a cyclohexene ring, a cyclopentane ring, a cyclopentene ring, or another heterocyclic ring. Examples of fused heterocyclyls include 1,2,3,5,8,8a-hexahydroindolizine; 2,3-dihydrobenzofuran;

25 2,3-dihydroindole; and 2,3-dihydrobenzothiophene. The heterocyclyl group may be unsubstituted or substituted with one, two, three, four or five substituents independently selected from the group consisting of: alkyl; alkoxy; acyloxy; aryloxy; amino; arylalkoxy; cycloalkyl; cycloalkoxy; halogen; heterocyclyl; heterocyclyl alkyl; heteroaryl; heteroaryl alkyl; heterocycliloxy; heteroaryloxy; hydroxyl; nitro; thiol; cyano; =O; =S; –NR₂, where each R is independently hydrogen, alkyl, acyl, aryl, arylalkyl, cycloalkyl,

30 heterocyclyl, or heteroaryl; –COOR^A, where R^A is hydrogen, alkyl, aryl, arylalkyl, cycloalkyl, heterocyclyl, or heteroaryl; and –CON(R^B)₂, where each R^B is independently hydrogen, alkyl, aryl, arylalkyl, cycloalkyl, heterocyclyl, or heteroaryl.

[0072] The term "heterocyclyl alkyl," as used herein, represents an alkyl group substituted with a heterocyclyl group. The heterocyclyl and alkyl portions of an optionally substituted heterocyclyl alkyl are

35 optionally substituted as described for heterocyclyl and alkyl, respectively.

[0073] The term "heterocyclylene," as used herein, represents a divalent substituent that is a heterocyclyl having one hydrogen atom replaced with a valency. An optionally substituted heterocyclylene is a heterocyclylene that is optionally substituted as described herein for heterocyclyl.

[0074] The term "heterocycliloxy," as used herein, refers to a structure –OR, in which R is

40 heterocyclyl. Heterocycliloxy can be optionally substituted as described for heterocyclyl.

[0075] The term "heteroorganic," as used herein, refers to (i) an acyclic hydrocarbon interrupted one or more times by one or two heteroatoms each time, or (ii) a cyclic hydrocarbon including one or more

(e.g., one, two, three, or four) endocyclic heteroatoms. Each heteroatom is independently O, N, or S. None of the heteroorganic groups includes two contiguous oxygen atoms. An optionally substituted heteroorganic group is a heteroorganic group that is optionally substituted as described herein for alkyl.

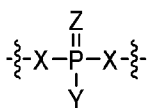
[0076] The term “hydrocarbon,” as used herein, refers to an acyclic, branched or acyclic, linear compound or group, or a monocyclic, bicyclic, tricyclic, or tetracyclic compound or group. The hydrocarbon, when unsubstituted, consists of carbon and hydrogen atoms. Unless specified otherwise, an unsubstituted hydrocarbon includes a total of 1 to 60 carbon atoms (e.g., 1 to 16, 1 to 12, or 1 to 6 carbon atoms). An optionally substituted hydrocarbon is an optionally substituted acyclic hydrocarbon or an optionally substituted cyclic hydrocarbon. An optionally substituted acyclic hydrocarbon is optionally substituted as described herein for alkyl. An optionally substituted cyclic hydrocarbon is an optionally substituted aromatic hydrocarbon or an optionally substituted non-aromatic hydrocarbon. An optionally substituted aromatic hydrocarbon is optionally substituted as described herein for aryl. An optionally substituted non-aromatic cyclic hydrocarbon is optionally substituted as described herein for cycloalkyl. In some embodiments, an acyclic hydrocarbon is alkyl, alkylene, alkane-triyl, or alkane-tetrayl. In certain embodiments, a cyclic hydrocarbon is aryl or arylene. In particular embodiments, a cyclic hydrocarbon is cycloalkyl or cycloalkylene.

[0077] The terms “hydroxyl” and “hydroxy,” as used interchangeably herein, represent -OH.

[0078] The term “hydrophobic moiety,” as used herein, represents a monovalent group covalently linked to an oligonucleotide backbone, where the monovalent group is a bile acid (e.g., cholic acid, taurocholic acid, deoxycholic acid, oleyl lithocholic acid, or oleoyl cholenic acid), glycolipid, phospholipid, sphingolipid, isoprenoid, vitamin, saturated fatty acid, unsaturated fatty acid, fatty acid ester, triglyceride, pyrene, porphyrine, texaphyrine, adamantane, acridine, biotin, coumarin, fluorescein, rhodamine, Texas-Red, digoxigenin, dimethoxytrityl, *t*-butyldimethylsilyl, *t*-butyldiphenylsilyl, cyanine dye (e.g., Cy3 or Cy5), Hoechst 33258 dye, psoralen, or ibuprofen. Non-limiting examples of the monovalent group include ergosterol, stigmasterol, β -sitosterol, campesterol, fucosterol, saringosterol, avenasterol, coprostanol, cholesterol, vitamin A, vitamin D, vitamin E, cardiolipin, and carotenoids. The linker connecting the monovalent group to the oligonucleotide may be an optionally substituted C₁₋₆₀ hydrocarbon (e.g., optionally substituted C₁₋₆₀ alkylene) or an optionally substituted C₂₋₆₀ heteroorganic (e.g., optionally substituted C₂₋₆₀ heteroalkylene), where the linker may be optionally interrupted with one, two, or three instances independently selected from the group consisting of an optionally substituted arylene, optionally substituted heterocyclene, and optionally substituted cycloalkylene. The linker may be bonded to an oligonucleotide through, e.g., an oxygen atom attached to a 5'-terminal carbon atom, a 3'-terminal carbon atom, a 5'-terminal phosphate or phosphorothioate, a 3'-terminal phosphate or phosphorothioate, or an internucleoside linkage.

[0079] The term “internucleoside linkage,” as used herein, represents a divalent group or covalent bond that forms a covalent linkage between adjacent nucleosides in an oligonucleotide. An internucleoside linkage is an unmodified internucleoside linkage or a modified internucleoside linkage. An “unmodified internucleoside linkage” is a phosphate (-O-P(O)(OH)-O-) internucleoside linkage (“phosphate phosphodiester”). A “modified internucleoside linkage” is an internucleoside linkage other than a phosphate phosphodiester. The two main classes of modified internucleoside linkages are defined by the presence or absence of a phosphorus atom. Non-limiting examples of phosphorus-containing internucleoside linkages include phosphodiester linkages, phosphotriester linkages, phosphorothioate

diester linkages, phosphorothioate triester linkages, phosphorodithioate linkages, boranophosphonate linkages, morpholino internucleoside linkages, methylphosphonates, and phosphoramidate. Non-limiting examples of non-phosphorus internucleoside linkages include methylenemethylimino ($-\text{CH}_2-\text{N}(\text{CH}_3)-\text{O}-\text{CH}_2-$), thiodiester ($-\text{O}-\text{C}(\text{O})-\text{S}-$), thionocarbamate ($-\text{O}-\text{C}(\text{O})(\text{NH})-\text{S}-$), siloxane ($-\text{O}-\text{Si}(\text{H})_2-\text{O}-$), and N,N'-dimethylhydrazine ($-\text{CH}_2-\text{N}(\text{CH}_3)-\text{N}(\text{CH}_3)-$). Phosphorothioate linkages are phosphodiester linkages and phosphotriester linkages in which one of the non-bridging oxygen atoms is replaced with a sulfur atom. In some embodiments, an internucleoside linkage is a group of the following structure:



10 where

Z is O, S, B, or Se;

Y is $-\text{X}-\text{L}-\text{R}^1$;

each X is independently $-\text{O}-$, $-\text{S}-$, $-\text{N}(-\text{L}-\text{R}^1)-$, or L;

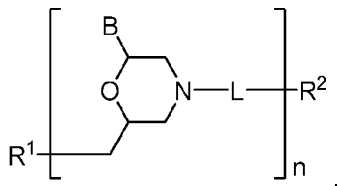
each L is independently a covalent bond or a linker (e.g., optionally substituted C_{1-60} hydrocarbon linker or optionally substituted C_{2-60} heteroorganic linker);

15 each R^1 is independently hydrogen, $-\text{S}-\text{S}-\text{R}^2$, $-\text{O}-\text{CO}-\text{R}^2$, $-\text{S}-\text{CO}-\text{R}^2$, optionally substituted C_{1-9} heterocyclyl, a hydrophobic moiety, or a targeting moiety; and

each R^2 is independently optionally substituted C_{1-10} alkyl, optionally substituted C_{2-10} heteroalkyl, optionally substituted C_{6-10} aryl, optionally substituted C_{6-10} aryl C_{1-6} alkyl, optionally substituted C_{1-9} heterocyclyl, or optionally substituted C_{1-9} heterocyclyl C_{1-6} alkyl.

When L is a covalent bond, R^1 is hydrogen, Z is oxygen, and all X groups are $-\text{O}-$, the internucleoside group is known as a phosphate phosphodiester. When L is a covalent bond, R^1 is hydrogen, Z is sulfur, and all X groups are $-\text{O}-$, the internucleoside group is known as a phosphorothioate diester. When Z is oxygen, all X groups are $-\text{O}-$, and either (1) L is a linker or (2) R^1 is not a hydrogen, the internucleoside group is known as a phosphotriester. When Z is sulfur, all X groups are $-\text{O}-$, and either (1) L is a linker or (2) R^1 is not a hydrogen, the internucleoside group is known as a phosphorothioate triester. Non-limiting examples of phosphorothioate triester linkages and phosphotriester linkages are described in US 2017/0037399, the disclosure of which is incorporated herein by reference.

[0080] The term "morpholino," as used herein in reference to a class of oligonucleotides, represents an oligomer of at least 10 morpholino monomer units interconnected by morpholino internucleoside linkages. A morpholino includes a 5' group and a 3' group. For example, a morpholino may be of the following structure:



where

35 n is an integer of at least 10 (e.g., 12 to 50) indicating the number of morpholino units;

each B is independently a nucleobase;

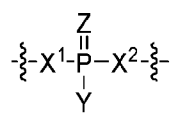
R¹ is a 5' group;

R² is a 3' group; and

L is (i) a morpholino internucleoside linkage or, (ii) if L is attached to R², a covalent bond.

A 5' group in morpholino may be, e.g., hydroxyl, a hydrophobic moiety, phosphate, diphosphate, triphosphate, phosphorothioate, diphosphorothioate, triphosphorothioate, phosphorodithioate, disphorodithioate, triphosphorodithioate, phosphonate, phosphoramidate, a cell penetrating peptide, an endosomal escape moiety, or a neutral organic polymer. A 3' group in morpholino may be, e.g., hydrogen, a hydrophobic moiety, phosphate, diphosphate, triphosphate, phosphorothioate, diphosphorothioate, triphosphorothioate, phosphorodithioate, disphorodithioate, triphosphorodithioate, phosphonate, phosphoramidate, a cell penetrating peptide, an endosomal escape moiety, or a neutral organic polymer.

[0081] The term "morpholino internucleoside linkage," as used herein, represents a divalent group of the following structure:



15 where

Z is O or S;

X¹ is a bond, -CH₂-, or -O-;

X² is a bond, -CH₂O-, or -O-; and

Y is -NR₂, where each R is independently C₁₋₆ alkyl (e.g., methyl), or both R combine together with the nitrogen atom to which they are attached to form a C₂₋₉ heterocyclyl (e.g., N-piperazinyl); provided that both X¹ and X² are not simultaneously a bond.

[0082] The term "nucleobase," as used herein, represents a nitrogen-containing heterocyclic ring found at the 1' position of the ribofuranose/2'-deoxyribofuranose of a nucleoside. Nucleobases are unmodified or modified. As used herein, "unmodified" or "natural" nucleobases include the purine bases adenine (A) and guanine (G), and the pyrimidine bases thymine (T), cytosine (C), and uracil (U). Modified nucleobases include 5-substituted pyrimidines, 6-azapyrimidines, alkyl or alkynyl substituted pyrimidines, alkyl substituted purines, and N-2, N-6 and O-6 substituted purines, as well as synthetic and natural nucleobases, e.g., 5-methylcytosine, 5-hydroxymethyl cytosine, xanthine, hypoxanthine, 2-aminoadenine, 6-alkyl (e.g., 6-methyl) adenine and guanine, 2-alkyl (e.g., 2-propyl) adenine and guanine, 2-thiouracil, 2-thiothymine, 2-thiocytosine, 5-halouracil, 5-halocytosine, 5-propynyl uracil, 5-propynyl cytosine, 5-trifluoromethyl uracil, 5-trifluoromethyl cytosine, 7-methyl guanine, 7-methyl adenine, 8-azaguanine, 8-azaadenine, 7-deazaguanine, 7-deazaadenine, 3-deazaguanine, 3-deazaadenine. Certain nucleobases are particularly useful for increasing the binding affinity of nucleic acids, e.g., 5-substituted pyrimidines; 6-azapyrimidines; N2-, N6-, and/or O6-substituted purines. Nucleic acid duplex stability can be enhanced using, e.g., 5-methylcytosine. Non-limiting examples of nucleobases include: 2-aminopropyladenine, 5-hydroxymethyl cytosine, xanthine, hypoxanthine, 2-aminoadenine, 6-N-methylguanine, 6-N-methyladenine, 2-propyladenine, 2-thiouracil, 2-thiothymine and 2-thiocytosine, 5-propynyl (-C≡C-CH₃) uracil, 5-propynylcytosine, 6-azouracil, 6-azocytosine, 6-azothymine, 5-ribosyluracil (pseudouracil), 4-thiouracil, 8-halo, 8-amino, 8-thiol, 8-thioalkyl, 8-hydroxyl, 8-aza and other 8-substituted purines, 5-halo, particularly 5-bromo, 5-trifluoromethyl, 5-halouracil, and 5-halocytosine, 7-methylguanine, 7-

methyladenine, 2-F-adenine, 2-aminoadenine, 7-deazaguanine, 7-deazaadenine, 3-deazaguanine, 3-deazaadenine, 6-N-benzoyladenine, 2-N-isobutyrylguanine, 4-N-benzoylcytosine, 4-N-benzoyluracil, 5-methyl 4-N-benzoylcytosine, 5-methyl 4-N-benzoyluracil, universal bases, hydrophobic bases, promiscuous bases, size-expanded bases, and fluorinated bases. Further modified nucleobases include tricyclic pyrimidines, such as 1,3-diazaphenoxazine-2-one, 1,3-diazaphenothiazine-2-one and 9-(2-aminoethoxy)-1,3-diazaphenoxazine-2-one (G-clamp). Modified nucleobases may also include those in which the purine or pyrimidine base is replaced with other heterocycles, for example, 7-deazaadenine, 7-deazaguanine, 2-aminopyridine, or 2-pyridone. Further nucleobases include those disclosed in U.S. Pat. No. 3,687,808; The Concise Encyclopedia of Polymer Science and Engineering, Kroschwitz, J. I., Ed., John Wiley & Sons, 1990, 858-859; Englisch et al., *Angewandte Chemie*, International Edition, 1991, 30, 613; Sanghvi, Y. S., Chapter 15, *Antisense Research and Applications*, Crooke, S. T. and Lebleu, B., Eds., CRC Press, 1993, 273-288; and in Chapters 6 and 15, *Antisense Drug Technology*, Crooke S. T., Ed., CRC Press, 2008, 163-166 and 442-443.

[0083] The term "nucleoside," as used herein, represents sugar-nucleobase compounds and groups known in the art (e.g., modified or unmodified ribofuranose-nucleobase and 2'-deoxyribofuranose-nucleobase compounds and groups known in the art). The sugar may be ribofuranose. The sugar may be modified or unmodified. An unmodified sugar nucleoside is ribofuranose or 2'-deoxyribofuranose having an anomeric carbon bonded to a nucleobase. An unmodified nucleoside is ribofuranose or 2'-deoxyribofuranose having an anomeric carbon bonded to an unmodified nucleobase. Non-limiting examples of unmodified nucleosides include adenosine, cytidine, guanosine, uridine, 2'-deoxyadenosine, 2'-deoxycytidine, 2'-deoxyguanosine, and thymidine. The modified compounds and groups include one or more modifications selected from the group consisting of nucleobase modifications and sugar modifications described herein. A nucleobase modification is a replacement of an unmodified nucleobase with a modified nucleobase. A sugar modification may be, e.g., a 2'-substitution, locking, carbocyclization, or unlocking. A 2'-substitution is a replacement of 2'-hydroxyl in ribofuranose with 2'-fluoro, 2'-methoxy, or 2'-(2-methoxy)ethoxy. A locking modification is an incorporation of a bridge between 4'-carbon atom and 2'-carbon atom of ribofuranose. Nucleosides having a locking modification are known in the art as bridged nucleic acids, e.g., locked nucleic acids (LNA), ethylene-bridged nucleic acids (ENA), and cEt nucleic acids. The bridged nucleic acids are typically used as affinity enhancing nucleosides.

[0084] The term "nucleotide," as used herein, represents a nucleoside bonded to an internucleoside linkage or a monovalent group of the following structure $-X^1-P(X^2)(R^1)_2$, where X^1 is O, S, or NH, and X^2 is absent, =O, or =S, and each R^1 is independently -OH, $-N(R^2)_2$, or $-O-CH_2CH_2CN$, where each R^2 is independently an optionally substituted alkyl, or both R^2 groups, together with the nitrogen atom to which they are attached, combine to form an optionally substituted heterocyclyl.

[0085] The term "oligonucleotide," as used herein, represents a structure containing 10 or more (e.g., 10 to 50) contiguous nucleosides covalently bound together by internucleoside linkages. An oligonucleotide includes a 5' end and a 3' end. The 5' end of an oligonucleotide may be, e.g., hydroxyl, a targeting moiety, a hydrophobic moiety, 5' cap, phosphate, diphosphate, triphosphate, phosphorothioate, diphosphorothioate, triphosphorothioate, phosphorodithioate, diphosphrodithioate, triphosphorodithioate, phosphonate, phosphoramidate, a cell penetrating peptide, an endosomal escape moiety, or a neutral organic polymer. The 3' end of an oligonucleotide may be, e.g., hydroxyl, a targeting moiety, a

hydrophobic moiety, phosphate, diphosphate, triphosphate, phosphorothioate, diphosphorothioate, triphosphorothioate, phosphorodithioate, disphorodithioate, triphosphorodithioate, phosphonate, phosphoramidate, a cell penetrating peptide, an endosomal escape moiety, or a neutral organic polymer (e.g., polyethylene glycol). An oligonucleotide having a 5'-hydroxyl or 5'-phosphate has an unmodified 5' terminus. An oligonucleotide having a 5' terminus other than 5'-hydroxyl or 5'-phosphate has a modified 5' terminus. An oligonucleotide having a 3'-hydroxyl or 3'-phosphate has an unmodified 3' terminus. An oligonucleotide having a 3' terminus other than 3'-hydroxyl or 3'-phosphate has a modified 3' terminus.

[0086] The term "oxo," as used herein, represents a divalent oxygen atom (e.g., the structure of oxo may be shown as =O).

[0087] The term "pharmaceutically acceptable," as used herein, refers to those compounds, materials, compositions, and/or dosage forms, which are suitable for contact with the tissues of an individual (e.g., a human), without excessive toxicity, irritation, allergic response and other problem complications commensurate with a reasonable benefit/risk ratio.

[0088] The term "protecting group," as used herein, represents a group intended to protect a functional group (e.g., a hydroxyl, an amino, or a carbonyl) from participating in one or more undesirable reactions during chemical synthesis. The term "*O*-protecting group," as used herein, represents a group intended to protect an oxygen containing (e.g., phenol, hydroxyl or carbonyl) group from participating in one or more undesirable reactions during chemical synthesis. The term "*N*-protecting group," as used herein, represents a group intended to protect a nitrogen containing (e.g., an amino or hydrazine) group from participating in one or more undesirable reactions during chemical synthesis. Commonly used *O*- and *N*-protecting groups are disclosed in Wuts, "Greene's Protective Groups in Organic Synthesis," 4th Edition (John Wiley & Sons, New York, 2006), which is incorporated herein by reference. Exemplary *O*- and *N*-protecting groups include alkanoyl, aryloyl, or carbamyl groups such as formyl, acetyl, propionyl, pivaloyl, *t*-butylacetyl, 2-chloroacetyl, 2-bromoacetyl, trifluoroacetyl, trichloroacetyl, phthalyl, *o*-nitrophenoxyacetyl, α -chlorobutyryl, benzoyl, 4-chlorobenzoyl, 4-bromobenzoyl, *t*-butyldimethylsilyl, *tri-iso*-propylsilyloxymethyl, 4,4'-dimethoxytrityl, isobutyryl, phenoxyacetyl, 4-isopropylphenoxyacetyl, dimethylformamidino, and 4-nitrobenzoyl.

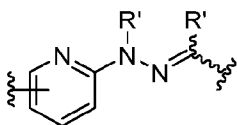
[0089] Exemplary *O*-protecting groups for protecting carbonyl containing groups include, but are not limited to: acetals, acylals, 1,3-dithianes, 1,3-dioxanes, 1,3-dioxolanes, and 1,3-dithiolanes.

[0090] Other *O*-protecting groups include, but are not limited to: substituted alkyl, aryl, and arylalkyl ethers (e.g., trityl; methylthiomethyl; methoxymethyl; benzyloxymethyl; siloxymethyl; 2,2,2-trichloroethoxymethyl; tetrahydropyranyl; tetrahydrofuranyl; ethoxyethyl; 1-[2-(trimethylsilyl)ethoxy]ethyl; 2-trimethylsilylethyl; *t*-butyl ether; *p*-chlorophenyl, *p*-methoxyphenyl, *p*-nitrophenyl, benzyl, *p*-methoxybenzyl, and nitrobenzyl); silyl ethers (e.g., trimethylsilyl; triethylsilyl; triisopropylsilyl; dimethylisopropylsilyl; *t*-butyldimethylsilyl; *t*-butyldiphenylsilyl; tribenzylsilyl; triphenylsilyl; and diphenylmethylsilyl); carbonates (e.g., methyl, methoxymethyl, 9-fluorenylmethyl; ethyl; 2,2,2-trichloroethyl; 2-(trimethylsilyl)ethyl; vinyl, allyl, nitrophenyl; benzyl; methoxybenzyl; 3,4-dimethoxybenzyl; and nitrobenzyl).

[0091] Other *N*-protecting groups include, but are not limited to, chiral auxiliaries such as protected or unprotected D, L or D, L-amino acids such as alanine, leucine, phenylalanine, and the like; sulfonyl-containing groups such as benzenesulfonyl, *p*-toluenesulfonyl, and the like; carbamate forming groups such as benzyloxycarbonyl, *p*-chlorobenzyloxycarbonyl, *p*-methoxybenzyloxycarbonyl, *p*-

nitrobenzyloxycarbonyl, 2-nitrobenzyloxycarbonyl, p-bromobenzyloxycarbonyl, 3,4-dimethoxybenzyloxycarbonyl, 3,5-dimethoxybenzyl oxycarbonyl, 2,4-dimethoxybenzyloxycarbonyl, 4-methoxybenzyloxycarbonyl, 2-nitro-4,5-dimethoxybenzyloxycarbonyl, 3,4,5-trimethoxybenzyloxycarbonyl, 1-(p-biphenyl)-1-methylethoxycarbonyl, α,α -dimethyl-3,5-dimethoxybenzyloxycarbonyl, benzhydroxy carbonyl, t-butyloxycarbonyl, diisopropylmethoxycarbonyl, isopropoxycarbonyl, ethoxycarbonyl, methoxycarbonyl, allyloxycarbonyl, 2,2,2-trichloroethoxycarbonyl, phenoxycarbonyl, 4-nitrophenoxy carbonyl, fluorenyl-9-methoxycarbonyl, cyclopentyloxycarbonyl, adamantyloxycarbonyl, cyclohexyloxycarbonyl, phenylthiocarbonyl, and the like, arylalkyl groups such as benzyl, triphenylmethyl, benzyloxymethyl, and the like and silyl groups such as trimethylsilyl, and the like.

10 **[0092]** The term "pyrid-2-yl hydrazone," as used herein, represents a group of the structure:



, where each R' is independently H or optionally substituted C₁₋₆ alkyl. Pyrid-2-yl hydrazone may be unsubstituted (i.e., each R' is H).

[0093] The term "splice site," as used herein, generally refers to a site in a genome corresponding to an end of an intron that may be involved in a splicing procedure. A splice site may be a 5' splice site (e.g., a 5' end of an intron) or a 3' splice site (e.g., a 3' end of an intron). A given 5' splice site may be associated with one or more candidate 3' splice sites, each of which may be coupled to its corresponding 5' splice site in a splicing operation.

[0094] The term "splicing enhancer," as used herein, refers to motifs with positive effects (e.g., causing an increase) on exon inclusion.

20 **[0095]** The term "splicing silencer," as used herein, refers to motifs with negative effects (e.g., causing a decrease) on exon inclusion.

[0096] The term "stereochemically enriched," as used herein, refers to a local stereochemical preference for one enantiomer of the recited group over the opposite enantiomer of the same group. Thus, an oligonucleotide containing a stereochemically enriched internucleoside linkage is an oligonucleotide, in which a stereogenic internucleoside linkage (e.g., phosphorothioate) of predetermined stereochemistry is present in preference to a stereogenic internucleoside linkage (e.g., phosphorothioate) of stereochemistry that is opposite of the predetermined stereochemistry. This preference can be expressed numerically using a diastereomeric ratio for the stereogenic internucleoside linkage (e.g., phosphorothioate) of the predetermined stereochemistry. The diastereomeric ratio for the stereogenic internucleoside linkage (e.g., phosphorothioate) of the predetermined stereochemistry is the molar ratio of the diastereomers having the identified stereogenic internucleoside linkage (e.g., phosphorothioate) with the predetermined stereochemistry relative to the diastereomers having the identified stereogenic internucleoside linkage (e.g., phosphorothioate) with the stereochemistry that is opposite of the predetermined stereochemistry. The diastereomeric ratio for the phosphorothioate of the predetermined stereochemistry may be greater than or equal to 1.1 (e.g., greater than or equal to 4, greater than or equal to 9, greater than or equal to 19, or greater than or equal to 39).

[0097] The term "subject," as used herein, represents a human or non-human animal (e.g., a mammal) that is suffering from, or is at risk of, disease, disorder, or condition, as determined by a qualified professional (e.g., a doctor or a nurse practitioner) with or without known in the art laboratory

test(s) of sample(s) from the subject. A non-limiting example of a disease, disorder, or condition includes Wilson disease (e.g., Wilson disease associated with exon 6 skipping).

[0098] A "sugar" or "sugar moiety," includes naturally occurring sugars having a furanose ring or a structure that is capable of replacing the furanose ring of a nucleoside. Sugars included in the nucleosides of the invention may be non-furanose (or 4'-substituted furanose) rings or ring systems or open systems. Such structures include simple changes relative to the natural furanose ring (e.g., a six-membered ring). Alternative sugars may also include sugar surrogates wherein the furanose ring has been replaced with another ring system such as, e.g., a morpholino or hexitol ring system. Non-limiting examples of sugar moieties useful that may be included in the oligonucleotides of the invention include β -D-ribose, β -D-2'-deoxyribose, substituted sugars (e.g., 2', 5', and bis substituted sugars), 4'-S-sugars (e.g., 4'-S-ribose, 4'-S-2'-deoxyribose, and 4'-S-2'-substituted ribose), bicyclic sugar moieties (e.g., the 2'-O—CH₂-4' or 2'-O—(CH₂)₂-4' bridged ribose derived bicyclic sugars) and sugar surrogates (when the ribose ring has been replaced with a morpholino or a hexitol ring system).

[0099] The term "targeting moiety," as used herein, represents a moiety (e.g., N-acetylgalactosamine or a cluster thereof) that specifically binds or reactively associates or complexes with a receptor or other receptive moiety associated with a given target cell population. An antisense oligonucleotide may contain a targeting moiety. An antisense oligonucleotide including a targeting moiety is also referred to herein as a conjugate. A targeting moiety may include one or more ligands (e.g., 1 to 6 ligands, 1 to 3 ligands, or 1 ligand). The ligand can be an antibody or an antigen-binding fragment or an engineered derivative thereof (e.g., Fcab or a fusion protein (e.g., scFv)). Alternatively, the ligand may be a small molecule (e.g., N-acetylgalactosamine).

[00100] The term "therapeutically effective amount," as used herein, represents the quantity of an antisense oligonucleotide of the invention necessary to ameliorate, treat, or at least partially arrest the symptoms of a disease or disorder (e.g., to increase the level of ATP7B mRNA molecules including exon 6). Amounts effective for this use may depend, e.g., on the severity of the disease and the weight and general state of the subject. Typically, dosages used *in vitro* may provide useful guidance in the amounts useful for *in vivo* administration of the pharmaceutical composition, and animal models may be used to determine effective dosages for treatment of particular disorders. In some embodiments, a therapeutically effective amount of an antisense oligonucleotide of the invention reduces 24-hour urinary copper level in the subject to <100 $\mu\text{g}/24$ hours (<1.6 $\mu\text{mol}/24$ hours) (e.g., to ≤ 40 $\mu\text{g}/24$ hours (≤ 0.6 $\mu\text{mol}/24$ hours)).

[00101] The term "thiocarbonyl," as used herein, represents a C(=S) group. - Non-limiting example of functional groups containing a "thiocarbonyl" includes thioesters, thioketones, thioaldehydes, thioanhydrides, thioacyl chlorides, thioamides, thiocarboxylic acids, and thiocarboxylates.

[00102] The term "thioheterocyclylene," as used herein, represents a divalent group —S—R'—, where R' is a heterocyclylene as defined herein.

[00103] The term "thiol," as used herein, represents an —SH group.

[00104] The term "triazolocycloalkenylene," as used herein, refers to the heterocyclenylenes containing a 1,2,3-triazole ring fused to an 8-membered ring, all of the endocyclic atoms of which are carbon atoms, and bridgehead atoms are sp²-hybridized carbon atoms. Triazolocycloalkenylenes can be optionally substituted in a manner described for heterocyclyl.

[00105] The term “triazoloheterocyclylene,” as used herein, refers to the heterocyclenylenes containing a 1,2,3-triazole ring fused to an 8-membered ring containing at least one heteroatom. The bridgehead atoms in triazoloheterocyclylene are carbon atoms. Triazoloheterocyclenylenes can be optionally substituted in a manner described for heterocyclyl.

5 [00106] Enumeration of positions within oligonucleotides and nucleic acids, as used herein and unless specified otherwise, starts with the 5'-terminal nucleoside as 1 and proceeds in the 3'-direction.

[00107] The compounds described herein, unless otherwise noted, encompass isotopically enriched compounds (e.g., deuterated compounds), tautomers, and all stereoisomers and conformers (e.g. enantiomers, diastereomers, *E/Z* isomers, atropisomers, etc.), as well as racemates thereof and mixtures of different proportions of enantiomers or diastereomers, or mixtures of any of the foregoing forms as well as salts (e.g., pharmaceutically acceptable salts).

10 [00108] Additional aspects and advantages of the present disclosure will become readily apparent to those skilled in this art from the following detailed description, wherein only illustrative embodiments of the present disclosure are shown and described. As will be realized, the present disclosure is capable of other and different embodiments, and its several details are capable of modifications in various obvious respects, all without departing from the disclosure. Accordingly, the drawings and description are to be regarded as illustrative in nature, and not as restrictive.

INCORPORATION BY REFERENCE

[00109] All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference. To the extent publications and patents or patent applications incorporated by reference contradict the disclosure contained in the specification, the specification is intended to supersede and/or take precedence over any such contradictory material.

BRIEF DESCRIPTION OF THE DRAWINGS

25 [00110] FIGS. 1A and B show the chr13:52535985:A:C [hg19/b37] variant reduces exon 6 inclusion in ATP7B minigenes. FIG. 1A shows RT-PCR analysis of HEK293T cells transfected with ATP7B minigenes. Exon inclusion (445 bp) and exclusion (368 bp) fragments are indicated by black solid arrowheads for both wildtype minigene (WT) and chr13:52535985:A:C [hg19/b37] (M645R) variant minigene. 100 bp DNA ladder is shown for size reference. FIG. 1B depicts the percentage of exon 6 inclusion in ATP7B minigenes calculated by quantification of the RT-PCR fragments observed in FIG. 1A.

30 [00111] FIGS. 2A, 2B, and 2C show antisense oligonucleotide target (“hotspot”) identification by coarse-tilling of ATP7B minigenes. FIG. 2A is a schematic representation of the relative locations of the set of antisense oligonucleotides having the sequences set forth in SEQ ID NOs: 3-34, coarse-tilled across exon 6 and the flanking introns. FIG. 2B shows capillary electrophoresis of RT-PCR products of HEK293T cells transfected with ATP7B wildtype and M645R ATP7B minigenes and antisense oligonucleotides having the sequence set forth in SEQ ID NOs: 3-34. A 100 bp DNA ladder is shown for size reference with the exon 6 inclusion band at 445 bp and exclusion band at 368 bp. FIG. 2C depicts the percentage of exon 6 inclusion in ATP7B wildtype and M645R ATP7B minigenes co-transfected with antisense oligonucleotides having the sequence set forth in SEQ ID NOs: 3-34 calculated by

quantification of the RT-PCR fragments observed in FIG. 2B. Inclusion percentages were normalized according to fragment sizes (n=4 for WT, n=5 for M645R).

[00112] FIG. 3 is a depiction of the forward strand of the human genome surrounding exon 6 of the ATP7B gene, which is in reverse complement (i.e., antisense) with respect to the ATP7B transcript. (SEQ ID NO: 163 CCAGGTAGAGGAAGGGACTTAGATGAGAGCTGGAGTTTATCTTTTGTGTTCTACCTAC and SEQ ID: 164

CTTGTCATTA AAAAGAGAGGGGTGGGGAAAAAGGAGGAAGG TACTTGGTTAAAATATGCATTGGCAG AAAGCACTTTTCAGCTTTGGAAATTAGAAAG) (underlined). The location and sequence of antisense oligonucleotides according to the invention are also shown SEQ ID NOs: 28-33, 47-51, 60, 61, 63-67, 76-81, 93-95, 120, 121, 130, 132-137, 147, and 150 and their corresponding effect on the percent of exon 6 spliced in (dPSI).

[00113] FIGS. 4A and 4B show recovery of copper tolerance and ATP7B protein levels upon treatment with a splice modulating antisense oligonucleotide having a sequence set forth in SEQ ID: 29. FIG. 4A depicts the results of a copper sensitivity assay using both HepG2 wild-type (Wt) and 2F3 cells as well as corresponding non-transfected (NT) controls. 2F3 cells are compound heterozygous, with one allele including the M645R mutation and the other allele inactivated by the insertion of a plasmid sequence. The M645R variant (2F3) has lower cell viability with increasing copper concentration as compared to wildtype cells. This phenotype is partially rescued by transfection with an oligonucleotide (SEQ ID NO: 29), which increases the inclusion of exon 6 (error bars representing the standard deviation for the experiment done in triplicate). FIG. 4B depicts a western blot against ATP7B using both HepG2 wild-type (Wt) and 2F3 cells as well as corresponding non-transfected (NT) controls. The mutant (2F3) shows a decrease in ATP7B protein levels. This phenotype is partially rescued by transfection with an oligonucleotide (SEQ ID NO: 29), which increases the inclusion of exon 6.

DETAILED DESCRIPTION

[00114] In general, the present invention provides antisense oligonucleotides, compositions, and methods that target ATP7B exon 6 or a flanking intron. Surprisingly, the inventors have found that altering ATP7B gene splicing to include exon 6 in the transcript may be used to treat Wilson disease and antisense oligonucleotides may be used to alter splicing of the ATP7B gene to include exon 6. The antisense oligonucleotides of the invention may modulate splicing of ATP7B pre-mRNA to increase the level of ATP7B mRNA molecules having exon 6. Accordingly, the antisense oligonucleotides may be used to treat Wilson disease in a subject in need of a treatment therefor. Typically, an antisense oligonucleotide includes a nucleobase sequence at least 70% complementary to an ATP7B target sequence in exon 6, a 5'-flanking intron, a 3'-flanking intron, or a combination of exon 6 and the 5'-flanking or 3'-flanking intron.

[00115] Genetic variants may correspond to changes or modifications in transcription and/or splicing. RNA is initially transcribed from DNA as pre-mRNA, with protein-coding and 5'UTR/3'UTR exons separated by introns. Splicing generally refers to the molecular process, carried out by the spliceosome complexes that may remove introns and adjoins exons, producing a mature mRNA sequence, which is then scanned and translated to protein by the ribosome. The molecular reaction catalyzed by the spliceosome may comprise (i) nucleophilic attack of the branch site adenosine 2'OH onto the outmost base of the intronic donor dinucleotide, with consequent release of the outmost exonic donor base 3'OH;

and (ii) nucleophilic attack of the exonic donor 3'OH onto the outmost exonic acceptor base, with consequent release of the intron lariat and the spliced exons.

[00116] Splicing sequence changes can include the following categories: (a) alteration of a splice site (denominated canonical splice site) or exon recognition sequence required for the proper composition of a gene product, and (b) activation and utilization of an incorrect splice site (denominated cryptic splice site), or incorrect recognition of intronic sequence as an exon (denominated pseudo exon); both may result in the improper composition of a gene product. The splice site recognition signal may be required for spliceosome assembly and can comprise the following structures: (i) highly conserved intronic dinucleotide (AG, GT), immediately adjacent to the exon-intron boundary, and (ii) consensus sequence surrounding the intronic dinucleotide (often delimited to 3 exonic and 6 intronic nucleotides for the donor site, 3 exonic and 20 intronic nucleotides for the acceptor site) and branch site (variable position on the intronic acceptor side); both with lower conservation and more sequence variety.

[00117] In addition to splice site recognition, the exon recognition signal may comprise a plethora of motifs recognized by splicing factors and other RNA binding proteins, some of which may be ubiquitously expressed and some of which may be tissue specific. These motifs may be distributed over the exon body and in the proximal intronic sequence. The term "splicing enhancer" refers to motifs with positive effects (e.g., causing an increase) on exon inclusion, and the term "splicing silencer" refers to motifs with negative effects (e.g., causing a decrease) on exon inclusion. The exon recognition signal may be particularly important for correct splicing in the presence of weak consensus sequence. When a variant weakens the splice site recognition, the exon can be skipped and/or a nearby cryptic splice site which is already fairly strong can be used; especially in the presence of short introns, full intron retention is also a possible outcome. In particular, alteration of the intronic dinucleotide often results in splicing alteration, whereas consensus sequence alteration may be, on average, less impactful and more context-dependent. When the exon recognition signal is weakened, exon skipping may be a more likely outcome, but cryptic splice site use is also possible, especially in the presence of very weak consensus sequence. Variants can also strengthen a weak cryptic splice site in proximity of the canonical splice site, and significantly increase its usage resulting in improper splicing and incorrect gene product (with effects including amino acid insertion/deletion, frameshift, and stop-gain). Finally, variants that are more distant from canonical splice site can induce recognition of an exonic sequence as an intron, again resulting in improper gene product composition; specifically, these variants can increase the strength of the splice sites or the exon recognition signal.

[00118] Antisense oligonucleotides can be used to modulate gene splicing (e.g., by targeting splicing regulatory elements of the gene).

[00119] Antisense oligonucleotides may comprise splice-switching oligonucleotides (SSOs), which may modulate splicing by steric blockage (e.g., to enhance the inclusion of exon 6), preventing the spliceosome assembly or the binding of splicing factors and RNA binding proteins. Blocking the spliceosome assembly proteins may be therapeutically used to cause exon skipping. Blocking binding of specific splicing factors or RNA binding proteins that have an inhibitory effect may be used to produce increased exon inclusion. Specific steric blocker antisense oligonucleotide chemistries may include the modified RNA chemistry with phosphorothioate backbone (PS) with a sugar modification (e.g., 2'-modification) and phosphorodiamidate morpholino (PMO). Exemplary PS backbone sugar modifications may include 2'-O-methyl (2'OMe) and 2'-O-methoxyethyl (2'-MOE), which is also known as 2'-

methoxyethoxy. Other nucleotide modifications may be used, for example, for the full length of the oligonucleotide or for specific bases. The oligonucleotides can be covalently conjugated to a targeting moiety (e.g., a GalNAc cluster), or to a peptide (e.g., a cell penetrating peptide), or to another molecular or multimolecular group (e.g., a hydrophobic moiety or neutral polymer) different from the rest of the oligonucleotide. Antisense oligonucleotides may be used as a single stereoisomer or a combination of stereoisomers.

[00120] The ATP7B gene (ATPase copper transporting beta, OMIM: 606882) may play an important role in pathogenicity of Wilson disease (also known as Wilson's disease). ATP7B is a gene encoding an intracellular trans-Golgi copper transporter. The gene may be expressed in liver hepatocytes and may be required for copper excretion from the bloodstream to the bile and for ceruloplasmin copper loading. Defective copper excretion and/or ceruloplasmin copper loading can lead to toxic effects in the liver and central nervous system. ATP7B homozygous or compound heterozygous loss-of-function may result in the autosomal recessive Wilson Disease (OMIM: 277900).

[00121] Recognizing a need for effective splicing modulation therapies for diseases such as Wilson disease, the present disclosure provides ATP7B splice-modulating antisense oligonucleotides comprising sequences targeted to a splicing regulatory element of an abnormally spliced exon or an intron adjacent to an abnormally spliced exon of ATP7B. The present disclosure also provides methods for modulating splicing of ATP7B RNA in a cell, tissue, or organ of a subject by bringing the cell, tissue, or organ in contact with an antisense oligonucleotide of the invention. An ATP7B splice-modulating antisense oligonucleotide may comprise a nucleobase sequence targeted to a splicing regulatory element of an abnormally spliced exon or an intron adjacent to an abnormally spliced exon of ATP7B. In addition, the present disclosure provides a method for treating Wilson disease in a subject by administering to the subject a therapeutically effective amount of an oligonucleotide of the invention. An ATP7B splice-modulating antisense oligonucleotide may comprise a sequence targeted to a splicing regulatory element of an abnormally spliced exon or an intron adjacent to an abnormally spliced exon of ATP7B.

[00122] Splicing regulatory elements may include, for example, exonic splicing silencer elements or intronic splicing silencer elements. The antisense oligonucleotides may comprise sequences targeted to an exon or an intron adjacent to the exon of ATP7B which modulates variant splicing of ATP7B RNA. The modulation of splicing may result in an increase in exon inclusion. Antisense oligonucleotides may comprise a total of 8 to 50 nucleotides (e.g., 8 to 16 nucleotides, 8 to 20 nucleotides, 12 to 20 nucleotides, 12 to 30 nucleotides, or 12 to 50 nucleotides).

[00123] Genetic aberrations of the ATP7B gene may play an important role in pathogenicity. In particular, an ATP7B M645R genetic aberration, ATP7B chr13:52535985:A:C [hg19/b37] (hg19 coordinates) (g.54646T>G mutant of SEQ ID NO: 1), may result in NM_000053.3 cDNA change 1934T>G and protein sequence Met645Arg (M645R) in exon 6. Genome coordinates may be expressed, for example, with respect to human genome reference hg19/b37. For example, this variant has been reported as pathogenic in patients with Wilson Disease.

[00124] Other exemplary genetic aberrations which are predicted *in silico* to cause a decrease in exon 6 inclusion and which have been observed in the Human Gene Mutation Database (HGMD) include chr13:52535964:T:C (position 54667 in SEQ ID NO: 1; HGMD ID: CS076596) and chr13:52535994:T:C (position 54637 in SEQ ID NO: 1; HGMD ID: CM164020).

[00125] These exemplary genetic aberrations may be targeted with antisense oligonucleotides to increase levels of exon inclusion, and other similar mutations in splicing regulatory elements may be targeted in a similar fashion.

5 [00126] Different antisense oligonucleotides can be combined for increasing the inclusion of exon 6 of ATP7B. A combination of two antisense oligonucleotides may be used in a method of the invention, such as two antisense oligonucleotides, three antisense oligonucleotides, four different antisense oligonucleotides, or five different antisense oligonucleotides targeting the same or different regions or hotspots.

10 [00127] An antisense oligonucleotide according to the invention may be indirectly administered using suitable techniques and methods known in the art. It may for example be provided to an individual or a cell, tissue or organ of the individual in the form of an expression vector wherein the expression vector encodes a transcript comprising said oligonucleotide. The expression vector is preferably introduced into a cell, tissue, organ or individual via a gene delivery vehicle. In an embodiment, there is provided a viral based expression vector comprising an expression cassette or a transcription cassette that drives
15 expression or transcription of an antisense oligonucleotide as identified herein. Accordingly, the present invention provides a viral vector expressing an antisense oligonucleotide according to the invention.

[00128] An antisense oligonucleotide according to the invention may be directly administered using suitable techniques and methods known in the art, e.g., using conjugates described herein.

20 Conjugates

[00129] Oligonucleotides of the invention may include an auxiliary moiety, e.g., a targeting moiety, hydrophobic moiety, cell penetrating peptide, or a polymer. An auxiliary moiety may be present as a 5' terminal modification (e.g., covalently bonded to a 5'-terminal nucleoside), a 3' terminal modification (e.g., covalently bonded to a 3'-terminal nucleoside), or an internucleoside linkage (e.g., covalently bonded to
25 phosphate or phosphorothioate in an internucleoside linkage).

Targeting Moieties

[00130] An oligonucleotide of the invention may include a targeting moiety.

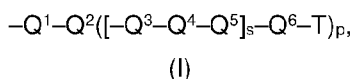
30 [00131] A targeting moiety is selected based on its ability to target oligonucleotides of the invention to a desired or selected cell population that expresses the corresponding binding partner (e.g., either the corresponding receptor or ligand) for the selected targeting moiety. For example, an oligonucleotide of the invention could be targeted to hepatocytes expressing asialoglycoprotein receptor (ASGP-R) by selecting a targeting moiety containing N-acetylgalactosamine (GalNAc).

[00132] A targeting moiety may include one or more ligands (e.g., 1 to 9 ligands, 1 to 6 ligands, 1 to 3 ligands, 3 ligands, or 1 ligand). The ligand may target a cell expressing asialoglycoprotein receptor
35 (ASGP-R), IgA receptor, HDL receptor, LDL receptor, or transferrin receptor. Non-limiting examples of the ligands include N-acetylgalactosamine, glycyrrhetic acid, glycyrrhizin, lactobionic acid, lactoferrin, IgA, or a bile acid (e.g., lithocholytaurine or taurocholic acid).

40 [00133] The ligand may be a small molecule, e.g., a small molecules targeting a cell expressing asialoglycoprotein receptor (ASGP-R). A non-limiting example of a small molecule targeting an asialoglycoprotein receptor is N-acetylgalactosamine. Alternatively, the ligand can be an antibody or an antigen-binding fragment or an engineered derivative thereof (e.g., Fcab or a fusion protein (e.g., scFv)).

[00134] A targeting moiety may be $-\text{LinkA}(-\text{T})_p$, where LinkA is a multivalent linker, each T is a ligand (e.g., asialoglycoprotein receptor-targeting ligand (e.g., N-acetylgalactosamine)), and p is an integer from 1 to 9. When each T is N-acetylgalactosamine, the targeting moiety is referred to as a galactosamine cluster. Galactosamine clusters that may be used in oligonucleotides of the invention are known in the art. Non-limiting examples of the galactosamine clusters that may be included in the oligonucleotides of the invention are provided in US 5,994,517; US 7,491,805; US 9,714,421; US 9,867,882; US 9,127,276; US 2018/0326070; US 2016/0257961; WO 2017/100461; and in Sliedregt et al., *J. Med. Chem.*, 42:609-618, 1999. Ligands other than GalNAc may also be used in clusters, as described herein for galactosamine clusters.

[00135] Targeting moiety $-\text{LinkA}(-\text{T})_p$ may be a group of formula (I):

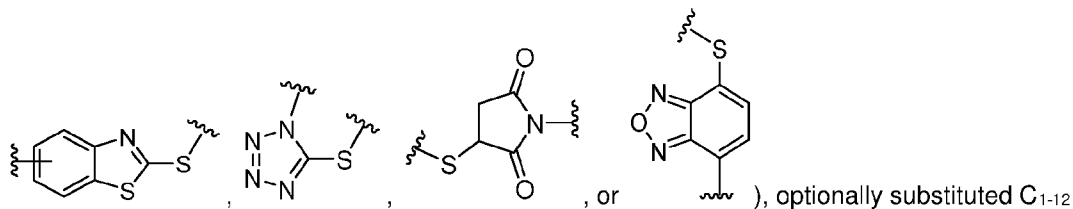
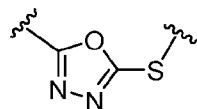


where

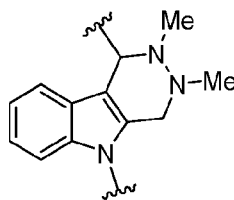
each s is independently an integer from 0 to 20 (e.g., from 0 to 10), where the repeating units are the same or different;

Q^1 is a conjugation linker (e.g., $[\text{-Q}^3-\text{Q}^4-\text{Q}^5]_s-\text{Q}^c-$, where Q^c is optionally substituted C_{2-12} heteroalkylene (e.g., a heteroalkylene containing $-\text{C}(\text{O})-\text{N}(\text{H})-$, $-\text{N}(\text{H})-\text{C}(\text{O})-$, $-\text{S}(\text{O})_2-\text{N}(\text{H})-$, $-\text{N}(\text{H})-$

$\text{S}(\text{O})_2-$, or $-\text{S}-\text{S}-$), optionally substituted C_{1-12} thioheterocyclylene (e.g.,

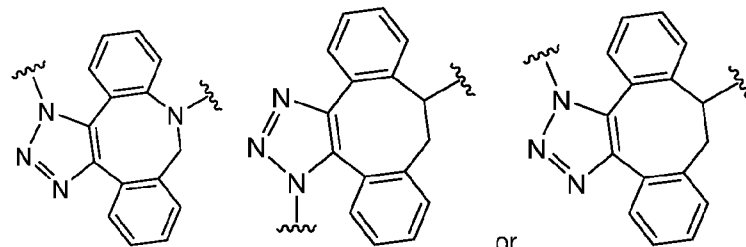
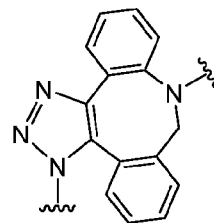


heterocyclylene (e.g., 1,2,3-triazole-1,4-diyl or

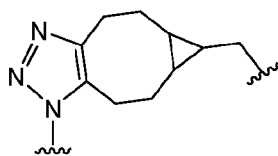


cyclobut-3-ene-1,2-dione-3,4-diyl,

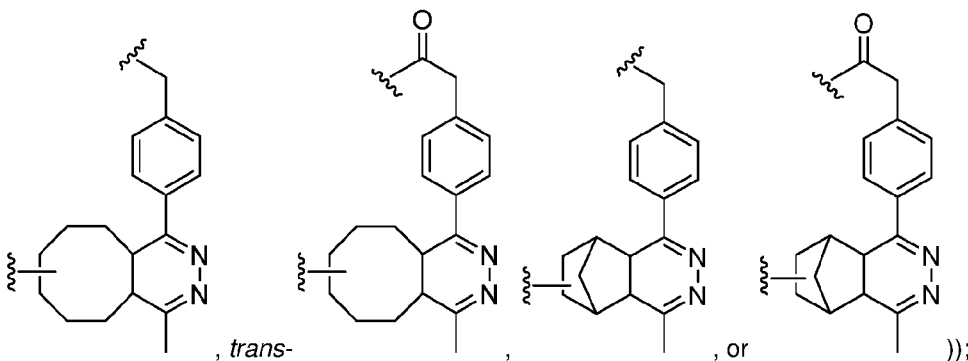
pyrid-2-yl hydrazone, optionally substituted C_{6-16} triazoloheterocyclylene (e.g.,

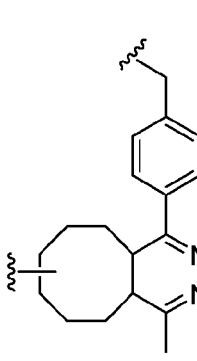
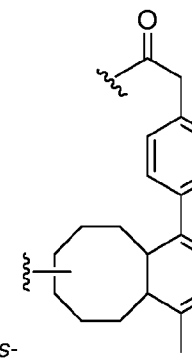
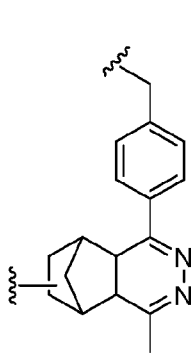


), optionally substituted C_{8-16}



triazolocycloalkenylene (e.g., , or a dihydropyridazine group (e.g., *trans-*



trans- , , or ));
 Q^2 is a linear group (e.g., $[-Q^3-Q^4-Q^5]_s-$), if p is 1, or a branched group (e.g., $[-Q^3-Q^4-Q^5]_s-Q^7([Q^3-Q^4-Q^5]_s-(Q^7)_{p1})_{p2}$, where $p1$ is 0, 1, or 2, and $p2$ is 0, 1, 2, or 3), if p is an integer from 2 to 9;

5 each Q^3 and each Q^6 is independently absent, $-CO-$, $-NH-$, $-O-$, $-S-$, $-SO_2-$, $-OC(O)-$, $-C(O)O-$, $-NHC(O)-$, $-C(O)NH-$, $-CH_2-$, $-CH_2NH-$, $-NHCH_2-$, $-CH_2O-$, or $-OCH_2-$;

each Q^4 is independently absent, optionally substituted C_{1-12} alkylene, optionally substituted C_{2-12} alkenylene, optionally substituted C_{2-12} alkynylene, optionally substituted C_{2-12} heteroalkylene, optionally substituted C_{6-10} arylene, optionally substituted C_{1-9} heteroarylene, or optionally substituted C_{1-9} heterocyclylene;

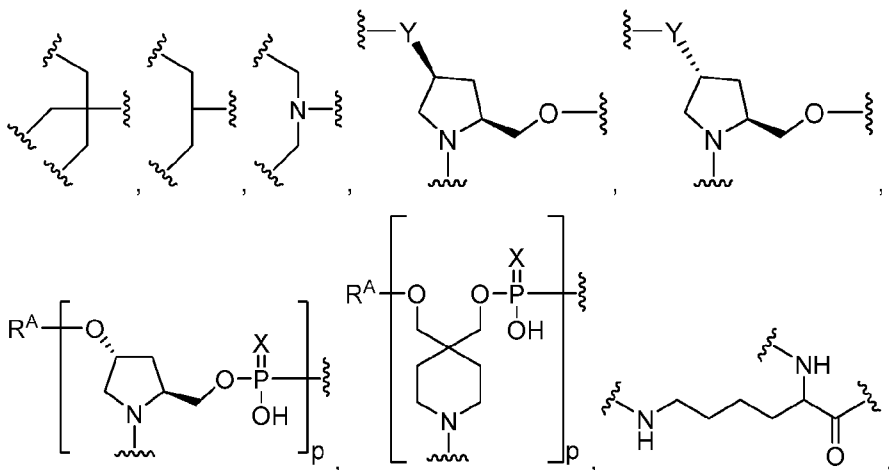
each Q^5 is independently absent, $-CO-$, $-NH-$, $-O-$, $-S-$, $-SO_2-$, $-CH_2-$, $-C(O)O-$, $-OC(O)-$, $-C(O)NH-$, $-NH-C(O)-$, $-NH-CH(R^a)-C(O)-$, $-C(O)-CH(R^a)-NH-$, $-OP(O)(OH)O-$, or $-OP(S)(OH)O-$;

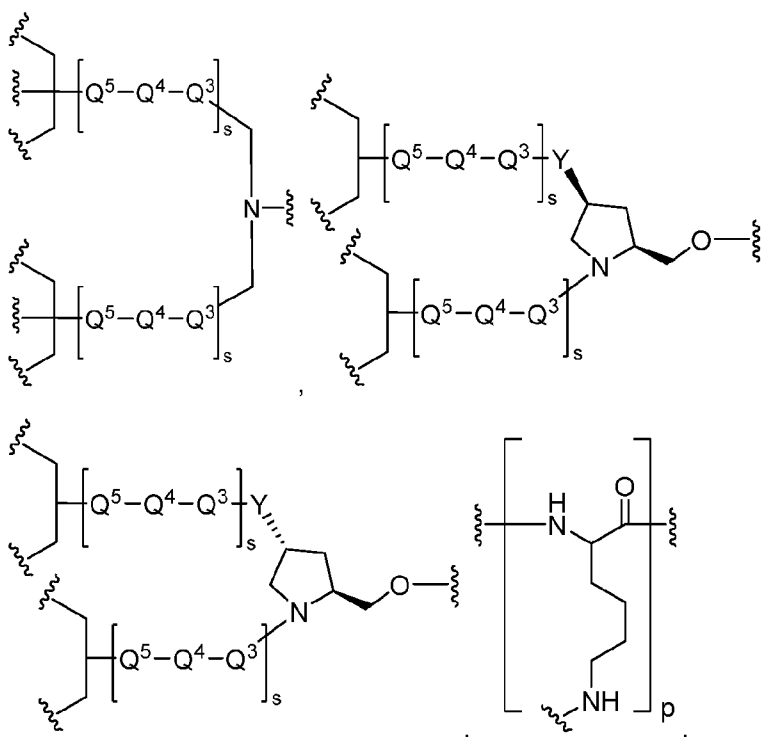
each Q^7 is independently optionally substituted hydrocarbon or optionally substituted heteroorganic (e.g., C_{1-6} alkane-triyl, optionally substituted C_{1-6} alkane-tetrayl, optionally substituted C_{2-6} heteroalkane-triyl, or optionally substituted C_{2-6} heteroalkane-tetrayl); and

each R^a is independently H or an amino acid side chain; provided that at least one of Q^3 , Q^4 , and Q^5 is present.

[00136] In some instances, for each occurrence of $[-Q^3-Q^4-Q^5]_s-$, at least one of Q^3 , Q^4 , and Q^5 is present.

20 **[00137]** In some instances, Q^7 may be a structure selected from the group consisting of:





[00138] where R^A is H or oligonucleotide, X is O or S, Y is O or NH, and the remaining variables are as described for formula (I).

- 5 **[00139]** Group –LinkA– may include a poly(alkylene oxide) (e.g., polyethylene oxide, polypropylene oxide, poly(trimethylene oxide), polybutylene oxide, poly(tetramethylene oxide), and diblock or triblock copolymers thereof). In some embodiments, –LinkA– includes polyethylene oxide (e.g., poly(ethylene oxide) having a molecular weight of less than 1 kDa).

Hydrophobic Moieties

- 10 **[00140]** Advantageously, an oligonucleotide including a hydrophobic moiety may exhibit superior cellular uptake, as compared to an oligonucleotide lacking the hydrophobic moiety. Oligonucleotides including a hydrophobic moiety may therefore be used in compositions that are substantially free of transfecting agents. A hydrophobic moiety is a monovalent group (e.g., a bile acid (e.g., cholic acid, taurocholic acid, deoxycholic acid, oleyl lithocholic acid, or oleyl cholenic acid), glycolipid, phospholipid, sphingolipid, isoprenoid, vitamin, saturated fatty acid, unsaturated fatty acid, fatty acid ester, triglyceride,
- 15 pyrene, porphyrine, texaphyrine, adamantine, acridine, biotin, coumarin, fluorescein, rhodamine, Texas-Red, digoxigenin, dimethoxytrityl, *t*-butyldimethylsilyl, *t*-butyldiphenylsilyl, cyanine dye (e.g., Cy3 or Cy5), Hoechst 33258 dye, psoralen, or ibuprofen) covalently linked to the oligonucleotide backbone (e.g., 5'-terminus). Non-limiting examples of the monovalent group include ergosterol, stigmasterol, β -sitosterol,
- 20 campesterol, fucosterol, saringosterol, avenasterol, coprostanol, cholesterol, vitamin A, vitamin D, vitamin E, cardiolipin, and carotenoids. The linker connecting the monovalent group to the oligonucleotide may be an optionally substituted C_{1-60} hydrocarbon (e.g., optionally substituted C_{1-60} alkylene) or an optionally substituted C_{2-60} heteroorganic (e.g., optionally substituted C_{2-60} heteroalkylene), where the linker may be optionally interrupted with one, two, or three instances independently selected from the group consisting
- 25 of an optionally substituted arylene, optionally substituted heterocyclylene, and optionally substituted cycloalkylene. The linker may be bonded to an oligonucleotide through, e.g., an oxygen atom attached to

a 5'-terminal carbon atom, a 3'-terminal carbon atom, a 5'-terminal phosphate or phosphorothioate, a 3'-terminal phosphate or phosphorothioate, or an internucleoside linkage.

Cell Penetrating Peptides

[00141] One or more cell penetrating peptides (e.g., from 1 to 6 or from 1 to 3) can be attached to an oligonucleotide disclosed herein as an auxiliary moiety. The CPP can be linked to the oligonucleotide through a disulfide linkage, as disclosed herein. Thus, upon delivery to a cell, the CPP can be cleaved intracellularly, e.g., by an intracellular enzyme (e.g., protein disulfide isomerase, thioredoxin, or a thioesterase) and thereby release the polynucleotide.

[00142] CPPs are known in the art (e.g., TAT or Arg₈) (Snyder and Dowdy, 2005, *Expert Opin. Drug Deliv.* 2, 43-51). Specific examples of CPPs including moieties suitable for conjugation to the oligonucleotides disclosed herein are provided, e.g., in WO 2015/188197; the disclosure of these CPPs is incorporated by reference herein.

[00143] CPPs are positively charged peptides that are capable of facilitating the delivery of biological cargo to a cell. It is believed that the cationic charge of the CPPs is essential for their function.

Moreover, the transduction of these proteins does not appear to be affected by cell type, and these proteins can efficiently transduce nearly all cells in culture with no apparent toxicity. In addition to full-length proteins, CPPs have also been used successfully to induce the intracellular uptake of DNA, antisense polynucleotides, small molecules, and even inorganic 40 nm iron particles suggesting that there is considerable flexibility in particle size in this process.

[00144] In one embodiment, a CPP useful in the methods and compositions of the invention includes a peptide featuring substantial alpha-helicity. It has been discovered that transfection is optimized when the CPP exhibits significant alpha-helicity. In another embodiment, the CPP includes a sequence containing basic amino acid residues that are substantially aligned along at least one face of the peptide. A CPP useful in the invention may be a naturally occurring peptide or a synthetic peptide.

Polymers

[00145] An oligonucleotide of the invention may include covalently attached neutral polymer-based auxiliary moieties. Neutral polymers include poly(C₁₋₆ alkylene oxide), e.g., poly(ethylene glycol) and poly(propylene glycol) and copolymers thereof, e.g., di- and triblock copolymers. Other examples of polymers include esterified poly(acrylic acid), esterified poly(glutamic acid), esterified poly(aspartic acid), poly(vinyl alcohol), poly(ethylene-co-vinyl alcohol), poly(*N*-vinyl pyrrolidone), poly(ethyloxazoline), poly(alkylacrylates), poly(acrylamide), poly(*N*-alkylacrylamides), poly(*N*-acryloylmorpholine), poly(lactic acid), poly(glycolic acid), poly(dioxanone), poly(caprolactone), styrene-maleic acid anhydride copolymer, poly(L-lactide-co-glycolide) copolymer, divinyl ether-maleic anhydride copolymer, *N*-(2-hydroxypropyl)methacrylamide copolymer (HMPA), polyurethane, *N*-isopropylacrylamide polymers, and poly(*N,N*-dialkylacrylamides). Exemplary polymer auxiliary moieties may have molecular weights of less than 100, 300, 500, 1000, or 5000 Da (e.g., greater than 100 Da). Other polymers are known in the art.

Nucleobase Modifications

[00146] Oligonucleotides of the invention may include one or more modified nucleobases.

Unmodified nucleobases include the purine bases adenine (A) and guanine (G), and the pyrimidine bases thymine (T), cytosine (C), and uracil (U). Modified nucleobases include 5-substituted pyrimidines, 6-azapyrimidines, alkyl or alkynyl substituted pyrimidines, alkyl substituted purines, and N-2, N-6 and O-6

substituted purines, as well as synthetic and natural nucleobases, e.g., 5-methylcytosine, 5-hydroxymethyl cytosine, xanthine, hypoxanthine, 2-aminoadenine, 6-alkyl (e.g., 6-methyl) adenine and guanine, 2-alkyl (e.g., 2-propyl) adenine and guanine, 2-thiouracil, 2-thiothymine, 2-thiocytosine, 5-halouracil, 5-halocytosine, 5-propynyl uracil, 5-propynyl cytosine, 5-trifluoromethyl uracil, 5-trifluoromethyl cytosine, 7-methyl guanine, 7-methyl adenine, 8-azaguanine, 8-azaadenine, 7-deazaguanine, 7-deazaadenine, 3-deazaguanine, 3-deazaadenine. Certain nucleobases are particularly useful for increasing the binding affinity of nucleic acids, e.g., 5-substituted pyrimidines; 6-azapyrimidines; N2-, N6-, and/or O6-substituted purines. Nucleic acid duplex stability can be enhanced using, e.g., 5-methylcytosine. Non-limiting examples of nucleobases include: 2-aminopropyladenine, 5-hydroxymethyl cytosine, xanthine, hypoxanthine, 2-aminoadenine, 6-N-methylguanine, 6-N-methyladenine, 2-propyladenine, 2-thiouracil, 2-thiothymine and 2-thiocytosine, 5-propynyl ($-\text{C}\equiv\text{C}-\text{CH}_3$) uracil, 5-propynylcytosine, 6-azouracil, 6-azocytosine, 6-azothymine, 5-ribosyluracil (pseudouracil), 4-thiouracil, 8-halo, 8-amino, 8-thiol, 8-thioalkyl, 8-hydroxyl, 8-aza and other 8-substituted purines, 5-halo, particularly 5-bromo, 5-trifluoromethyl, 5-halouracil, and 5-halocytosine, 7-methylguanine, 7-methyladenine, 2-F-adenine, 2-aminoadenine, 7-deazaguanine, 7-deazaadenine, 3-deazaguanine, 3-deazaadenine, 6-N-benzoyladenine, 2-N-isobutyrylguanine, 4-N-benzoylcytosine, 4-N-benzoyluracil, 5-methyl 4-N-benzoylcytosine, 5-methyl 4-N-benzoyluracil, universal bases, hydrophobic bases, promiscuous bases, size-expanded bases, and fluorinated bases. Further modified nucleobases include tricyclic pyrimidines, such as 1,3-diazaphenoxazine-2-one, 1,3-diazaphenothiazine-2-one and 9-(2-aminoethoxy)-1,3-diazaphenoxazine-2-one (G-clamp). Modified nucleobases may also include those in which the purine or pyrimidine base is replaced with other heterocycles, for example 7-deazaadenine, 7-deazaguanine, 2-aminopyridine and 2-pyridone. Further nucleobases include those disclosed in Merigan et al., U.S. Pat. No. 3,687,808, those disclosed in The Concise Encyclopedia Of Polymer Science And Engineering, Kroschwitz, J. I., Ed., John Wiley & Sons, 1990, 858-859; Englisch et al., *Angewandte Chemie*, International Edition, 1991, 30, 613; Sanghvi, Y. S., Chapter 15, *Antisense Research and Applications*, Croke, S. T. and Lebleu, B., Eds., CRC Press, 1993, 273-288; and those disclosed in Chapters 6 and 15, *Antisense Drug Technology*, Croke S. T., Ed., CRC Press, 2008, 163-166 and 442-443.

[00147] The replacement of cytidine with 5-methylcytidine can reduce immunogenicity of oligonucleotides, e.g., those oligonucleotides having CpG units.

[00148] The replacement of one or more guanosines with, e.g., 7-deazaguanosine or 6-thioguanosine, may inhibit the antisense activity reducing G tetraplex formation within antisense oligonucleotides.

Sugar Modifications

[00149] Oligonucleotides of the invention may include one or more sugar modifications in nucleosides. Nucleosides having an unmodified sugar include a sugar moiety that is a furanose ring as found in ribonucleosides and 2'-deoxyribonucleosides.

[00150] Sugars included in the nucleosides of the invention may be non-furanose (or 4'-substituted furanose) rings or ring systems or open systems. Such structures include simple changes relative to the natural furanose ring (e.g., a six-membered ring). Alternative sugars may also include sugar surrogates wherein the furanose ring has been replaced with another ring system such as, e.g., a morpholino or hexitol ring system. Non-limiting examples of sugar moieties useful that may be included in the

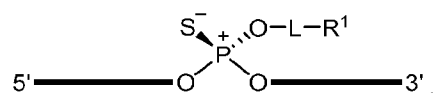
oligonucleotides of the invention include β -D-ribose, β -D-2'-deoxyribose, substituted sugars (e.g., 2', 5', and bis substituted sugars), 4'-S-sugars (e.g., 4'-S-ribose, 4'-S-2'-deoxyribose, and 4'-S-2'-substituted ribose), bridged sugars (e.g., the 2'-O—CH₂-4' or 2'-O—(CH₂)₂-4' bridged ribose derived bicyclic sugars) and sugar surrogates (when the ribose ring has been replaced with a morpholino or a hexitol ring system).

[00151] Typically, a sugar modification may be, e.g., a 2'-substitution, locking, carbocyclization, or unlocking. A 2'-substitution is a replacement of 2'-hydroxyl in ribofuranose with 2'-fluoro, 2'-methoxy, or 2'-(2-methoxy)ethoxy. A locking modification is an incorporation of a bridge between 4'-carbon atom and 2'-carbon atom of ribofuranose. Nucleosides having a sugar with a locking modification are known in the art as bridged nucleic acids, e.g., locked nucleic acids (LNA), ethylene-bridged nucleic acids (ENA), and cEt nucleic acids. The bridged nucleic acids are typically used as affinity enhancing nucleosides.

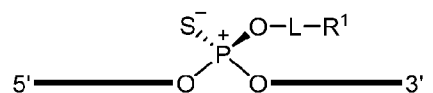
Internucleoside Linkage Modifications

[00152] Oligonucleotides of the invention may include one or more internucleoside linkage modifications. The two main classes of internucleoside linkages are defined by the presence or absence of a phosphorus atom. Non-limiting examples of phosphorus-containing internucleoside linkages include phosphodiester linkages, phosphotriester linkages, phosphorothioate diester linkages, phosphorothioate triester linkages, morpholino internucleoside linkages, methylphosphonates, and phosphoramidate. Non-limiting examples of non-phosphorus internucleoside linkages include methylenemethylimino (—CH₂—N(CH₃)—O—CH₂—), thiodiester (—O—C(O)—S—), thionocarbamate (—O—C(O)(NH)—S—), siloxane (—O—Si(H)₂—O—), and N,N'-dimethylhydrazine (—CH₂—N(CH₃)—N(CH₃)—). Modified linkages, compared to natural phosphodiester linkages, can be used to alter, typically increase, nuclease resistance of the oligonucleotide. Methods of preparation of phosphorous-containing and non-phosphorous-containing internucleoside linkages are known in the art.

[00153] Internucleoside linkages may be stereochemically enriched. For example, phosphorothioate-based internucleoside linkages (e.g., phosphorothioate diester or phosphorothioate triester) may be stereochemically enriched. The stereochemically enriched internucleoside linkages including a stereogenic phosphorus are typically designated *S*_P or *R*_P to identify the absolute stereochemistry of the phosphorus atom. Within an oligonucleotide, *S*_P phosphorothioate indicates the following structure:



Within an oligonucleotide, *R*_P phosphorothioate indicates the following structure:



[00154] The oligonucleotides of the invention may include one or more neutral internucleoside linkages. Non-limiting examples of neutral internucleoside linkages include phosphotriesters, phosphorothioate triesters, methylphosphonates, methylenemethylimino (5'-CH₂—N(CH₃)—O-3'), amide-3 (5'-CH₂—C(=O)—N(H)-3'), amide-4 (5'-CH₂—N(H)—C(=O)-3'), formacetal (5'-O—CH₂—O-3'), and thioformacetal (5'-S—CH₂—O-3'). Further neutral internucleoside linkages include nonionic linkages including siloxane (dialkylsiloxane), carboxylate ester, carboxamide, sulfide, sulfonate ester, and amides

(See for example: Carbohydrate Modifications in Antisense Research; Y. S. Sanghvi and P. D. Cook, Eds., ACS Symposium Series 580; Chapters 3 and 4, 40-65).

Terminal Modifications

5 [00155] Oligonucleotides of the invention may include a terminal modification, e.g., a 5'-terminal modification or a 3'-terminal modification.

[00156] The 5' end of an oligonucleotide may be, e.g., hydroxyl, a hydrophobic moiety, a targeting moiety, 5' cap, phosphate, diphosphate, triphosphate, phosphorothioate, diphosphorothioate, triphosphorothioate, phosphorodithioate, diphosphorodithioate, triphosphorodithioate, phosphonate, 10 phosphoramidate, a cell penetrating peptide, an endosomal escape moiety, or a neutral organic polymer. An unmodified 5'-terminus is hydroxyl or phosphate. An oligonucleotide having a 5' terminus other than 5'-hydroxyl or 5'-phosphate has a modified 5' terminus.

[00157] The 3' end of an oligonucleotide may be, e.g., hydroxyl, a targeting moiety, a hydrophobic moiety, phosphate, diphosphate, triphosphate, phosphorothioate, diphosphorothioate, 15 triphosphorothioate, phosphorodithioate, diphosphorodithioate, triphosphorodithioate, phosphonate, phosphoramidate, a cell penetrating peptide, an endosomal escape moiety, or a neutral organic polymer (e.g., polyethylene glycol). An unmodified 3'-terminus is hydroxyl or phosphate. An oligonucleotide having a 3' terminus other than 3'-hydroxyl or 3'-phosphate has a modified 3' terminus.

[00158] The terminal modification (e.g., 5'-terminal modification) may be, e.g., a targeting moiety as 20 described herein.

[00159] The terminal modification (e.g., 5'-terminal modification) may be, e.g., a hydrophobic moiety as described herein.

Complementarity

25 [00160] In some embodiments, oligonucleotides of the invention are complementary to an ATP7B target sequence over the entire length of the oligonucleotide. In other embodiments, oligonucleotides are at least 99%, 95%, 90%, 85%, 80%, or 70% complementary to the ATP7B target sequence. In further 30 embodiments, oligonucleotides are at least 80% (e.g., at least 90% or at least 95%) complementary to the ATP7B target sequence over the entire length of the oligonucleotide and include a nucleobase sequence that is fully complementary to an ATP7B target sequence. The nucleobase sequence that is fully complementary may be, e.g., 6 to 20, 10 to 18, or 18 to 20 contiguous nucleobases in length.

[00161] An oligonucleotide of the invention may include one or more (e.g., 1, 2, 3, or 4) mismatched 35 nucleobases relative to the target nucleic acid. In certain embodiments, a splice-switching activity against the target is reduced by such mismatch, but activity against a non-target is reduced by a greater amount. Thus, the off-target selectivity of the oligonucleotides may be improved.

Methods for preparing compositions

[00162] The present disclosure provides methods for preparing or generating compositions provided 40 herein. A nucleic acid molecule, such as an oligonucleotide, comprising a targeted sequence may be generated, for example, by various nucleic acid synthesis approaches. For example, a nucleic acid molecule comprising a sequence targeted to a splice site may be generated by oligomerization of modified and/or unmodified nucleosides, thereby producing DNA or RNA oligonucleotides. Antisense

oligonucleotides can be prepared, for example, by solid phase synthesis. Such solid phase synthesis can be performed, for example, in multi-well plates using equipment available from vendors such as Applied Biosystems (Foster City, CA). It is well known to use similar techniques to prepare oligonucleotides such as the phosphorothioates and alkylated derivatives. Oligonucleotides may be subjected to purification and/or analysis using methods known to those skilled in the art. For example, analysis methods may include capillary electrophoresis (CE) and electrospray-mass spectroscopy.

Pharmaceutical Compositions

[00163] An oligonucleotide of the invention may be included in a pharmaceutical composition. A pharmaceutical composition typically includes a pharmaceutically acceptable diluent or carrier. A pharmaceutical composition may include (e.g., consist of), e.g., a sterile saline solution and an oligonucleotide of the invention. The sterile saline is typically a pharmaceutical grade saline. A pharmaceutical composition may include (e.g., consist of), e.g., sterile water and an oligonucleotide of the invention. The sterile water is typically a pharmaceutical grade water. A pharmaceutical composition may include (e.g., consist of), e.g., phosphate-buffered saline (PBS) and an oligonucleotide of the invention. The sterile PBS is typically a pharmaceutical grade PBS.

[00164] Pharmaceutical compositions may include one or more oligonucleotides and one or more excipients. Excipients may be selected from water, salt solutions, alcohol, polyethylene glycols, gelatin, lactose, amylase, magnesium stearate, talc, silicic acid, viscous paraffin, hydroxymethylcellulose and polyvinylpyrrolidone.

[00165] Pharmaceutical compositions including an oligonucleotide encompass any pharmaceutically acceptable salts of the oligonucleotide. Pharmaceutical compositions including an oligonucleotide, upon administration to a subject (e.g., a human), are capable of providing (directly or indirectly) the biologically active metabolite or residue thereof. Accordingly, for example, the disclosure is also drawn to pharmaceutically acceptable salts of oligonucleotides. Suitable pharmaceutically acceptable salts include, but are not limited to, sodium and potassium salts. In certain embodiments, prodrugs include one or more conjugate group attached to an oligonucleotide, wherein the conjugate group is cleaved by endogenous enzymes within the body.

[00166] Lipid moieties have been used in nucleic acid therapies in a variety of methods. In certain such methods, the nucleic acid, such as an oligonucleotide, is introduced into preformed liposomes or lipoplexes made of mixtures of cationic lipids and neutral lipids. DNA complexes with mono- or poly-cationic lipids may form, e.g., without the presence of a neutral lipid. A lipid moiety may be, e.g., selected to increase distribution of a pharmaceutical agent to a particular cell or tissue. A lipid moiety may be, e.g., selected to increase distribution of a pharmaceutical agent to fat tissue. A lipid moiety may be, e.g., selected to increase distribution of a pharmaceutical agent to muscle tissue.

[00167] Pharmaceutical compositions may include a delivery system. Examples of delivery systems include, but are not limited to, liposomes and emulsions. Certain delivery systems are useful for preparing certain pharmaceutical compositions including those including hydrophobic compounds. Certain organic solvents such as dimethylsulfoxide may be used.

[00168] Pharmaceutical compositions may include one or more tissue-specific delivery molecules designed to deliver the one or more pharmaceutical agents of the present invention to specific tissues or

cell types. For example, pharmaceutical compositions may include liposomes coated with a targeting moiety as described herein.

[00169] Pharmaceutical compositions may include a co-solvent system. Certain co-solvent systems include, e.g., benzyl alcohol, a nonpolar surfactant, a water-miscible organic polymer, and an aqueous phase. Such co-solvent systems may be used, e.g., for hydrophobic compounds. A non-limiting example of a co-solvent system is the VPD co-solvent system, which is a solution of absolute ethanol including 3% w/v benzyl alcohol, 8% w/v of the nonpolar surfactant Polysorbate 80™ and 65% w/v polyethylene glycol 300. The proportions of such co-solvent systems may be varied considerably without significantly altering their solubility and toxicity characteristics. Furthermore, the identity of co-solvent components may be varied: for example, other surfactants may be used instead of Polysorbate 80™; the fraction size of polyethylene glycol may be varied; other biocompatible polymers may replace polyethylene glycol, e.g., polyvinyl pyrrolidone; and other sugars or polysaccharides may substitute for dextrose.

[00170] Pharmaceutical compositions may be prepared for administration by injection or infusion (e.g., intravenous, subcutaneous, intramuscular, intrathecal, intracerebroventricular, etc.). A

pharmaceutical composition may include, e.g., a carrier and may be formulated, e.g., in aqueous solution, e.g., water or physiologically compatible buffers, e.g., Hanks's solution, Ringer's solution, or physiological saline buffer. Other ingredients may also be included (e.g., ingredients that aid in solubility or serve as preservatives). Injectable suspensions may be prepared, e.g., using appropriate liquid carriers, suspending agents and the like. Certain pharmaceutical compositions for injection are presented in unit dosage form, e.g., in ampoules or in multi-dose containers. Certain pharmaceutical compositions for injection may be, e.g., suspensions, solutions, or emulsions in oily or aqueous vehicles, and may contain excipients (e.g., suspending, stabilizing and/or dispersing agents). Certain solvents suitable for use in pharmaceutical compositions for injection include, but are not limited to, lipophilic solvents and fatty oils, e.g., sesame oil, synthetic fatty acid esters (e.g., ethyl oleate or triglycerides), and liposomes.

Methods of the Invention

[00171] The invention provides methods of using oligonucleotides of the invention.

[00172] A method of the invention may be a method of increasing the level of exon 6-containing ATP7B mRNA molecules in a cell expressing an aberrant ATP7B gene by contacting the cell with the antisense oligonucleotide of the invention.

[00173] A method of the invention may be a method of treating Wilson disease in a subject having an aberrant ATP7B gene by administering a therapeutically effective amount of the antisense oligonucleotide of the invention or a pharmaceutical composition of the invention to the subject in need thereof.

[00174] The oligonucleotide of the invention or the pharmaceutical composition of the invention may be administered to the subject using methods known in the art. For example, the oligonucleotide of the invention or the pharmaceutical composition of the invention may be administered parenterally (e.g., intravenously, intramuscularly, subcutaneously, transdermally, intranasally, or intrapulmonarily) to the subject.

[00175] Dosing is typically dependent on a variety of factors including, e.g., severity and responsiveness of the disease state to be treated. The treatment course may last, e.g., from several days to several months, or until a cure is effected or a diminution of the disease state is achieved. Optimal dosing schedules can be calculated from measurements of drug accumulation in the body of the

patient. Thus, optimum dosages, dosing methodologies and repetition rates can be established as needed. Optimum dosages may vary depending on the relative potency of individual oligonucleotides, and can generally be estimated based on EC₅₀s found to be effective in *in vitro* and *in vivo* animal models. In general, dosage may be from 0.01 µg to 1 g per kg of body weight, and may be given once or more daily, weekly, monthly, bimonthly, trimonthly, every six months, annually, or biannually. Frequency of dosage may vary. Repetition rates for dosing may be established, for example, based on measured residence times and concentrations of the drug in bodily fluids or tissues. Following successful treatment, it may be desirable to have the patient undergo maintenance therapy to prevent the recurrence of the disease state, wherein the oligonucleotide is administered in maintenance doses, ranging from 0.01 µg to 1 g per kg of body weight, e.g., once daily, twice daily, three times daily, every other day, weekly, biweekly, monthly, bimonthly, trimonthly, every six months, annually or biannually.

[00176] Methods of treating Wilson disease in a subject in need thereof may also include administering to the subject a pharmaceutically acceptable chelating agent or a pharmaceutically acceptable salt of zinc. Non-limiting examples of pharmaceutically acceptable salts of zinc include zinc acetate, zinc gluconate, and zinc sulfate. Non-limiting examples of pharmaceutically acceptable chelating agents include D-penicillamine, trientine, sodium mercaptosuccinate, dimercaptosuccinic acid, and tetrathiomolybdate. In some embodiments, the method includes administering to the subject a pharmaceutically acceptable salt of zinc (e.g., zinc acetate, zinc gluconate, or zinc sulfate). In one example, an oligonucleotide of the invention and a pharmaceutically acceptable chelating agent or salt of zinc are administered together in the same pharmaceutical composition. In another example, an oligonucleotide of the invention and a pharmaceutically acceptable chelating agent or salt of zinc are administered separately at about the same time (e.g., one minute apart or less, or five minutes apart or less). In some embodiments, an oligonucleotide of the invention and a pharmaceutically acceptable chelating agent or salt of zinc are administered separately via the same route of administration (e.g., intravenous injection). In some embodiments, an oligonucleotide of the invention and a pharmaceutically acceptable chelating agent or salt of zinc are administered separately via different routes of administration (e.g., intravenous injection of an oligonucleotide of the invention and oral administration of a pharmaceutically acceptable chelating agent or salt of zinc).

[00177] In some embodiments, an oligonucleotide of the invention is administered prior to a chelating agent or salt of zinc. In further embodiments, an oligonucleotide of the invention is administered within 1 hour of the chelating agent or salt of zinc administration (e.g., before, e.g., 15 min, 30 min, or 1 hour before). In some embodiments, an oligonucleotide of the invention is administered within 12 hours of the chelating agent or salt of zinc administration (e.g., before, e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12 hours before). In certain embodiments, an oligonucleotide of the invention is administered within 24 hours of the chelating agent or salt of zinc administration (e.g., before, e.g., 12 or 24 hours before). In particular embodiments, an oligonucleotide of the invention is administered within 1 week of the chelating agent or salt of zinc administration (e.g., before, e.g., 1, 2, 3, 4, 5, or 6 days before). In some embodiments, an oligonucleotide of the invention is administered within 1 month of the chelating agent or salt of zinc administration (e.g., before, e.g., 1, 2, 3, or 4 weeks before).

[00178] In some embodiments, an oligonucleotide of the invention is administered after a chelating agent or salt of zinc. In further embodiments, an oligonucleotide of the invention is administered within 1 hour of the chelating agent or salt of zinc administration (e.g., after, e.g., 15 min, 30 min, or 1 hour after).

In some embodiments, an oligonucleotide of the invention is administered within 12 hours of the chelating agent or salt of zinc administration (e.g., after, e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12 hours after). In certain embodiments, an oligonucleotide of the invention is administered within 24 hours of the chelating agent or salt of zinc administration (e.g., after, e.g., 12 or 24 hours after). In particular embodiments, an oligonucleotide of the invention is administered within 1 week of the chelating agent or salt of zinc administration (e.g., after, e.g., 1, 2, 3, 4, 5, or 6 days after). In some embodiments, an oligonucleotide of the invention is administered within 1 month of the chelating agent or salt of zinc administration (e.g., after, e.g., 1, 2, 3, or 4 weeks after).

EXAMPLES

[00179] The following materials, methods, and examples are illustrative only and not intended to be limiting.

Materials and Methods

[00180] In general, the practice of the present invention employs, unless otherwise indicated, conventional techniques of chemistry, molecular biology, recombinant DNA technology, and standard techniques in electrophoresis. See, e.g., Sambrook, Fritsch and Maniatis, *Molecular Cloning: Cold Spring Harbor Laboratory Press* (1989) and *Current Protocols in Molecular Biology*, eds. Ausubel et al., John Wiley & Sons (1992).

[00181] Oligonucleotides. All antisense oligonucleotides used were obtained from Integrated DNA Technologies Inc. (USA). All bases in the antisense oligonucleotides were 2'-O-methoxyethyl-modified (MOE) with a full phosphorothioate backbone.

[00182] Construction of ATP7B minigenes. Minigene plasmids for ATP7B exon 6 were designed to contain fragments corresponding to exon 5 to 7 of the genomic locus of ATP7B gene, including complete intronic sequences. To minimize aberrant splicing of the transcribed mRNA fragments, consensus splice acceptor sequences of exon 5 were removed by deleting nine nucleotides from the 5' end of exon 5, likewise consensus splice donor sequences of exon 7 were removed by deleting 40 nucleotides from the 3' end of exon 7. Minigenes were constructed by DNA assembly of PCR fragments that were amplified from HEK293T genomic DNA using KOD Hot Start DNA polymerase (Novagen). For the wild-type minigene, the full fragment was amplified with primers P461

(GATCCACCGGTCCGCCACCATGACCTGCGCGTCTGTGTC) (SEQ ID: 165) and P463 (TCCTCGCCCTTGCTCACCATGGACAGTCCTGGAATGATGTTGTGG) (SEQ ID: 166). For the mutant minigene, the NM_000053.3(ATP7B):c.1934T>G(p.Met645Arg) variant was introduced by site-directed mutagenesis of two overlapping fragments which were amplified with primer combination P461 (SEQ ID: 165) and P465 (CTGCTTTATTTCCCTCTTGTGGTCCAAGTGATGAGC) (SEQ ID: 167) and primer combination P464 (GACCACAAGAGGGAAATAAAGCAGTAGGTAGAACAC) (SEQ ID: 168) and P463 (SEQ ID: 166) respectively. PCR fragments were cloned into mClover2 plasmid that was linearized with primers P459 (ATGGTGAGCAAGGGCGAGGA) (SEQ ID: 169) and P460 (CATGGTGGCGACCGGTGGAT) (SEQ ID: 170) using a NEBuilder HiFi DNA Assembly Kit (New England Biolabs) according to manufacturer's instructions. Plasmid DNA was isolated using the Presto Mini Plasmid Kit (Geneaid).

[00183] HepG2 mutant line, 2F3. This line was created from HepG2 cells by inserting the M645R variant using a CRISPR/ Cas 9 according to commonly used molecular biology techniques. The resulting

2F3 line carries the M645R variant at one allele and a large plasmid insertion at the other. This insertion has been assumed to render that allele unable to produce functional protein, thus creating a situation analogous to a compound heterozygote, consistent with what found in Wilson disease patients (Margarit et al, *Clin Genet.*, 68:61-68, 2005).

5 **[00184]** Cell culture. HEK293T cells were grown in Iscove's Modified Dulbecco's Medium (Gibco) supplemented with 10% (v/v) Cosmic Calf Serum (HyClone), 2mM L-Glutamine (Gibco) and 1% antibiotics (100-U/ml penicillin G and 100-ug/ml streptomycin, Gibco) in a humidified incubator at 37°C with 5% CO₂. Upon reaching confluency the cells were passaged by washing with Phosphate-Buffered Saline followed by Trypsin (Gibco) dissociation and plated in 10 to 20-fold dilution. HepG2 wild-type and
10 mutant 2F3 cells were grown in Dulbecco's Modified Eagle's Medium (Gibco) supplemented with 10% heat inactivated fetal bovine serum (Gibco) in a humidified incubator at 37°C with 5% CO₂. Upon reaching confluency the cells were passaged by washing with Phosphate-Buffered Saline followed by TrypLE (Gibco) dissociation and plated in a culture flask in 2 to 4-fold dilution.

[00185] Transfection of HEK293T cells with minigene plasmids. For transfection of HEK293T cells
15 with minigene plasmids, 300,000 cells were plated in 1 ml of complete medium with antibiotics in 12-well tissue culture plates and incubated at 37°C and 5% CO₂ for 24 hours. Plasmid transfection mixes were made by combining 1,000 ng of plasmid DNA (~ 5 µl) diluted in 50 µl Opti-MEM reduced serum medium (Gibco) with 3.0 µl X-tremeGENE HP DNA Transfection Reagent solution (Roche). Plasmid transfection mixes were incubated at room temperature for 20 minutes and then added to the HEK293T cells, which
20 were subsequently incubated at 37°C and 5% CO₂. After 24 hours transfection media was replaced with 2,000 µl complete media. 48 hours after transfection, cells were lysed for RNA isolation and RT-PCR analysis.

[00186] Co-transfection of HEK293T cells with antisense oligonucleotides and minigene plasmids. Antisense oligonucleotides and minigene plasmids were co-transfected into HEK293T cells in 96-well
25 format. Antisense oligonucleotide stock solutions (100 µM) were diluted to 5 µM in Opti-MEM reduced serum medium (Gibco). Antisense oligonucleotides were transfected at absolute amounts of 50 pmol of an antisense oligonucleotide per well containing 50,000 HEK293T cells. For this, 10-µl aliquots of 5 µM antisense oligonucleotide solutions were transferred to the wells of a 96-well tissue culture plate and 10 µl lipid transfection reagent solution containing 9.7 µl Opti-MEM and 0.3 µl Lipofectamine RNAiMAX
30 (Invitrogen) was added to the wells. Antisense oligonucleotide-lipid complexes in the mixture were formed by gentle mixing through pipetting twice and subsequent tapping of the plate followed by incubation for 20 minutes at room temperature. Next, 50,000 HEK293T cells in 100 µl complete media solution without antibiotics were added to the antisense oligonucleotide-lipid complexes and incubated for five hours at 37°C and 5% CO₂. After incubation, cells were transfected with minigene plasmids. For this, plasmid
35 transfection mixes were made by combining 5 µl containing 200 ng of plasmid diluted in Opti-MEM with 0.6 µl X-tremeGENE 9 DNA Transfection Reagent solution (Roche). Plasmid transfection mixes were incubated at room temperature for 20 minutes and then added to the HEK293T cells, which were subsequently incubated at 37°C and 5% CO₂. After 24 hours transfection media was replaced with 200 µl complete media. 48 hours after transfection, cells were lysed for RNA isolation and RT-PCR analysis.

40 **[00187]** Transfection HepG2 wild-type and mutant 2F3 cells. All reagents were used according to manufacturer's recommendations. Cells were suspended by incubation with TrypLE for 15-20 minutes and diluted to 250000-500000 cells per milliliter in Dulbecco's Modified Eagle's Medium with 10% heat

inactivated fetal calf serum. 50 pmol of oligonucleotide in transfection medium, containing RNAiMAX (Invitrogen) and Opti-MEM (Gibco), was combined with 25000-50000 cells from the culture suspension above. RNA was collected 48 hours after transfection unless otherwise stated.

[00188] RNA preparation. RNA was prepared by using a SingleShot Cell Lysis kit (Bio-Rad) or RNeasy total RNA kit (QIAGEN) according to manufacturer's recommendations, alternatively Direct-zol TM-96 MagBead RNA (Zymo Research) was used according to manufacturer's recommendations except wherein all washes with volumes of 500 μ L only 300 μ L was used and for all rpm speeds of 900 rpm, 1050 rpm was used.

[00189] RT-PCR analysis. Synthesis of first-strand cDNA was performed with the ImProm-II Reverse Transcription System (Promega) according to manufacturer's recommendations with minor modifications. 50-300 ng of purified RNA were incubated in a 96-well PCR plate with 1 μ L Oligo-dT-VN primer (100 μ M, TTTTTTTTTTTTTTTTTT VN) for 5 min at 70°C, followed by rapid cooling for 5 min at 4°C. 14.5- μ L of reverse transcriptase mixture, containing 20 Units ImProm-II Reverse Transcriptase, reaction buffer, 4 mM MgCl₂, 0.5 mM dNTPs (FroggaBio) and 40 units RNase Inhibitor (Bioshop) was added to the RNA-Oligo-dT-VN reaction and incubated for 5 min at 25°C, 60 min at 42°C and finally cooled to 12°C. Target-specific splicing fragments were amplified by PCR. PCR primers for HepG2 wild-type and mutant 2F3 cell experiments were CCAGCAAAGCCCTTGTTAAG (SEQ ID NO: 156) and GCTCGTTGCTGGGTATCAG (SEQ ID NO: 157). PCR primers for minigene experiments were GATCACAGGGATGACCTGC (SEQ ID NO: 158) and GTTTACGTCGCCGTCCAG (SEQ ID NO: 159). PCR reactions contained 5 μ L first-strand cDNA product, 0.4 μ M forward primer, 0.4 μ M reverse primer, 300 μ M of each dNTP, 25 mM Tricine, 7.0% Glycerol (m/v), 1.6% DMSO (m/v), 2 mM MgCl₂, 85 mM NH₄-acetate (pH8.7), and 1 unit Taq DNA polymerase (FroggaBio) in a total volume of 25 μ L. Fragments were amplified by a touchdown PCR program (95°C for 120 sec; 10 cycles of 95°C for 20 sec, 68°C for 30 sec with a decrement of 1°C per cycle, and 72°C for 60 sec; followed by 30 cycles of 95°C for 20 sec, 58°C for 30 sec, and 72°C for 60 sec; 72°C for 180 sec).

[00190] Capillary electrophoresis. Samples were analyzed using a LabChip GX Touch Nucleic Acid Analyzer (GE) using a DNA 1K Hi Sensitivity LabChip and associated reagents (GE) according to manufacturer's recommendations.

[00191] Western blotting. Cells were grown and transfected as above. After 48 hours the media was removed, and cells were rinsed with DPBS. The cells were suspended with TrypLE (Gibco) and pelleted. The TrypLE was removed and 150 μ L of ice cold RIPA buffer (SIGMA) with 1x HALT protease inhibitor (Pierce Biotechnology) was added to the well. The solution was placed on ice for 10 minutes and then centrifuged at 15000 rcf at 4°C. The supernatant was put into a fresh tube and the pellet was discarded. Using a protein quantification kit (Pierce) the protein concentrations was determined. Twenty to thirty μ g of lysate protein was heated at 70°C with Nupage buffer (Novex) and loaded onto a 10% Bis-Tris gel (Invitrogen). The gel was run for ~40 minutes at 200V in 1x MOPS buffer (Novex). The gel was removed and transferred to a PVDF membrane (GE) on ice for 90 minutes at 350 mA constant current. After transfer, the membrane was blocked in TBST-5% milk for 60 minutes at room temperature. After blocking, primary antibodies for GAPDH (Abcam) and ATP7B (Abcam) were added in TBSB-1% milk and refrigerated at 4°C overnight. The membrane was then rinsed with TBST for 5 minutes 5 times. Secondary antibodies conjugated with horseradish peroxidase (Cell Signalling technology) were added to

the solution for 60 minutes at room temperature. The membrane was then rinsed with TBST for 5 minutes 5 times. The images were recorded with a GE AI600RGB device.

[00192] Copper sensitivity assay. Cells were grown and transfected as stated above. Cells were then transfected with an antisense oligonucleotide or not transfected for control. Forty-eight hours after
5 transfected, CuCl₂ (Sigma) was prepared in deionized water at a concentration of 0.5M. This was then diluted in DMEM supplemented with 10% fetal calf serum to final concentrations of 0.2 mM, 0.5 mM, 0.75 mM, 1.0 mM, and 1.25 mM. A media change was then performed on the cells using the media + CuCl₂. After 48 hours the cell viability was read with a Neo2 instrument (Biotek) using CellTiter-Fluor™ Cell Viability Assay (Promega). Data was normalized to the copper-free treatment within groups.

10 **Example 1 The splicing of ATP7B exon 6 is disrupted in the chr13:52535985:A:C [hg19/b37] variant and can be partially rescued through the use of antisense oligonucleotides**

[00193] To confirm exon 6 skipping in the chr13:52535985:A:C [hg19/b37] (M645R) variant, wild type and variant containing minigenes were constructed containing exons 5-7 and the corresponding introns, 5 and 6. Minigenes were then transfected into HEK293T cells to examine the effect of the M645R variant
15 on splicing. As seen in FIG. 1A, wildtype minigenes showed both exon 6 inclusion, represented by the upper band, and exclusion. M645R mutants, however, showed no exon 6 inclusion indicating the chr13:52535985:A:C [hg19/b37] mutation induces exon 6 skipping. The results of the experiment in FIG 1A were replicated and quantified. As seen in FIG 1B. there is a robust (standard deviations of 5.7% and 1.3% for wildtype and M645R minigenes respectively) decrease in exon 6 inclusion due to the
20 chr13:52535985:A:C [hg19/b37] mutation.

[00194] To examine the ability of antisense oligonucleotides to promote exon 6 inclusion in the M645R variant the minigenes above were co-transfected with antisense oligonucleotides having sequences set forth in SEQ ID NOs: 3-34 (see Table 1). Antisense oligonucleotides were tiled along exon 6 and the surrounding introns. FIG. 2A depicts the location of the targeted ASOs relative to exon 6 and
25 the surrounding introns. FIG. 2B shows the RT-PCR samples measured by capillary electrophoresis. A 100 bp DNA ladder is shown for size reference with the exon 6 inclusion band at 445 bp and exclusion band at 368 bp. These results were quantified and are depicted in FIG. 2C. Observing both FIG. 2B and 2C it is clear that targeting the intronic regions surrounding exon 6 induces exon 6 inclusion of both wildtype and M645R variant minigenes. These observations suggest antisense oligonucleotides targeting
30 these regions or "hotspots" (positions 54522-54593 and 54665-54718 in SEQ ID NO: 1; chr13:52536038-52536109 and chr13:52535966-52535913), e.g., those complementary to a nucleobase sequence in SEQ ID NOs: 3-12 for hotspot 1 and SEQ ID NOs: 28-34 for hotspot 2, may be particularly useful in the treatment of Wilson disease associated with exon 6 skipping (e.g., Wilson disease caused by the M645R mutation).

[00195] Table 1

SEQ ID NO	Sequence
3	GTACTTGGTTAAAATATGCA
4	AGGAAGGTACTTGGTTAAAA
5	AAAAGGAGGAAGGTACTTGG
6	TGGGGAAAAAGGAGGAAGGT
7	AGGGGTGGGGAAAAAGGAGG
8	AAAGAGAGGGGTGGGGAAAA
9	CATTAAAAAGAGAGGGGTGG
10	CTTGTCATTAAAAAGAGAGG
11	AATTTCTTGTTCATTAAAAA
12	AAAGCCAATTTCTTGTTCAT
13	AGCATGAAAGCCAATTTCTT
14	AGGGAAGCATGAAAGCCAAT
15	TGGGCCAGGGAAGCATGAAA
16	TTTCTCTGGGCCAGGGAAGC
17	TGGGGTTTCTCTGGGCCAGG
18	GAGCGTTGGGGTTTCTCTGG
19	AGTGATGAGCGTTGGGGTTT
20	GGTCCAAGTGATGAGCGTTG
21	CTTGTGGTCCAAGTGATGAG
22	TTCCCTCTTGTGGTCCAAGT
23	CTTTATTTCCCTCTTGTGGT
24	TACTGCTTTATTTCCCTCTT
25	TCTACCTACTGCTTTATTTCT
26	TTGTGTTCTACCTACTGCTT
27	TATCTTTTGTGTTCTACCTA
28	GAGTTTATCTTTTGTGTTCT
29	GAGCTGGAGTTTATCTTTTG
30	AGATGAGAGCTGGAGTTTAT
31	GACTTAGATGAGAGCTGGAG
32	GGAAGGGACTTAGATGAGAG
33	GGTAGAGGAAGGGACTTAGA
34	GCCCAGGTAGAGGAAGGGAC

Example 2 Characterization of target regions (hot spots) for increasing inclusion of ATP7B exon 6

[00196] To explore the possible use of splice-switching oligonucleotides as a treatment for Wilson disease patients carrying the M645R variant, a hepatic cell line, HepG2, carrying this mutation, 2F3, was derived. The 2F3 line carries the M645R variant at one allele and a large plasmid insertion at the other. This insertion is assumed to render that allele unable to produce functional protein, thus creating a situation analogous to a compound heterozygote, consistent with what found in Wilson disease patients.

[00197] The oligonucleotides listed in Table 2 were transfected into 2F3 cells, and RT-PCR products were analyzed using capillary electrophoresis. These oligonucleotides were designed to hybridize to the above-identified hotspots and to expand the search for additional hotspots. Percent spliced in (PSI) for

exon 6 was then calculated as well as the change in percent spliced in compared to an inactive control antisense oligonucleotide (dPSI) (Table 2). As seen in Table 2, certain antisense oligonucleotides have a negative dPSI indicating an increase in exon 6 exclusion (e.g., SEQ ID NOs: 115-118) which is opposite of the intended effect. Antisense oligonucleotides which are targeted to intronic regions either side of exon 6 are effective showing positive dPSIs.

[00198] Certain oligonucleotides with high dPSIs were aligned to the reference genome chr13: 52535914-52536146[hg19/b37] (SEQ ID NOs: 28-33, 47-51, 60, 61, 63-67, 76-81, 93-95, 120, 121, 130, 132, 133-137, 147, and 150). As seen in FIG. 3, a third hotspot for antisense oligonucleotide binding to induce exon 6 inclusion in ATP7B M645R mutants was discovered spanning the area covered by antisense oligonucleotides having sequences set forth in SEQ ID NOs: 119-124 (genomic antisense: positions 54472-54516 in SEQ ID NO:1; chr13:52536115-52536159), in addition to the areas covered by antisense oligonucleotides having sequences set forth in SEQ ID NOs: 3-12 (genomic antisense: positions 54522-54593 in SEQ ID NO: 1; chr13:52536038-52536109) and SEQ ID NOs: 28-34 (genomic antisense: positions 54665-54718 in SEQ ID NO: 1; chr13:52535913-52535966). Three exemplary core sequences were also identified in these areas: SEQ ID NO: 160 (genomic sense: TTATCTTTT; genomic antisense: positions 54672-54680 in SEQ ID NO: 1), SEQ ID NO: 161 (genomic sense: GACTTAGATGA; genomic antisense: positions 54691-54701 in SEQ ID NO: 1), and SEQ ID NO: 162 (genomic sense: TTTCAGCTTTTGAAA; genomic antisense: positions 54492-54506).

[00199] Table 2

SEQ ID NO	PSI	sequence	Start Chr13 [hg19/b37]	End Chr13 [hg19/b37]	length	dPSI
29	0.94903506	GAGCTGGAGTTTATCTTTTG	52535941	52535960	20	0.491132
30	0.93643194	AGATGAGAGCTGGAGTTTAT	52535935	52535954	20	0.478529
35	0.70974518	AGATGAGAGCTGGAGT	52535935	52535950	16	0.251842
36	0.79611546	GATGAGAGCTGGAGTT	52535936	52535951	16	0.338213
37	0.80660668	ATGAGAGCTGGAGTTT	52535937	52535952	16	0.348704
38	0.62920358	TGAGAGCTGGAGTTTA	52535938	52535953	16	0.171301
39	1	GAGAGCTGGAGTTTAT	52535939	52535954	16	0.542097
40	0.82915652	AGAGCTGGAGTTTATC	52535940	52535955	16	0.371254
41	0.80242893	GAGCTGGAGTTTATCT	52535941	52535956	16	0.344526
42	0.93324554	AGCTGGAGTTTATCTT	52535942	52535957	16	0.475343
43	0.91806589	GCTGGAGTTTATCTTT	52535943	52535958	16	0.460163
44	0.92097701	CTGGAGTTTATCTTTT	52535944	52535959	16	0.463074
45	0.88136593	TGGAGTTTATCTTTTG	52535945	52535960	16	0.423463
46	0.92978378	GGAGTTTATCTTTTGT	52535946	52535961	16	0.471881
47	0.93878061	GAGTTTATCTTTTGTG	52535947	52535962	16	0.480878
48	0.95719947	AGTTTATCTTTTGTGT	52535948	52535963	16	0.499297
49	0.96989269	GTTTATCTTTTGTGTT	52535949	52535964	16	0.51199
50	0.95199346	TTTATCTTTTGTGTTT	52535950	52535965	16	0.494091
51	0.94531532	TTATCTTTTGTGTTCT	52535951	52535966	16	0.487412
52	0.57919401	AGATGAGAGCTGGAGTT	52535935	52535951	17	0.121291
53	0.42220616	GATGAGAGCTGGAGTTT	52535936	52535952	17	-0.0357

SEQ ID NO	PSI	sequence	Start Chr13 [hg19/b37]	End Chr13 [hg19/b37]	length	dPSI
54	0.54186296	ATGAGAGCTGGAGTTTA	52535937	52535953	17	0.08396
55	0.75146207	TGAGAGCTGGAGTTTAT	52535938	52535954	17	0.293559
56	0.83250872	GAGAGCTGGAGTTTATC	52535939	52535955	17	0.374606
57	0.84600061	AGAGCTGGAGTTTATCT	52535940	52535956	17	0.388098
58	0.90189881	GAGCTGGAGTTTATCTT	52535941	52535957	17	0.443996
59	0.85045831	AGCTGGAGTTTATCTTT	52535942	52535958	17	0.392555
60	0.94235165	GCTGGAGTTTATCTTTT	52535943	52535959	17	0.484449
61	0.96260732	CTGGAGTTTATCTTTTG	52535944	52535960	17	0.504704
62	0.93743667	TGGAGTTTATCTTTTGT	52535945	52535961	17	0.479534
63	0.96488622	GGAGTTTATCTTTTGTG	52535946	52535962	17	0.506983
64	0.95897848	GAGTTTATCTTTTGTGT	52535947	52535963	17	0.501076
65	0.97370995	AGTTTATCTTTTGTGTT	52535948	52535964	17	0.515807
66	0.96669576	GTTTATCTTTTGTGTTT	52535949	52535965	17	0.508793
67	0.94990072	TTTATCTTTTGTGTTCT	52535950	52535966	17	0.491998
68	0.41427269	AGATGAGAGCTGGAGTTT	52535935	52535952	18	-0.04363
69	0.29548406	GATGAGAGCTGGAGTTTA	52535936	52535953	18	-0.16242
70	0.65272521	ATGAGAGCTGGAGTTTAT	52535937	52535954	18	0.194822
71	0.82775724	TGAGAGCTGGAGTTTATC	52535938	52535955	18	0.369854
72	0.89482076	GAGAGCTGGAGTTTATCT	52535939	52535956	18	0.436918
73	0.89873087	AGAGCTGGAGTTTATCTT	52535940	52535957	18	0.440828
74	0.93420851	GAGCTGGAGTTTATCTTT	52535941	52535958	18	0.476306
75	0.88748876	AGCTGGAGTTTATCTTTT	52535942	52535959	18	0.429586
76	0.95705511	GCTGGAGTTTATCTTTTG	52535943	52535960	18	0.499152
77	0.95710864	CTGGAGTTTATCTTTTGT	52535944	52535961	18	0.499206
78	0.95718201	TGGAGTTTATCTTTTGTG	52535945	52535962	18	0.499279
79	0.95723276	GGAGTTTATCTTTTGTGT	52535946	52535963	18	0.49933
80	0.9682069	GAGTTTATCTTTTGTGTT	52535947	52535964	18	0.510304
81	0.96703305	AGTTTATCTTTTGTGTTT	52535948	52535965	18	0.50913
82	0.89944316	GTTTATCTTTTGTGTTCT	52535949	52535966	18	0.44154
83	0.35701069	AGATGAGAGCTGGAGTTTA	52535935	52535953	19	-0.10089
84	0.37085899	GATGAGAGCTGGAGTTTAT	52535936	52535954	19	-0.08704
85	0.81174544	ATGAGAGCTGGAGTTTATC	52535937	52535955	19	0.353843
86	0.86312479	TGAGAGCTGGAGTTTATCT	52535938	52535956	19	0.405222
87	0.92042588	GAGAGCTGGAGTTTATCTT	52535939	52535957	19	0.462523
88	0.94378406	AGAGCTGGAGTTTATCTTT	52535940	52535958	19	0.485881
89	0.90121758	GAGCTGGAGTTTATCTTTT	52535941	52535959	19	0.443315
90	0.97875323	AGCTGGAGTTTATCTTTTG	52535942	52535960	19	0.52085
91	0.97165722	GCTGGAGTTTATCTTTTGT	52535943	52535961	19	0.513754
92	0.974632	CTGGAGTTTATCTTTTGTG	52535944	52535962	19	0.516729
93	0.98143024	TGGAGTTTATCTTTTGTGT	52535945	52535963	19	0.523527
94	0.96598484	GGAGTTTATCTTTTGTGTT	52535946	52535964	19	0.508082

SEQ ID NO	PSI	sequence	Start Chr13 [hg19/b37]	End Chr13 [hg19/b37]	length	dPSI
95	0.96947187	GAGTTTATCTTTTGTGTTC	52535947	52535965	19	0.511569
96	0.51215069	AGTTTATCTTTTGTGTTCT	52535948	52535966	19	0.054248
97	0.43801448	GATGAGAGCTGGAGTTTATC	52535936	52535955	20	-0.01989
98	0.84294034	ATGAGAGCTGGAGTTTATCT	52535937	52535956	20	0.385037
99	0.91506349	TGAGAGCTGGAGTTTATCTT	52535938	52535957	20	0.457161
100	0.95571491	GAGAGCTGGAGTTTATCTTT	52535939	52535958	20	0.497812
101	0.9250529	AGAGCTGGAGTTTATCTTTT	52535940	52535959	20	0.46715
102	0.91454039	AGCTGGAGTTTATCTTTTGT	52535942	52535961	20	0.456638
103	0.95584009	GCTGGAGTTTATCTTTTGTG	52535943	52535962	20	0.497937
104	0.96866415	CTGGAGTTTATCTTTTGTGT	52535944	52535963	20	0.510761
105	0.50424102	GTTGGGCCAGGTAGAGGAA	52535908	52535927	20	0.046338
106	0.46400523	GCAGAGTTGGGCCAGGTAG	52535903	52535922	20	0.006102
107	0.55283098	AGCTGGCAGAGTTGGGCCCA	52535898	52535917	20	0.094928
108	0.70816205	AGACCAGCTGGCAGAGTTGG	52535893	52535912	20	0.250259
109	0.44154369	AGACAAGACCAGCTGGCAGA	52535888	52535907	20	-0.01636
110	0.44883783	TGGGAAGACAAGACCAGCTG	52535883	52535902	20	-0.00907
111	0.25330097	CACCATGGGAAGACAAGACC	52535878	52535897	20	-0.2046
112	0.1584088	GAAGGCACCATGGGAAGACA	52535873	52535892	20	-0.29949
113	0.050187	AGGAGGAAGGCACCATGGGA	52535868	52535887	20	-0.40772
114	0.05564216	AATCCAGGAGGAAGGCACCA	52535863	52535882	20	-0.40226
115	0.0583237	TGGTTAAAATATGCATTGGC	52536095	52536114	20	-0.39958
116	0.0814945	AAAATATGCATTGGCAGAAA	52536100	52536119	20	-0.37641
117	0.18600916	ATGCATTGGCAGAAAGCACT	52536105	52536124	20	-0.27189
118	0.2612183	TTGGCAGAAAGCACTTTTCA	52536110	52536129	20	-0.19668
119	0.7320813	AGAAAGCACTTTTCAGCTTT	52536115	52536134	20	0.274178
120	0.92565362	GCACTTTTCAGCTTTGAAA	52536120	52536139	20	0.467751
121	0.9502844	TTTCAGCTTTGGAAATTAGA	52536125	52536144	20	0.492382
122	0.96330809	GCTTTGGAAATTAGAAAGTG	52536130	52536149	20	0.505405
123	0.80993619	GGAAATTAGAAAGTGAATCT	52536135	52536154	20	0.352033
124	0.71516338	TTAGAAAGTGAATCTAAAAG	52536140	52536159	20	0.257261
125	0.52494194	GGTAGAGGAAGGGACTTA	52535918	52535935	18	0.067039
126	0.6689587	GTAGAGGAAGGGACTTAG	52535919	52535936	18	0.211056
127	0.68622134	TAGAGGAAGGGACTTAGA	52535920	52535937	18	0.228319
128	0.78427472	AGAGGAAGGGACTTAGAT	52535921	52535938	18	0.326372
129	0.7981034	GAGGAAGGGACTTAGATG	52535922	52535939	18	0.340201
130	0.89063399	AGGAAGGGACTTAGATGA	52535923	52535940	18	0.432731
131	0.9141607	GGAAGGGACTTAGATGAG	52535924	52535941	18	0.456258
132	0.89012483	GAAGGGACTTAGATGAGA	52535925	52535942	18	0.432222
133	0.93330513	AAGGGACTTAGATGAGAG	52535926	52535943	18	0.475402
134	0.85689543	AGGGACTTAGATGAGAGC	52535927	52535944	18	0.398993
135	0.82924288	GGGACTTAGATGAGAGCT	52535928	52535945	18	0.37134

SEQ ID NO	PSI	sequence	Start Chr13 [hg19/b37]	End Chr13 [hg19/b37]	length	dPSI
136	0.89801786	GGACTTAGATGAGAGCTG	52535929	52535946	18	0.440115
137	0.92780754	GACTTAGATGAGAGCTGG	52535930	52535947	18	0.469905
138	0.78670155	ACTTAGATGAGAGCTGGA	52535931	52535948	18	0.328799
139	0.85607847	CTTAGATGAGAGCTGGAG	52535932	52535949	18	0.398176
140	0.8755492	TTAGATGAGAGCTGGAGT	52535933	52535950	18	0.417646
141	0.81911248	TAGATGAGAGCTGGAGTT	52535934	52535951	18	0.36121
142	0.65870755	GTAGAGGAAGGGACTTAGAT	52535919	52535938	20	0.200805
143	0.68963137	TAGAGGAAGGGACTTAGATG	52535920	52535939	20	0.231729
144	0.71236425	AGAGGAAGGGACTTAGATGA	52535921	52535940	20	0.254461
145	0.77181564	GAGGAAGGGACTTAGATGAG	52535922	52535941	20	0.313913
146	0.91591182	AGGAAGGGACTTAGATGAGA	52535923	52535942	20	0.458009
147	0.93671833	GAAGGGACTTAGATGAGAGC	52535925	52535944	20	0.478815
148	0.9264989	AAGGGACTTAGATGAGAGCT	52535926	52535945	20	0.468596
149	0.96644251	AGGGACTTAGATGAGAGCTG	52535927	52535946	20	0.50854
150	0.9477045	GGACTTAGATGAGAGCTGG	52535928	52535947	20	0.489802
151	0.88244294	GGACTTAGATGAGAGCTGGA	52535929	52535948	20	0.42454
152	0.82302381	ACTTAGATGAGAGCTGGAGT	52535931	52535950	20	0.365121
153	0.68879408	CTTAGATGAGAGCTGGAGTT	52535932	52535951	20	0.230891
154	0.61269452	TTAGATGAGAGCTGGAGTTT	52535933	52535952	20	0.154792
155	0.50052141	TAGATGAGAGCTGGAGTTTA	52535934	52535953	20	0.042619

Example 4 Treatment of 2F3 cells with a splice modulating antisense oligonucleotide increases protein level and copper tolerance

[00200] To model the effectiveness of an exon 6 inclusion inducing antisense oligonucleotide as a potential treatment for Wilson disease an *in vitro* copper sensitivity assay has been used. As seen in FIG. 4A, the M645R mutation reduces copper tolerance in 2F3 cells, mirroring Wilson disease where cells are unable to process copper as a result of ATP7B mutations. Transfection with an antisense oligonucleotide having the sequence set forth in SEQ ID 29 increases copper tolerance in 2F3 cells demonstrating that the copper sensitive phenotype can be at least partially rescued by transfection with an oligonucleotide shown herein to increase the inclusion of exon 6. Western blots against the ATP7B protein are consistent with these results, as 2F3 cells produce markedly less ATP7B protein than wild-type HepG2 cells (FIG. 4B). Transfection with an antisense oligonucleotide having the sequence set forth in SEQ ID 29 partially rescues this phenotype and increases ATP7B protein levels in 2F3 cells. This increase in ATP7B protein levels and function demonstrates that treatment with an antisense oligonucleotide known to increase the inclusion of exon 6 partially rescues the Wilson disease phenotype in an *in vitro* model.

OTHER EMBODIMENTS

[00201] Various modifications and variations of the described invention will be apparent to those skilled in the art without departing from the scope and spirit of the invention. Although the invention has been described in connection with specific embodiments, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments. Indeed, various modifications of the

described modes for carrying out the invention that are obvious to those skilled in the art are intended to be within the scope of the invention.

WHAT IS CLAIMED IS:

CLAIMS

1. An antisense oligonucleotide comprising a nucleobase sequence at least 70% complementary to an ATP7B target sequence in exon 6, a 5'-flanking intron, a 3'-flanking intron, or a combination of exon 6 and the 5'-flanking or 3'-flanking intron.
2. The antisense oligonucleotide of claim 1, wherein the ATP7B target sequence reduces the binding of a splicing factor to an intronic splicing silencer in the 5'-flanking or 3'-flanking intron.
3. The antisense oligonucleotide of claim 1, wherein the ATP7B target sequence comprises at least one nucleotide located among positions 54672-54680 in SEQ ID NO: 1.
4. The antisense oligonucleotide of claim 1, wherein the ATP7B target sequence comprises at least one nucleotide located among positions 54691-54701 in SEQ ID NO: 1.
5. The antisense oligonucleotide of claim 1, wherein the ATP7B target sequence comprises at least one nucleotide located among positions 54492-54506 in SEQ ID NO: 1.
6. The antisense oligonucleotide of claim 1, wherein the ATP7B target sequence comprises at least one nucleotide located among positions 54472-54516, 54522-54593, and 54665-54718 in SEQ ID NO: 1.
7. The antisense oligonucleotide of claim 1, wherein the nucleobase sequence is complementary to a sequence within the 5'-flanking intron.
8. The antisense oligonucleotide of claim 1, wherein the ATP7B target sequence is located within the 5'-flanking intron among positions up to 54517 in SEQ ID NO: 1.
9. The antisense oligonucleotide of claim 1, wherein the nucleobase sequence has at least 70% sequence identity to SEQ ID NO: 119, 120, 121, 122, 123, or 124.
10. The antisense oligonucleotide of claim 1, wherein the nucleobase sequence has at least 70% sequence identity to SEQ ID NO: 122.
11. The antisense oligonucleotide of claim 1, wherein the ATP7B target sequence is located within the 5'-flanking intron among positions 54522 to 54581 in SEQ ID NO: 1.
12. The antisense oligonucleotide of claim 1, wherein the nucleobase sequence has at least 70% sequence identity to SEQ ID NO: 3, 4, 5, 6, 7, 8, 9, or 10.
13. The antisense oligonucleotide of claim 1, wherein the ATP7B target sequence is located within the combination of the 5'-flanking intron and exon 6.

14. The antisense oligonucleotide of claim 1, wherein the ATP7B target sequence is located within the combination of the 5'-flanking intron and exon 6 among positions 54562 to 54593 in SEQ ID NO: 1.
15. The antisense oligonucleotide of claim 1, wherein the nucleobase sequence has at least 70% sequence identity to SEQ ID NO: 11.
16. The antisense oligonucleotide of claim 1, wherein the ATP7B target sequence is located within exon 6 or the combination of the 3'-flanking intron and exon 6.
17. The antisense oligonucleotide of claim 1, wherein the ATP7B target sequence is located among positions 54631 to 54677 in SEQ ID NO: 1.
18. The antisense oligonucleotide of claim 1, wherein the nucleobase sequence has at least 70% sequence identity to SEQ ID NO: 22, 23, 24, or 25.
19. The antisense oligonucleotide of claim 1, wherein the ATP7B target sequence is located within the 3'-flanking intron.
20. The antisense oligonucleotide of claim 1, wherein the ATP7B target sequence is located among positions 54655 to 54738 in SEQ ID NO: 1.
21. The antisense oligonucleotide of claim 5, 6, 19, or 20, wherein the 5'-terminal nucleotide of the oligonucleotide is complementary to neither position 54695 nor position 54696 of SEQ ID NO: 1.
22. The antisense oligonucleotide of claim 1, wherein the nucleobase sequence has at least 70% sequence identity to SEQ ID NO: 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, or 155.
23. The antisense oligonucleotide of claim 1, wherein the nucleobase sequence has at least 70% sequence identity to SEQ ID NOs: 39, 48, 49, 50, 61, 63, 64, 65, 66, 67, 76, 77, 78, 79, 80, 81, 90, 91, 92, 93, 94, 95, 100, 103, 104, 121, and 149.
24. The antisense oligonucleotide of claim 9, 10, 12, 15, 18, 22, or 23, wherein the sequence identity is at least 90%.
25. The antisense oligonucleotide of claim 24, wherein the sequence identity is 100%.
26. The antisense oligonucleotide of any one of claims 1 to 25, wherein the antisense oligonucleotide comprises at least one modified nucleobase.

27. The antisense oligonucleotide of any one of claims 1 to 26, wherein the antisense oligonucleotide comprises at least one modified internucleoside linkage.
28. The antisense oligonucleotide of claim 27, wherein the modified internucleoside linkage is a phosphorothioate linkage.
29. The antisense oligonucleotide of claim 28, wherein the phosphorothioate linkage is a stereochemically enriched phosphorothioate linkage.
30. The antisense oligonucleotide of any one of claims 27 to 29, wherein at least 50% of internucleoside linkages in the antisense oligonucleotide are independently the modified internucleoside linkage.
31. The antisense oligonucleotide of claim 30, wherein at least 70% of internucleoside linkages in the antisense oligonucleotide are independently the modified internucleoside linkage.
32. The antisense oligonucleotide of claim 31, wherein all internucleoside linkages in the antisense oligonucleotide are independently the modified internucleoside linkage.
33. The antisense oligonucleotide of any one of claims 1 to 32, wherein the antisense oligonucleotide comprises at least one modified sugar nucleoside.
34. The antisense oligonucleotide of claim 33, wherein at least one modified sugar nucleoside is a 2'-modified sugar nucleoside.
35. The antisense oligonucleotide of claim 34, wherein at least one 2'-modified sugar nucleoside comprises a 2'-modification selected from the group consisting of 2'-fluoro, 2'-methoxy, and 2'-methoxyethoxy.
36. The antisense oligonucleotide of claim 35, wherein the 2'-modified sugar nucleoside comprises the 2'-methoxyethoxy modification.
37. The antisense oligonucleotide of any one of claims 33 to 36, wherein at least one modified sugar nucleoside is a bridged nucleic acid.
38. The antisense oligonucleotide of claim 37, wherein the bridged nucleic acid is a locked nucleic acid (LNA), ethylene-bridged nucleic acid (ENA), or cEt nucleic acid.
39. The antisense oligonucleotide of any one of claims 33 to 38, wherein all nucleosides in the antisense oligonucleotide are independently the modified sugar nucleosides.

40. The antisense oligonucleotide of any one of claims 1 to 26, wherein the antisense oligonucleotide is a morpholino oligomer.
41. The antisense oligonucleotide of any one of claims 1 to 40, further comprising a targeting moiety.
42. The antisense oligonucleotide of claim 41, wherein the targeting moiety is covalently conjugated at the 5'-terminus of the antisense oligonucleotide.
43. The antisense oligonucleotide of claim 41, wherein the targeting moiety is covalently conjugated at the 3'-terminus of the antisense oligonucleotide.
44. The antisense oligonucleotide of claim 41, wherein the targeting moiety is covalently conjugated at an internucleoside linkage of the antisense oligonucleotide.
45. The antisense oligonucleotide of any one of claims 42 to 44, wherein the targeting moiety is covalently conjugated through a linker.
46. The antisense oligonucleotide of claim 45, wherein the linker is a cleavable linker.
47. The antisense oligonucleotide of any one of claims 42 to 46, wherein the targeting moiety comprises N-acetylgalactosamine.
48. The antisense oligonucleotide of claim 47, wherein the targeting moiety is an N-acetylgalactosamine cluster.
49. The antisense oligonucleotide of any one of claims 1 to 48, wherein the antisense oligonucleotide comprises at least 12 nucleosides.
50. The antisense oligonucleotide of claim 49, wherein the antisense oligonucleotide comprises at least 16 nucleosides.
51. The antisense oligonucleotide of any one of claims 1 to 50, wherein the antisense oligonucleotide comprises a total of 50 nucleosides or fewer.
52. The antisense oligonucleotide of any one of claims 1 to 50, wherein the antisense oligonucleotide comprises a total of 30 nucleosides or fewer.
53. The antisense oligonucleotide of any one of claims 1 to 50, wherein the antisense oligonucleotide comprises a total of 20 nucleosides or fewer.
54. The antisense oligonucleotide of any one of claims 1 to 48, wherein the antisense oligonucleotide comprises a total of 16 to 20 nucleosides.

55. The antisense oligonucleotide of any one of claims 1 to 48, wherein the antisense oligonucleotide comprises a total of 16 to 19 nucleosides.
56. A pharmaceutical composition comprising the antisense oligonucleotide of any one of claims 1 to 55 and a pharmaceutically acceptable excipient.
57. A method of increasing the level of exon 6-containing ATP7B mRNA molecules in a cell expressing an aberrant ATP7B gene, the method comprising contacting the cell with the antisense oligonucleotide of any one of claims 1 to 55.
58. The method of claim 57, wherein the cell is in a subject.
59. A method of treating Wilson disease in a subject having an aberrant ATP7B gene, the method comprising administering a therapeutically effective amount of the antisense oligonucleotide of any one of claims 1 to 55 or the pharmaceutical composition of claim 56 to the subject in need thereof.
60. The method of claim 59, wherein the administering step is performed parenterally.
61. The method of any one of claims 57 to 60, wherein the aberrant ATP7B gene is ATP7B having a g.54646T>G mutation in SEQ ID NO: 1.

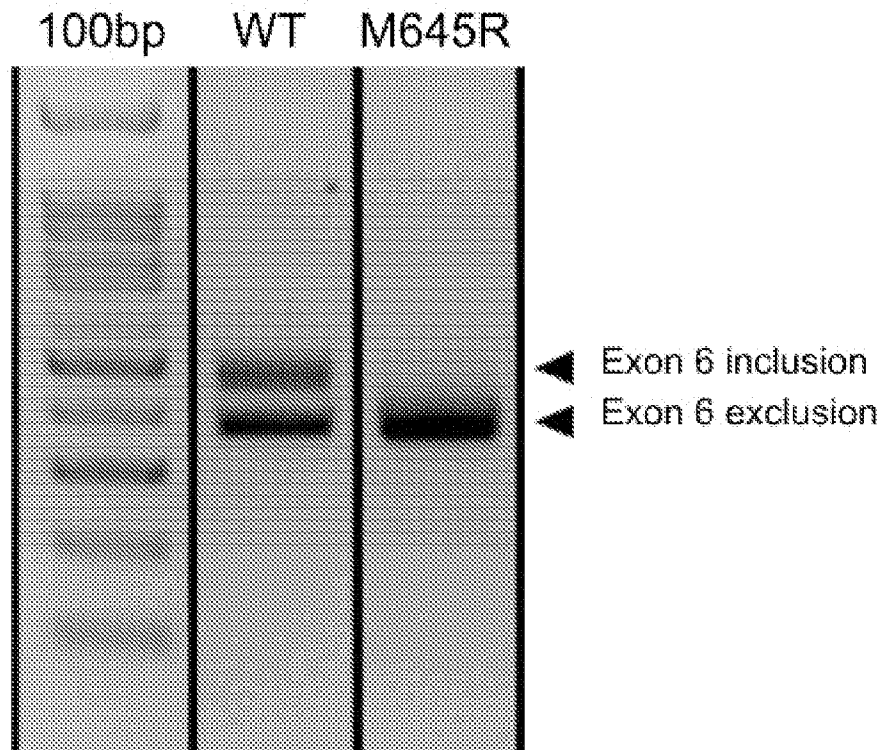


FIG. 1A

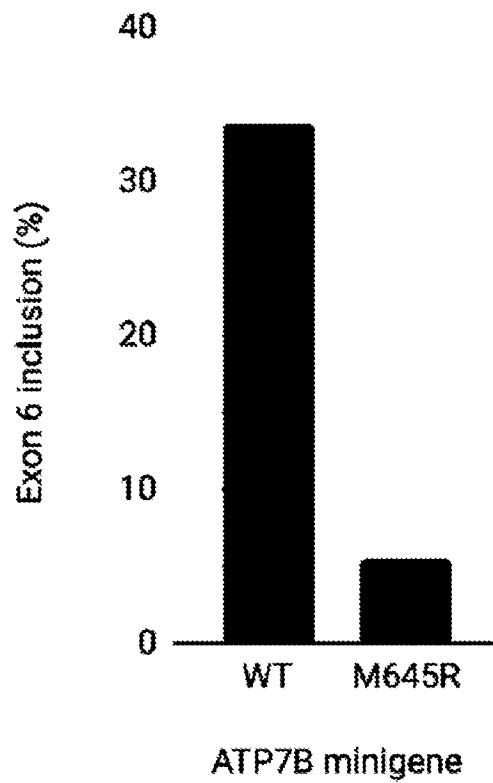


FIG. 1B

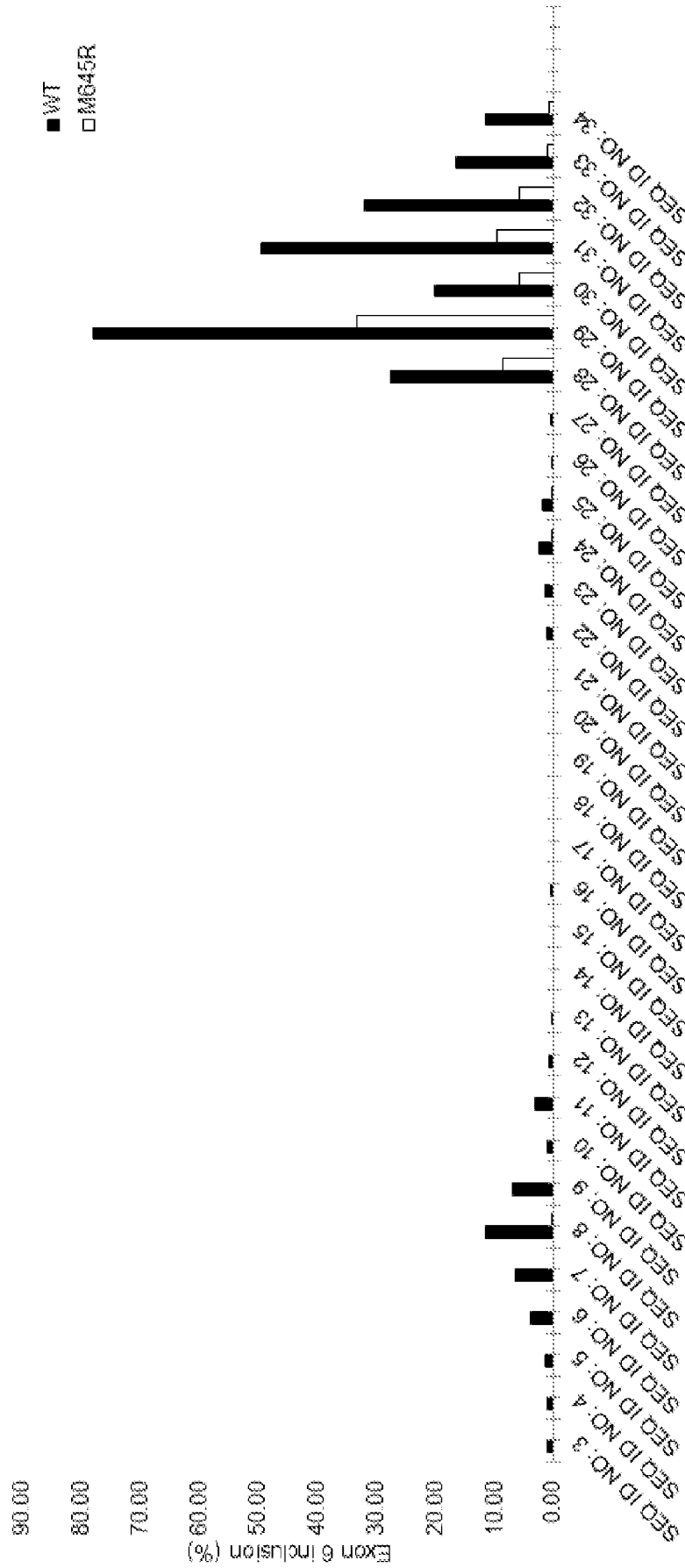
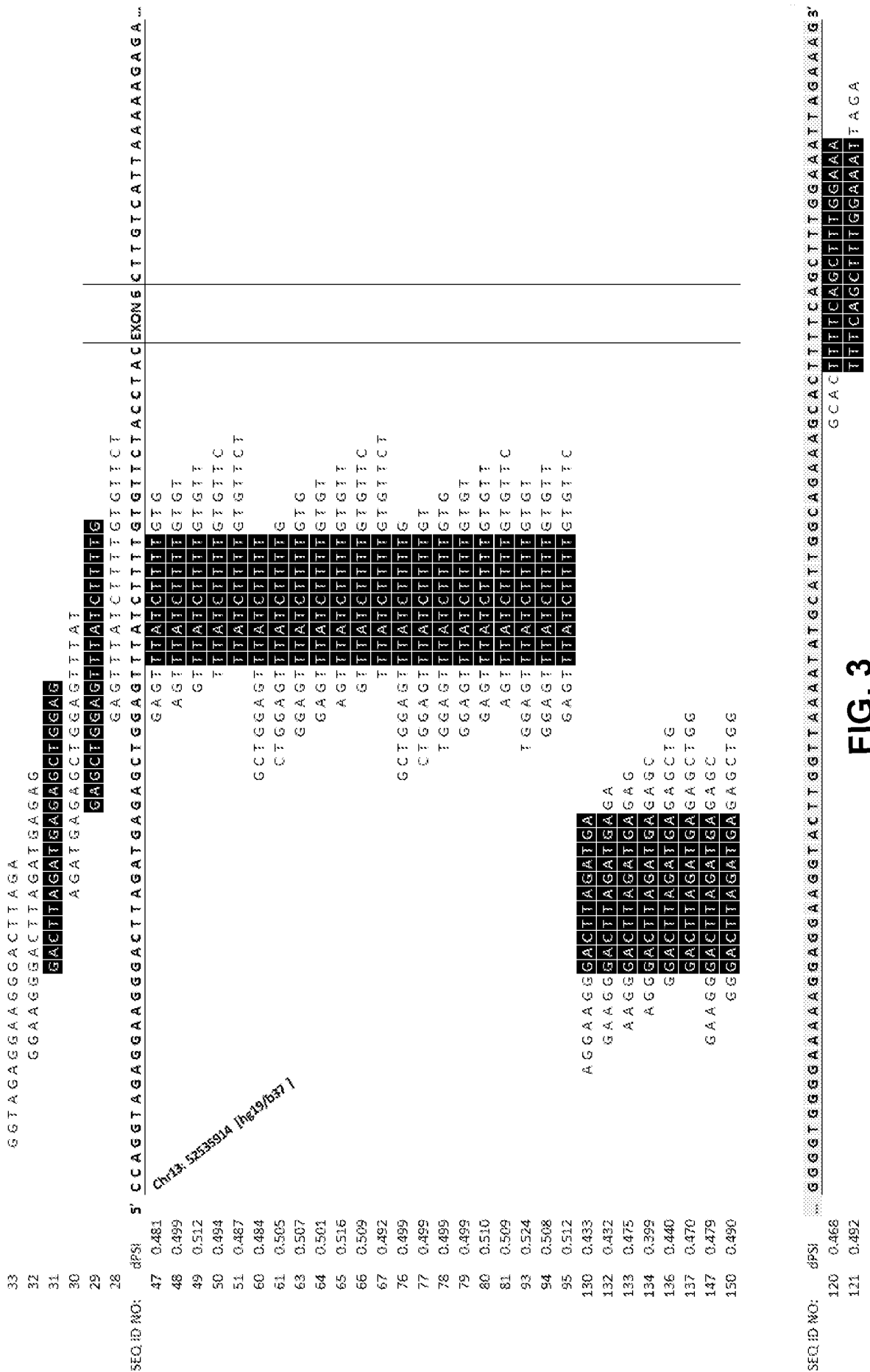


FIG. 2C



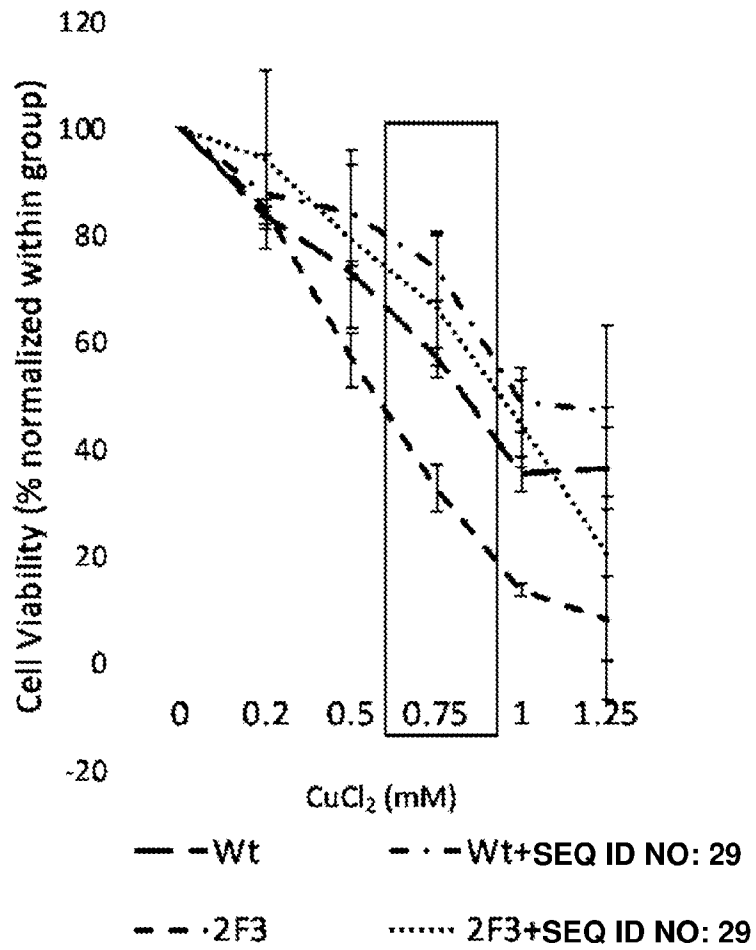


FIG. 4A

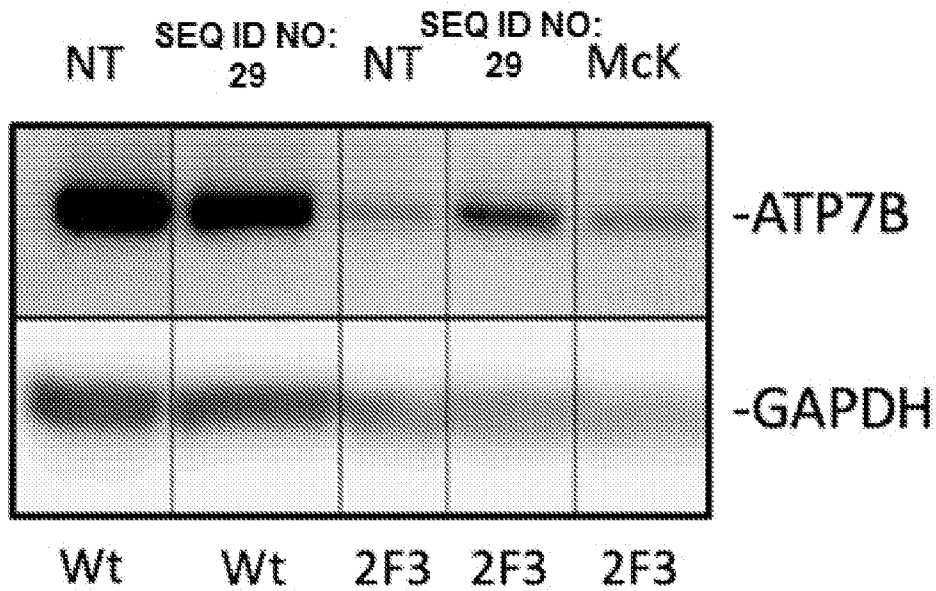


FIG. 4B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 19/18076

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - C12N 15/11, C12N 15/12 (2019.01)
CPC - C12N15/1138, C12N15/113, C12N2310/315, C12N2310/11, A61K31/712, A61K31/7125

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History Document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History Document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- A	WO 2017/106283 A1 (COLD SPRING HARBOR LABORATORY) 22 June 2017 (22.06.2017) Claim 19; SEQ ID NO 78444; para [0005], [0067], [00277], [00279], [00333], [00352]	1-2, 7-8 ----- 9, (24-25)/9
A	EP 1,783,645 A1 (ACTIGENICS) 9 May 2007 (09.05.2007) Claim 5; SEQ ID NO 3371; Claim 19; SEQ ID NO 78444	9, (24-25)/9

Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 08 July 2019	Date of mailing of the international search report 30 JUL 2019
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Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 19/18076

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. Claims Nos.: 26-61
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

-----Please see Supplemental Sheet-----

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.: 1-2, 7-9 and 24-25 (in part), limited to a ATP7B targeted antisense oligonucleotide having at least 70% sequence identity to SEQ ID NO: 119

Remark on Protest

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 19/18076

Continuation of Box. No. III Observations where unity of invention is lacking:

Group I+: Claims 1-25 directed to an antisense oligonucleotide comprising a nucleobase sequence at least 70% complementary to an ATP7B target sequence in exon 6, a 5'-flanking intron, a 3'-flanking intron, or a combination. The oligonucleotide will be searched to the extent that the antisense oligonucleotide nucleobase sequence has at least 70% sequence identity to SEQ ID NO: 119. It is believed that claims 1-2, 7-9 and 24-25 (in part), limited to a ATP7B targeted antisense oligonucleotide having at least 70% sequence identity to SEQ ID NO: 119 encompass this first named invention, and thus these claims will be searched without fee to the extent that said oligonucleotide at least 70% sequence identity to SEQ ID NO: 119. Additional ATP7B targeted antisense oligonucleotides will be searched upon the payment of additional fees. Applicants must specify the claims that encompass any additionally elected oligonucleotides. Applicants must further indicate, if applicable, the claims which encompass the first named invention, if different than what was indicated above for this group. Failure to clearly identify how any paid additional invention fees are to be applied to the "+" group(s) will result in only the first claimed invention to be searched. An exemplary election would be an antisense oligonucleotide wherein the nucleobase sequence has at least 70% sequence identity to SEQ ID NO: 122 (claims 1-2, 7-10 and 24-25 (in part)).

The inventions listed as Groups I+ do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Special Technical Features

No technical features are shared between the antisense oligonucleotides of Groups I+ and, accordingly, these groups lack unity a priori.

Additionally, even if the inventions listed as Group I+ were considered to share technical features, these shared technical features are previously disclosed by the prior art, as further discussed below.

Common Technical Features

The feature shared by the inventions listed as Group I+ is an antisense oligonucleotide comprising a nucleobase sequence at least 70% complementary to an ATP7B target sequence in exon 6, a 5'-flanking intron, a 3'-flanking intron, or a combination.

However, this shared technical features does not represent a contribution over prior art, because the shared technical features anticipated by WO 2017/106283 A1 to Cold Spring Harbor Laboratory (hereinafter "CSHL"). CSHL teaches an antisense oligonucleotide comprising a nucleobase sequence at least 70% complementary to an ATP7B target sequence in exon 6 (Claim 19; SEQ ID NO 78444; nts 3009-3279 exhibit 100% identity to ATP7B target sequence in exon 6), a 5'-flanking intron, a 3'-flanking intron, or a combination of exon 6 and the 5'-flanking or 3'-flanking intron (para [0005] "treating a liver disease in a subject in need thereof by increasing the expression of a target protein or functional RNA by cells of the subject, wherein the cells have a retained-intron-containing pre-mRNA (RIC pre-mRNA), the RIC pre-mRNA comprising a retained intron, an exon flanking the 5' splice site, an exon flanking the 3' splice site, and wherein the RIC pre-mRNA encodes the target protein or functional RNA, the method comprising contacting the cells of the subject with an antisense oligomer (ASO) complementary to a targeted portion of the RIC pre-mRNA", para [00352] "To determine whether an increase in expression of ATP7B could be achieved by improving splicing efficiency of a retained intron using ASOs, the methods described herein were used. ARPE-19 cells were mock-transfected, or transfected with ATP7B targeting ASOs [e.g. exon 6, SEQ ID NO 78444] or a non-targeting ASO control ... Results of this analysis indicated that several ATP7B targeting ASOs increase gene transcript levels. These results show that inducing splicing of a retained intron in the gene using ASOs leads to an increase in gene expression ... improving the splicing efficiency of a rate limiting intron in the ATP7B gene using ASOs led to an increase in ATP7B gene expression.").

As the technical feature was known in the art at the time of the invention, this cannot be considered a special technical feature that would otherwise unify the inventions.

Group I+ therefore lack unity under PCT Rule 13 because they do not share the same or corresponding special technical feature.

Item 4, continued: claims 26-61 are not not drafted in accordance with the second and third sentences of Rule 6.4(a) regarding multiply dependent claims).