

ADENOVIRAL VECTOR ENCODING HUMAN ATONAL HOMOLOG-1 (HATH1)

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims the benefit of U.S. Provisional Patent Application No. 62/061,748, filed October 9, 2014, which is incorporated by reference.

INCORPORATION-BY-REFERENCE OF MATERIAL SUBMITTED ELECTRONICALLY

[0002] Incorporated by reference in its entirety herein is a computer-readable nucleotide/amino acid sequence listing submitted concurrently herewith and identified as follows: One 49,240 Byte ASCII (Text) file named "721767_ST25.TXT," created on September 25, 2015.

BACKGROUND OF THE INVENTION

[0003] A majority of the world's population likely will experience some reduction in hearing capacity or a balance disorder in their lifetime. Approximately 17 percent (36 million) of American adults report some degree of hearing loss, and about 2-3 out of every 1,000 children in the United States are born deaf or hard-of-hearing (statistics from the National Institute on Deafness and Other Communication Disorders (NIDCD)).

[0004] In both hearing and balance, mechanical stimuli are translated into neural signals by sensory hair cells, damage to which is responsible for many types of hearing loss and balance disorders. Mechanical damage by, for example, loud noises, bends cochlear hair cells to the point that the hair cell can no longer transduce signals to the auditory nerves. As mammalian hair cells do not regenerate naturally, permanent hearing loss can occur if hair cells are damaged. Aside from acoustic trauma, which is the predominant cause of hearing impairment, hearing loss also can be caused by hereditary syndromes, bacterial or viral infections, use of prescription drugs, and presbycusis (hearing loss associated with old age). Likewise, balance disorders, especially vestibular disorders, can be caused by infection, head injury, pharmaceutical use, and age.

[0005] The most common treatments for hearing loss involve hearing aids and cochlear implants. Approximately 188,000 people worldwide have received cochlear implants, which includes roughly 41,599 adults and 25,500 children in the United States (NIDCD statistics). Treatment options for balance disorders include balance retraining, anti-vertigo or anti-nausea medications, and vestibular rehabilitation therapy. Such therapies, however, likely will be required over extended periods of time if the disorder is progressive, and many therapies for balance disorders do not provide permanent relief from dizziness. Currently, there are no effective pharmaceutical treatments for disorders involving loss or damage of sensory hair cells in the ear.

[0006] Thus, there remains a need for agents which can ameliorate disorders associated with destruction or loss of sensory hair cells, such as hearing loss and balance disorders. This invention provides such an agent.

BRIEF SUMMARY OF THE INVENTION

[0007] The invention provides an adenoviral vector comprising a serotype 5 adenoviral genome, except that two base pairs are deleted in the VA RNA I region, one or more endogenous nucleotides of the E1 region are deleted to render an endogenous gene in the E1 region functionally deficient, one or more endogenous nucleotides of the E3 region are deleted, and one or more endogenous nucleotides of the E4 region are deleted to render an endogenous gene in the E4 region functionally deficient, wherein a right side inverted terminal repeat (ITR), an E4 region polyadenylation sequence, and an E4 region promoter are retained, (b) an SV40 early polyadenylation sequence, (c) a nucleic acid sequence encoding a human atonal homolog-1 (Hath1) protein comprising SEQ ID NO: 1, (d) a human glial fibrillary acidic protein (GFAP) promoter, and (e) a transcriptionally inert spacer (TIS). Elements (b), (c), and (d) are located in sequence from 3' to 5' relative to the adenoviral genome in the E1 region of the adenoviral genome, and element (e) is located in the E4 region of the adenoviral genome between the E4 polyadenylation sequence and the E4 promoter.

[0008] The invention also provides a composition and method utilizing the aforementioned adenoviral vector to generate sensory cells in the inner ear of a human.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0009] Figure 1 is a schematic map of the plasmid pAdE1(GFAP.Hath1)E3(10)E4(TIS1).

[0010] Figure 2 is a schematic map of the adenoviral vector AdGFAP.HATH1.11D.

DETAILED DESCRIPTION OF THE INVENTION

[0011] The invention is predicated, at least in part, on the discovery that sensory hair cells can be generated by delivering to the inner ear a serotype 5 adenoviral vector which comprises a nucleic acid sequence encoding a human atonal homolog-1 (Hath1) protein.

[0012] The term “adenoviral vector,” as used herein, refers to an adenovirus in which the adenoviral genome has been manipulated to accommodate a nucleic acid sequence that is non-native with respect to the adenoviral genome. Typically, an adenoviral vector is generated by introducing one or more mutations (e.g., a deletion, insertion, or substitution) into the adenoviral genome of the adenovirus so as to accommodate the insertion of a non-native nucleic acid sequence into the adenovirus.

[0013] The source of the viral genome for the adenoviral vector is a human serotype 5 adenovirus. Human adenovirus is classified as subgroup A (e.g., serotypes 12, 18, and 31), subgroup B (e.g., serotypes 3, 7, 11, 14, 16, 21, 34, 35, and 50), subgroup C (e.g., serotypes 1, 2, 5, and 6), subgroup D (e.g., serotypes 8, 9, 10, 13, 15, 17, 19, 20, 22-30, 32, 33, 36-39, and 42-48), subgroup E (e.g., serotype 4), subgroup F (e.g., serotypes 40 and 41), or an unclassified serogroup (e.g., serotypes 49 and 51). Adenoviral serotypes 1 through 51 (i.e., Ad1 through Ad51) are available from the American Type Culture Collection (ATCC, Manassas, Virginia).

[0014] The inventive adenoviral vector is replication-deficient. A replication-deficient adenoviral vector requires complementation of one or more gene functions or regions of the adenoviral genome that are required for replication, as a result of, for example, a deficiency in one or more replication-essential gene function or regions, such that the adenoviral vector does not replicate in typical host cells, especially those in a human to be infected by the adenoviral vector.

[0015] A deficiency in a gene function or genomic region, as used herein, is defined as a disruption (e.g., deletion) of sufficient genetic material of the adenoviral genome to obliterate or impair the function of the gene (e.g., such that the function of the gene product is reduced by at

least about 2-fold, 5-fold, 10-fold, 20-fold, 30-fold, or 50-fold) whose nucleic acid sequence was disrupted (e.g., deleted) in whole or in part, thereby rendering the gene or genomic region “functionally deficient.” Deletion of an entire gene region often is not required for disruption of a replication-essential gene function. However, for the purpose of providing sufficient space in the adenoviral genome for one or more transgenes, removal of a majority of one or more gene regions may be desirable. In this respect, the adenoviral vector desirably comprises an adenoviral genome, except that one or more endogenous nucleotides of one or more replication-essential genes or genomic regions are deleted to render an endogenous gene or genomic region functionally deficient. While deletion of genetic material is preferred, mutation of genetic material also is appropriate for disrupting gene function. Replication-essential gene functions are those gene functions that are required for adenovirus replication (e.g., propagation) and are encoded by, for example, the adenoviral early regions (e.g., the E1, E2, and E4 regions), late regions (e.g., the L1, L2, L3, L4, and L5 regions), genes involved in viral packaging (e.g., the IVa2 gene), and virus-associated RNAs (e.g., VA-RNA-1 and/or VA-RNA-2).

[0016] The replication-deficient adenoviral vector preferably retains at least a portion of the adenoviral genome. The adenoviral vector can comprise any portion of the adenoviral genome, including protein coding and non-protein coding regions. The adenoviral vector can comprise a nucleic acid sequence that encodes any suitable adenovirus protein, such as, for example, a protein encoded by any one of the early region genes (i.e., E1A, E1B, E2A, E2B, E3, and/or E4 regions), or a protein encoded by any one of the late region genes, which encode the virus structural proteins (i.e., L1, L2, L3, L4, and L5 regions). Alternatively, the adenoviral vector can comprise non-protein coding regions of the adenoviral genome, including, for example one or more promoters, transcription termination sequences, or polyadenylation sequences of early region or late region genes, or one or more inverted terminal repeat (ITR) sequences. In one embodiment, the inventive adenoviral vector retains at least a right side inverted terminal repeat (ITR), an E4 region polyadenylation sequence, and an E4 region promoter.

[0017] The replication-deficient adenoviral vector can be modified in any suitable manner to cause the deficiencies in the one or more replication-essential gene functions in one or more regions of the adenoviral genome for propagation. The complementation of the deficiencies in the one or more replication-essential gene functions of one or more regions of the adenoviral

genome refers to the use of exogenous means to provide the functionally deficient replication-essential gene functions. Such complementation can be effected in any suitable manner, for example, by using complementing cells and/or exogenous DNA (e.g., helper adenovirus) encoding the disrupted replication-essential gene functions.

[0018] The adenoviral vector can be deficient in one or more replication-essential gene functions of only the early regions (i.e., E1-E4 regions) of the adenoviral genome, only the late regions (i.e., L1-L5 regions) of the adenoviral genome, both the early and late regions of the adenoviral genome, or all adenoviral genes (i.e., a high capacity adenovector (HC-Ad)). See Morsy et al., *Proc. Natl. Acad. Sci. USA*, 95: 965-976 (1998); Chen et al., *Proc. Natl. Acad. Sci. USA*, 94: 1645-1650 (1997); and Kochanek et al., *Hum. Gene Ther.*, 10: 2451-2459 (1999). Examples of replication-deficient adenoviral vectors are disclosed in U.S. Patents 5,837,511; 5,851,806; 5,994,106; 6,127,175; 6,482,616; and 7,195,896, and International Patent Application Publications WO 1994/028152, WO 1995/002697, WO 1995/016772, WO 1995/034671, WO 1996/022378, WO 1997/012986, WO 1997/021826, and WO 2003/022311.

[0019] The early regions of the adenoviral genome include the E1, E2, E3, and E4 regions. The E1 region comprises the E1A and E1B subregions, and one or more deficiencies in replication-essential gene functions in the E1 region can include one or more deficiencies in replication-essential gene functions in either or both of the E1A and E1B subregions, thereby requiring complementation of the E1A subregion and/or the E1B subregion of the adenoviral genome for the adenoviral vector to propagate (e.g., to form adenoviral vector particles). The E2 region comprises the E2A and E2B subregions, and one or more deficiencies in replication-essential gene functions in the E2 region can include one or more deficiencies in replication-essential gene functions in either or both of the E2A and E2B subregions, thereby requiring complementation of the E2A subregion and/or the E2B subregion of the adenoviral genome for the adenoviral vector to propagate (e.g., to form adenoviral vector particles).

[0020] The E3 region does not include any replication-essential gene functions, such that a deletion of the E3 region in part or in whole does not require complementation of any gene functions in the E3 region for the adenoviral vector to propagate (e.g., to form adenoviral vector particles). In the context of the invention, the E3 region is defined as the region that initiates with the open reading frame that encodes a protein with high homology to the 12.5K protein

from the E3 region of human adenovirus 5 (NCBI reference sequence AP_000218) and ends with the open reading frame that encodes a protein with high homology to the 14.7K protein from the E3 region of human adenovirus 5 (NCBI reference sequence AP_000224.1). The E3 region may be deleted in whole or in part, or retained in whole or in part. The size of the deletion may be tailored so as to retain an adenoviral vector whose genome closely matches the optimum genome packaging size. A larger deletion will accommodate the insertion of larger heterologous nucleic acid sequences in the adenoviral genome. In one embodiment of the invention, the L4 polyadenylation signal sequences, which reside in the E3 region, are retained.

[0021] The E4 region comprises multiple open reading frames (ORFs) that encode multiple endogenous genes. An adenoviral vector with a deletion of all of the open reading frames of the E4 region except ORF6, and in some cases ORF3, does not require complementation of any gene functions in the E4 region for the adenoviral vector to propagate (e.g., to form adenoviral vector particles). Conversely, an adenoviral vector with a disruption or deletion of ORF6, and in some cases ORF3, of the E4 region (e.g., with a deficiency in a replication-essential gene function based in ORF6 and/or ORF3 of the E4 region), with or without a disruption or deletion of any of the other open reading frames of the E4 region or the native E4 promoter, polyadenylation sequence, and/or the right-side inverted terminal repeat (ITR), requires complementation of the E4 region (specifically, of ORF6 and/or ORF3 of the E4 region) for the adenoviral vector to propagate (e.g., to form adenoviral vector particles).

[0022] The late regions of the adenoviral genome include the L1, L2, L3, L4, and L5 regions. The adenoviral vector also can have a mutation in the major late promoter (MLP), as discussed in International Patent Application Publication WO 2000/000628, which can render the adenoviral vector replication-deficient if desired.

[0023] Preferably, the one or more regions of the adenoviral genome that contain one or more deficiencies in replication-essential gene functions desirably are one or more early regions of the adenoviral genome, i.e., the E1, E2, and/or E4 regions, optionally with a deletion in part or in whole of the E3 region.

[0024] In one embodiment, one or more endogenous nucleotides of the E1 region and the E4 region are deleted in the inventive adenoviral vector to render an endogenous gene in the E1 region functionally deficient and an endogenous gene in the E4 region functionally deficient

(denoted an E1/E4-deficient adenoviral vector). The inventive adenoviral vector can comprise a deletion in at least one replication-essential gene function of the E1 region of the adenoviral genome, and preferably comprises a deletion of all of the replication-essential gene functions of the E1 region. In this respect, the deletion of the E1 region of the inventive adenoviral vector can comprise deletion of the promoters and coding regions of the E1A and E1B endogenous genes. The deletion of the E4 region desirably comprises at least one replication-essential gene function of the E4 region, and preferably comprises a deletion of all of the replication-essential gene functions of the E4 region. In this respect, the deletion of the E4 region of the inventive adenoviral vector can comprise deletion of all of the endogenous genes of the E4 region. In addition to the deletion of the E1 region and the E4 region of the adenoviral genome, one or more endogenous nucleotides of the E3 region can be deleted in the inventive adenoviral vector, and preferably the inventive adenoviral vector comprises a deletion of at least one gene function of the nonessential E3 region of the adenoviral genome (denoted an E1/E3/E4-deficient adenoviral vector). In addition to deletions of the E1, E3, and E4 regions of the serotype 5 adenoviral genome, the inventive adenoviral vector also desirably comprises a deletion in one of the virus-associated RNAs (e.g., VA-RNA-1 and/or VA-RNA-2). Preferably, the inventive adenoviral vector comprises a deletion in the VA-RNA-I region. The deletion of the VA-RNA-I region can be of any suitable size, but desirably is from 1 to 10 base pairs, preferably from 1 to 5 base pairs, and most preferably from 1 to 3 base pairs, or a range defined by any two of the foregoing values. In one embodiment, two base pairs are deleted in the VA RNA I region of the adenoviral vector.

[0025] In a preferred embodiment, the genome of the inventive serotype 5 adenoviral vector comprises a deletion of E1 region nucleotides 356-3510, inclusive, a deletion of E3 region nucleotides 28,593-30,471, inclusive, a deletion of E4 region nucleotides 32,827-35,563, and a deletion of VA-RNA-1 region nucleotides 10,594 and 10595. However, other deletions may be appropriate. For example nucleotides 356-3329 or 356-3510 can be removed to create a deficiency in replication-essential E1 gene functions, and nucleotides 28,594-30,469 can be deleted from the E3 region of the adenoviral genome.

[0026] The inventive adenoviral vector comprises a transcriptionally inert spacer (TIS). The transcriptionally inert spacer sequence provides growth of a multiply replication-deficient

adenoviral vector (e.g., an E1/E4-deficient adenoviral vector) in a complementing cell line similar to that achieved by an adenoviral vector deficient in a single replication-essential gene function (e.g., an E1-deficient adenoviral vector). The TIS sequence can contain any nucleotide sequence or sequences which are of a desired length, such as sequences at least about 15 nucleotides (e.g., between about 15 nucleotides and about 12,000 nucleotides), preferably about 100 nucleotides to about 10,000 nucleotides, more preferably about 500 nucleotides to about 8,000 nucleotides, even more preferably about 1,500 nucleotides to about 6,000 nucleotides, and most preferably about 2,000 to about 3,000 nucleotides in length, or a range defined by any two of the foregoing values. The TIS sequence can be coding or non-coding and native or non-native with respect to the adenoviral genome, but does not restore the replication-essential function to the deficient region. The TIS also can contain an expression cassette.

[0027] In one embodiment, the transcriptionally inert spacer comprises a polyadenylation sequence and/or a gene that is non-native with respect to the adenoviral vector. The spacer element can comprise any suitable polyadenylation sequence, such as, for example, the polyadenylation sequences of bovine growth hormone (BGH), polyoma virus, thymidine kinase (TK), Epstein Barr Virus (EBV), human papillomavirus (HPV) and bovine papillomavirus (BPV). Preferably, the TIS sequence comprises a simian virus-40 (SV40) polyadenylation sequence. Examples of suitable non-native genes for inclusion in the TIS include, but are not limited to, nucleic acid sequences encoding marker proteins such as pGUS, secretory alkaline phosphatase, luciferase, β -galactosidase, and human anti-trypsin; therapeutic factors; potential immune modifiers such as B3-19K, E3-14.7, ICP47, fas ligand, and CTLA4; biologically inactive sequences (e.g., sequences that are (i) not transcribed to produce a product or (ii) encode a defective or biologically inactive product); and other innocuous sequences (e.g., the β -glucuronidase gene).

[0028] Preferably, the TIS comprises in sequence from 5' to 3' relative to the adenoviral genome (i) a polyadenylation (poly(A)) sequence and transcription termination sequence from simian virus 40 (SV40), (ii) a nucleic acid sequence encoding a β -glucuronidase gene, and (iii) a polyadenylation (poly(A)) sequence and transcription termination sequence from the bovine growth hormone (BGH) gene. The use of a transcriptionally inert spacer in an adenoviral vector

is further described in, for example, U.S. Patent 5,851,806 and International Patent Application Publication WO 1997/021826.

[0029] By removing all or part of the adenoviral genome, for example, one or more endogenous nucleotides of the E1, E3, and E4 regions of the adenoviral genome, the resulting adenoviral vector is able to accept inserts of exogenous nucleic acid sequences while retaining the ability to be packaged into adenoviral capsids. An exogenous nucleic acid sequence can be inserted at any position in the adenoviral genome so long as insertion in the position allows for the formation of the adenoviral vector particle. The exogenous nucleic acid sequence preferably is positioned in the E1 region, the E3 region, or the E4 region of the adenoviral genome.

[0030] The replication-deficient adenoviral vector of the invention can be produced in complementing cell lines that provide gene functions not present in the replication-deficient adenoviral vector, but required for viral propagation, at appropriate levels in order to generate high titers of viral vector stock. Such complementing cell lines are known and include, but are not limited to, 293 cells (described in, e.g., Graham et al., *J. Gen. Virol.*, 36: 59-72 (1977)), PER.C6 cells (described in, e.g., International Patent Application Publication WO 1997/000326, and U.S. Patents 5,994,128 and 6,033,908), and 293-ORF6 cells (described in, e.g., International Patent Application Publication WO 95/34671 and Brough et al., *J. Virol.*, 71: 9206-9213 (1997)). Other suitable complementing cell lines include cells that have been generated to propagate adenoviral vectors encoding transgenes whose expression inhibits viral growth in host cells (see, e.g., U.S. Patent Application Publication No. 2008/0233650). Additional suitable complementing cells are described in, for example, U.S. Patents 6,677,156 and 6,682,929, and International Patent Application Publication WO 2003/020879. In some instances, the cellular genome need not comprise nucleic acid sequences, the gene products of which complement for all of the deficiencies of a replication-deficient adenoviral vector. One or more replication-essential gene functions lacking in a replication-deficient adenoviral vector can be supplied by a helper virus, e.g., an adenoviral vector that supplies in *trans* one or more essential gene functions required for replication of the replication-deficient adenoviral vector. Alternatively, the inventive adenoviral vector can comprise a non-native replication-essential gene that complements for the one or more replication-essential gene functions lacking in the inventive replication-deficient adenoviral vector. For example, an E1/E4-deficient adenoviral vector can

be engineered to contain a nucleic acid sequence encoding E4 ORF 6 that is obtained or derived from a different adenovirus (e.g., an adenovirus of a different serotype than the inventive adenoviral vector, or an adenovirus of a different species than the inventive adenoviral vector).

[0031] The inventive adenoviral vector comprises a nucleic acid sequence encoding a human atonal homolog-1 (Hath1) protein. Hath1 is an atonal-associated factor. Atonal-associated factors are transcription factors of the basic helix-loop-helix (bHLH) family of proteins that transdifferentiate supporting cells into sensory hair cells in the ear. The basic domain of the protein is responsible for DNA binding and protein function. Atonal-associated factors are found in a variety of animals and insects, including mice (mouse atonal homolog-1 (*Math1*)), chickens (chicken atonal homolog-1 (*Cath1*)), *Xenopus* (*Xenopus* atonal homolog-1 (*Xath1*)), and humans (human atonal homolog-1 (*Hath1*)). Atonal-associated proteins like Math1 and Hath1 have been shown to be essential for hair cell development and can stimulate hair cell regeneration in the ear (see, e.g., Groves et al., *Annu. Rev. Neurosci.*, 36: 361-381 (2013)). Hath1 is further characterized in, for example, Ben-Arie et al., *Human Molecular Genetics*, 5, 1207-1216 (1996); and Mulvaney, J. and Dabdoub, A., *J. Assoc. Res. Otolaryngol.*, 13(3): 281-289 (2012), and atonal-associated factors are generally described in International Patent Application WO 00/73764.

[0032] Hath1 nucleic acid and amino acid sequences are publicly available as, for example, GenBank Accession Nos. U61148 (GI No. 1575354) and AAB41305.1 (GI No. 1575355), respectively. Preferably, the inventive adenoviral vector comprises a nucleic acid sequence comprising SEQ ID NO: 1, which encodes a Hath1 protein.

[0033] While the nucleic acid sequence encoding a Hath1 protein comprises SEQ ID NO: 1, many modifications and variations (e.g., mutation) of the nucleic acid sequence are possible and appropriate in the context of the invention. It is believed that the function of atonal-associated factors is dependent on the helix-loop-helix (HLH) portion of the protein, particularly the basic region of the HLH domain (Chien et al., *Proc. Natl. Acad. Sci.*, 93, 13239-13244 (1996)). Accordingly, any modification of the nucleic acid sequence encoding the Hath1 protein desirably is located outside of the basic domain of the protein such that the function of the Hath1 protein is retained or enhanced.

[0034] In addition to the nucleic acid sequence encoding a Hath1 protein, the inventive adenoviral vector preferably comprises expression control sequences, such as promoters, enhancers, polyadenylation signals, transcription terminators, internal ribosome entry sites (IRES), and the like, that provide for the expression of the nucleic acid sequence in a host cell. Exemplary expression control sequences are known in the art and are described in, for example, Goeddel, *Gene Expression Technology: Methods in Enzymology*, Vol. 185, Academic Press, San Diego, California (1990). Ideally, the Hath1-encoding nucleic acid sequence is operably linked to a promoter and a polyadenylation sequence. The promoter desirably is a tissue-specific promoter, i.e., a promoter that is preferentially activated in a given tissue and results in expression of a gene product in the tissue where activated. A tissue specific promoter for use in the inventive adenoviral vector can be chosen based upon the target tissue or cell-type in which the Hath1-encoding nucleic acid sequence is to be expressed. Preferred tissue-specific promoters for use in the inventive adenoviral vector are specific to supporting cells or sensory hair cells. Tissue specific promoters specifically activated in hair cells include, for example, an atonal promoter or a myosin VIIa promoter. Tissue specific promoters specifically activated in supporting cells include, for example, a hes-1 promoter and a human glial fibrillary acidic protein (GFAP) promoter. In a preferred embodiment, the promoter is a human GFAP promoter comprising SEQ ID NO: 2. The human GFAP protein is a soluble structural protein expressed primarily in astrocytes of the central nervous system, non-myelin forming Schwann cells, and other select cell types. Within the anatomy of the inner ear, GFAP expression is primarily restricted to the supporting cells of the sensory organs (i.e., the Deiter's cells and phalangeal cells of the organ of Corti, those located within the canal ampullae, and supporting cells of the extratriolar regions in the utricle/sacculae maculae).

[0035] Other examples of tissue-specific promoters that could be used in the invention include the BRN.3C promoter, the BRN 3.1 promoter, the POU ORF3 factor promoter, the BRK1 promoter, the BRK3 promoter, the chordin promoter, the noggin promoter, the jagged1 promoter, the jagged2 promoter, and the notch1 promoter.

[0036] To optimize protein production, the Hath1-encoding nucleic acid sequence further comprises a polyadenylation sequence downstream of the Hath1 coding sequence. Any suitable polyadenylation sequence can be used, including a synthetic optimized sequence, as well as the

polyadenylation sequence of bovine growth hormone (BGH), polyoma virus, thymidine kinase (TK), Epstein Barr Virus (EBV), human papillomavirus (HPV) and bovine papillomavirus (BPV). The polyadenylation sequence preferably is a simian virus-40 (SV40) early polyadenylation sequence, which is the polyadenylation sequence for the SV40 early RNA products (see, e.g., Carswell, S. and Alwine, J.C., *Mol. Cell. Biol.*, 9(10): 4248-4258 (1989)). In addition to the promoter and polyadenylation sequence, the nucleic acid sequence encoding Hath1 desirably comprises all of the proper transcription signals (and translation signals, where appropriate) correctly arranged such that the nucleic acid sequence is properly expressed in the cells into which it is introduced. If desired, the nucleic acid sequence also can incorporate splice sites (i.e., splice acceptor and splice donor sites) to facilitate mRNA production.

[0037] The tissue-specific promoter, the nucleic acid sequence encoding a Hath1 protein, and the SV40 early polyadenylation sequence can be positioned within the inventive adenoviral vector in any suitable orientation, so long as production of the adenoviral vector is not impeded and the Hath1-encoding nucleic acid sequence is efficiently expressed in host cells. In general, the promoter will be positioned upstream of the Hath1-encoding nucleic acid sequence, and the SV40 early polyadenylation sequence will be positioned downstream of the Hath1-encoding nucleic acid sequence. In one embodiment, the adenoviral vector can comprise the aforementioned elements in sequence from 5' to 3' relative to the adenoviral genome: a tissue specific promoter (e.g., a human GFAP promoter), the nucleic acid sequence encoding a Hath1 protein, and the SV40 early polyadenylation sequence. Alternatively, the adenoviral vector can comprise the aforementioned elements in sequence from 3' to 5' relative to the adenoviral genome: the SV40 early polyadenylation sequence, the nucleic acid sequence encoding a Hath1 protein, and a tissue specific promoter (e.g., a human GFAP promoter). The nucleic acid sequence encoding a Hath1 protein, as well as the tissue-specific promoter and SV40 early poly(a) sequence operatively linked thereto, can be inserted at any position in the adenoviral genome so long as insertion in the position allows for the formation of the adenoviral vector particle. Preferably, the Hath1-encoding nucleic acid sequence is positioned in the E1 region or the E4 region of the adenoviral genome. In a preferred embodiment, the E1 region of the adenoviral genome is replaced with the SV40 early polyadenylation sequence, the nucleic acid

sequence encoding a Hath1 protein, and a human GFAP promoter in sequence from 3' to 5' relative to the adenoviral genome.

[0038] The inventive adenoviral vector can comprise the nucleic acid sequence of, for example, SEQ ID NO: 3.

[0039] The invention provides a composition comprising the adenoviral vector described herein and a carrier therefor (e.g., a pharmaceutically acceptable carrier). The composition desirably is a physiologically acceptable (e.g., pharmaceutically acceptable) composition, which comprises a carrier, preferably a physiologically (e.g., pharmaceutically) acceptable carrier, and the adenoviral vector. Any suitable carrier can be used within the context of the invention, and such carriers are well known in the art. The choice of carrier will be determined, in part, by the particular use of the composition (e.g., administration to an animal) and the particular method used to administer the composition. Ideally, in the context of replication-deficient adenoviral vectors, the pharmaceutical composition preferably is free of replication-competent adenovirus. The pharmaceutical composition optionally can be sterile.

[0040] Suitable compositions include aqueous and non-aqueous isotonic sterile solutions, which can contain anti-oxidants, buffers, and bacteriostats, and aqueous and non-aqueous sterile suspensions that can include suspending agents, solubilizers, thickening agents, stabilizers, and preservatives. The composition can be presented in unit-dose or multi-dose sealed containers, such as ampules and vials, and can be stored in a freeze-dried (lyophilized) condition requiring only the addition of the sterile liquid carrier, for example, water, immediately prior to use. Extemporaneous solutions and suspensions can be prepared from sterile powders, granules, and tablets. Preferably, the carrier is a buffered saline solution. More preferably, the adenoviral vector is part of a composition formulated to protect the adenoviral vector from damage prior to administration. For example, the composition can be formulated to reduce loss of the adenoviral vector on devices used to prepare, store, or administer the adenoviral vector, such as glassware, syringes, or needles. The composition can be formulated to decrease the light sensitivity and/or temperature sensitivity of the adenoviral vector. To this end, the composition preferably comprises a pharmaceutically acceptable liquid carrier, such as, for example, those described above, and a stabilizing agent selected from the group consisting of polysorbate 80, L-arginine, polyvinylpyrrolidone, trehalose, and combinations thereof. Use of such a composition will

extend the shelf life of the adenoviral vector, and facilitate its administration. Formulations for adenoviral vector-containing compositions are further described in, for example, U.S. Patent 6,225,289, U.S. Patent 6,514,943, and International Patent Application Publication WO 2000/034444.

[0041] The composition also can be formulated to enhance transduction efficiency. In addition, one of ordinary skill in the art will appreciate that the adenoviral vector can be present in a composition with other therapeutic or biologically-active agents. For example, factors that control inflammation, such as ibuprofen or steroids, can be part of the composition to reduce swelling and inflammation associated with *in vivo* administration of the adenoviral vector.

Antibiotics, i.e., microbicides and fungicides, can be present to treat existing infection and/or reduce the risk of future infection, such as infection associated with gene transfer procedures.

[0042] The invention also provides a method of generating sensory cells in the inner ear of a human in need thereof. The method comprises administering a composition comprising the inventive adenoviral vector described herein, whereupon the nucleic acid sequence encoding the Hath1 protein is expressed and sensory cells in the inner ear are generated. As used herein, the terms “treatment,” “treating,” and the like refer to obtaining a desired pharmacologic and/or physiologic effect. Preferably, the effect is therapeutic, i.e., the effect partially or completely cures a disease and/or adverse symptom attributable to the disease. To this end, the inventive method comprises administering to the human a “therapeutically effective amount” of the composition. A “therapeutically effective amount” refers to an amount effective, at dosages and for periods of time necessary, to achieve a desired therapeutic result. The therapeutically effective amount may vary according to factors such as the disease state, age, sex, and weight of the individual, and the ability of the inventive adenoviral vector to elicit a desired response in the individual. For example, a therapeutically effective amount of the composition of the invention is an amount which results in expression of the Hath1 protein at levels that treats hearing loss or a balance disorder in a human.

[0043] Alternatively, the pharmacologic and/or physiologic effect may be prophylactic, i.e., the effect completely or partially prevents a disease or symptom thereof. In this respect, the inventive method comprises administering a “prophylactically effective amount” of the composition comprising the inventive adenoviral vector. A “prophylactically effective amount”

refers to an amount effective, at dosages and for periods of time necessary, to achieve a desired prophylactic result (e.g., prevention of disease onset). Therapeutic or prophylactic efficacy can be monitored by periodic assessment of treated patients.

[0044] Suitable doses and dosage regimens can be determined by conventional range-finding techniques known to those of ordinary skill in the art. Desirably, a single dose of adenoviral vector comprises about 1×10^5 or more particles (which also are referred to as particle units (pu)) of the adenoviral vector, e.g., about 1×10^6 or more particles, about 1×10^7 or more particles, about 1×10^8 or more particles, about 1×10^9 or more particles, or about 3×10^8 or more particles of the adenoviral vector. Alternatively, or in addition, a single dose of adenoviral vector comprises about 3×10^{14} particles or less of the adenoviral vector, e.g., about 1×10^{13} particles or less, about 1×10^{12} particles or less, about 3×10^{11} particles or less, about 1×10^{11} particles or less, about 1×10^{10} particles or less, or about 1×10^9 particles or less of the adenoviral vector. Thus, a single dose of adenoviral vector can comprise a quantity of particles of the adenoviral vector in a range defined by any two of the aforementioned values. For example, a single dose of adenoviral vector can comprise 1×10^5 - 1×10^{14} particles, 1×10^7 - 1×10^{12} particles, 1×10^8 - 1×10^{11} particles, 3×10^8 - 3×10^{11} particles, 1×10^9 - 1×10^{12} particles, 1×10^9 - 1×10^{11} particles, 1×10^9 - 1×10^{10} particles, or 1×10^{10} - 1×10^{12} particles, of the adenoviral vector. In other words, a single dose of adenoviral vector can comprise, for example, about 1×10^6 pu, 2×10^6 pu, 4×10^6 pu, 1×10^7 pu, 2×10^7 pu, 4×10^7 pu, 1×10^8 pu, 2×10^8 pu, 3×10^8 pu, 4×10^8 pu, 1×10^9 pu, 2×10^9 pu, 3×10^9 pu, 4×10^9 pu, 1×10^{10} pu, 2×10^{10} pu, 3×10^{10} pu, 4×10^{10} pu, 1×10^{11} pu, 2×10^{11} pu, 3×10^{11} pu, 4×10^{11} pu, 1×10^{12} pu, 2×10^{12} pu, 3×10^{12} pu, or 4×10^{12} pu of the adenoviral vector. Of course, other routes of administration may require smaller or larger doses to achieve a therapeutic effect. Any necessary variations in dosages and routes of administration can be determined by the ordinarily skilled artisan using routine techniques known in the art.

[0045] The interior space of the structures of the inner ear is limited. The volume of pharmaceutical composition administered directly into the inner ear structures should be carefully monitored, as forcing too much composition will damage the sensory epithelium. For a human patient, the volume administered is preferably about 1 μ l to about 500 μ l (e.g., from about 10 μ l to about 400 μ l) of composition. For example, from about 10 μ l to about 200 μ l (e.g., about 15 μ l, 20 μ l, 30 μ l, 40 μ l, 50 μ l, 60 μ l, 70 μ l, 80 μ l, 90 μ l, 100 μ l, 125 μ l, 150 μ l, 175 μ l,

or a range defined by any two of the foregoing values) of composition can be administered. In one embodiment, the entire fluid contents of the inner ear structure, e.g., the cochlea or semi-circular canals, is replaced with pharmaceutical composition. In another embodiment, a pharmaceutical composition comprising the expression vector of the inventive method is slowly released into the inner ear structure, such that mechanical trauma is minimized.

[0046] In one embodiment of the inventive method, the composition comprising the Hath1-encoding adenoviral vector desirably is administered only once to the inner ear of the human during a given treatment period. In other words, the inventive method comprises administration of a single dose of the inventive adenoviral vector to the inner ear of a human. In other embodiments, it may be advantageous to administer the composition two or more (i.e., multiple) times to the inner ear of the human. Thus, the invention provides administration of two or more doses of the inventive adenoviral vector to the inner ear of a human. For example, the composition comprising the inventive adenoviral vector can be administered at least twice to the same ear. When the composition is administered multiple times to the inner ear of a human, each administration can be separated by days, weeks, months, or even years depending on the response of the human to the first and subsequent administrations of the composition. For example, the multiple administrations can be separated by about 1 week to about 4 weeks (e.g., 2 or 3 weeks), or by about 30 days to about 90 days (e.g., about 40 days, about 50 days, about 60 days, about 70 days, about 80 days, or a range defined by any two of the foregoing values). However, multiple administrations of the composition (e.g., 3, 4, 5, 6, or more administrations) can be separated by any suitable number of days (e.g., 2, 7, 10, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77, 85 or more days between doses), months (e.g., 1, 3, 6, or 9 months between doses), or years (e.g., 1, 2, 3, 4, 5 or more years between doses) so long as the nucleic acid sequence encoding the Hath1 protein is sufficiently expressed and sensory cells in the inner ear are generated.

[0047] The composition desirably is administered to a human to treat a disorder associated with loss, damage, or absence of sensory hair cells in the inner ear, such as hearing loss and balance disorders. In this respect, the composition can be administered to a human suffering from hearing loss or a balance disorder, or a human suffering from both hearing loss and a balance disorder. Hearing loss can be caused by damage of hair cells of the organ of Corti due to bacterial or viral infection, heredity, physical injury, acoustic trauma, and the like. While

hearing loss is easily identified, balance disorders manifest in a broad variety of complications easily attributable to other ailments. Symptoms of a balance disorder include disorientation, dizziness, vertigo, nausea, blurred vision, clumsiness, and frequent falls. Balance disorders treated by the inventive method preferably involve a peripheral vestibular disorder (i.e., a disturbance in the vestibular apparatus) involving dysfunctional translation of mechanical stimuli into neural impulses due to damage or lack of sensory hair cells. In embodiments, the composition is administered to a human to treat severe-to-profound bilateral hearing loss.

[0048] The composition can be administered to the inner ear of a human using any suitable method known in the art. The inner ear in humans is comprised of the bony labyrinth, which is a system of passages comprising two main parts: (a) the cochlea dedicated to hearing and (b) vestibular system dedicated to balance. The composition desirably is administered to the cochlea or the vestibular system, or to both the cochlea and the vestibular system. No matter the route of administration, the inventive adenoviral vector must reach the sensory epithelium of the inner ear, for example, the sensory epithelium of the cochlea and/or vestibular system. The most direct routes of administration, therefore, entail surgical procedures which allow access to the interior of the structures of the inner ear. Inoculation via cochleostomy allows administration of the expression vector directly to the regions of the inner ear associated with hearing. Cochleostomy involves drilling a hole through the cochlear wall, e.g., in the otic capsule below the stapedia artery as described in Kawamoto et al., *Molecular Therapy*, 4(6), 575-585 (2001), and release of the composition comprising the adenoviral vector. Administration to the endolymphatic compartment is particularly useful for administering the composition to the areas of the inner ear responsible for hearing. Alternatively, the composition can be administered to the semicircular canals via canalostomy. Canalostomy provides for transgene expression in the vestibular system and the cochlea, whereas cochleostomy does not provide as efficient transduction in the vestibular space. The risk of damage to cochlear function is reduced using canalostomy in as much as direct injection into the cochlear space can result in mechanical damage to hair cells (Kawamoto et al., *supra*). Administration procedures also can be performed under fluid (e.g., artificial perilymph), which can comprise factors to alleviate side effects of treatment or the administration procedure, such as apoptosis inhibitors or anti-inflammatories.

[0049] Another direct route of administration to the inner ear is through the round window, either by injection or topical application to the round window. Administration via the round window is especially preferred for delivering an adenoviral vector to the perilymphatic space. Transgene expression in cochlear and vestibular neurons and cochlear sensory epithelia has been observed following administration of expression vectors via the round window (Staecker et al., *Acta Otolaryngol*, 121, 157-163 (2001)). In another embodiment, the composition can be administered to the inner ear via intra-labyrinthine (IL) infusion through the oval window for delivering the composition to the perilymphatic space. In certain cases, it may be appropriate to administer multiple applications and/or employ multiple routes, e.g., canalostomy and cochleostomy, to ensure sufficient exposure of supporting cells to the adenoviral vector. A particularly preferred method for delivery of the inventive composition to the inner ear is described in, e.g., U.S. Patent 7,387,614.

[0050] The composition comprising the inventive adenoviral vector can be present in or on a device that allows controlled or sustained release of the adenoviral vector, such as a sponge, meshwork, mechanical reservoir or pump, or mechanical implant. For example, a biocompatible sponge or gelform soaked in the composition comprising the adenoviral vector can be placed adjacent to the round window, through which the expression vector permeates to reach the cochlea (as described in Jero et al., *Hum. Gene Ther.*, 12: 539-548 (2001)). In another embodiment, mini-osmotic pumps can be used to provide sustained release of the adenoviral vector over extended periods of time (e.g., five to seven days), allowing small volumes of composition comprising the adenoviral vector to be administered, which can prevent mechanical damage to endogenous sensory cells. The composition also can be administered in the form of sustained-release formulations (see, e.g., U.S. Patent 5,378,475) comprising, for example, gelatin, chondroitin sulfate, a polyphosphoester, such as bis-2-hydroxyethyl-terephthalate (BHET), or a polylactic-glycolic acid.

[0051] While not preferred, the composition comprising the inventive adenoviral vector can be administered parenterally, intramuscularly, intravenously, or intraperitoneally. If parenterally administered to a patient, the adenoviral vector desirably is specifically targeted to sensory epithelial cells, such as supporting cells. For example, the adenoviral vector can be targeted to scarred sensory epithelium to promote generation of exogenous hair cells to replace damaged

endogenous hair cells. An adenoviral vector can be modified to alter the binding specificity or recognition of an expression vector for a receptor on a potential host cell by deleting regions of the fiber, penton, or hexon, inserting various native or non-native ligands into portions of the coat protein, and the like. One of ordinary skill in the art will appreciate that parenteral administration can require large doses or multiple administrations to effectively deliver the expression vector to the appropriate host cells.

[0052] In one embodiment, the inventive method comprises administering a single dose comprising between about 20 μL and 90 μL of the inventive composition (at a concentration of 5.0×10^{11} particles (vp)/mL of adenoviral vector) to a human via intra-labyrinthine (IL) infusion.

[0053] In one embodiment, the inventive method comprises administering a single dose comprising between about 20 μL and 90 μL of the inventive composition (at a concentration of 5.0×10^{11} particles (vp)/mL of adenoviral vector) to a human via intra-labyrinthine (IL) infusion at an infusion rate of between about 10 $\mu\text{L}/\text{minute}$ to about 20 $\mu\text{L}/\text{minute}$.

[0054] The inventive method can be part of a treatment regimen involving other therapeutic modalities. For example, the inventive method can be performed on a human that has been treated, is being treated, or will be treated with one or more drugs or surgery. In addition, the inventive method can be used in conjunction with proliferation agents that induce proliferation of supporting cells in the inner ear, such as vascular endothelial growth factors (VEGF), fibroblast growth factors (FGFs), epidermal growth factor (EGF), E2F, and cell cycle up-regulators. The inventive method also can be performed in conjunction with the implantation of hearing devices, such as cochlear implants.

[0055] Sensory cell (e.g., hair cell) generation in the inner ear can be determined using a variety of means known in the art. For example, sensory hair cells can be detected via scanning electron microscopy or via detection of myosin VIIa, which is a hair cell-specific protein detected by immunocytochemistry. However, the mere presence of sensory hair cells does not necessarily imply a functional system for recognizing environmental stimuli. Functional sensory cells must be operably linked to neural pathways, such that mechanical stimuli are translated to nerve impulses recognized by the brain. Accordingly, while detection of hair cell generation is appropriate for determining successful expression of the Hath1-encoding nucleic acid sequence to target tissue, the generation of sensory cells preferably leads to an improvement in sensory

perception by the human subject. In this respect, examination of subject awareness is an indicator of changes in sensory perception.

[0056] A change in the ability of a subject to detect sound can be assessed through administration of simple hearing tests, such as a tone test commonly administered by an audiologist. In most mammals, a reaction to different frequencies indicates a change in sensory perception. In humans, comprehension of language also is appropriate. For example, it is possible for a subject to hear while being unable to understand speech. A change in sensory perception is indicated by the ability to distinguish different types of acoustic stimuli, such as differentiating language from background noise, and by understanding speech. Speech threshold and discrimination tests are useful for such evaluations.

[0057] Evaluation of changes in balance, motion awareness, and/or timing of response to motion stimuli also can be achieved using a variety of techniques. Vestibular function can be measured by comparing the magnitude of response to motion stimulus (gain) or timing of initiation of response (phase). Animals can be tested for Vestibulo-Ocular Reflex (VOR) gain and phase using scleral search coils to evaluate improvements in sensory perception. Electronystagmography (ENG) records eye movements in response to stimuli such as, for instance, moving or flashing lights, body repositioning, fluid movement inside the semicircular canals, and the like. Evaluation of balance during movement using a rotating chair or moving platform also is useful in this respect.

[0058] The following examples further illustrate the invention but, of course, should not be construed as in any way limiting its scope.

EXAMPLE 1

[0059] This example demonstrates a method of generating the inventive serotype 5 adenoviral vector.

[0060] An adenovirus vector comprising a serotype 5 adenoviral genome with a deletion of the E1, E3, and E4 regions and encoding the Hath1 protein was constructed using the ADFAST™ protocol described in, e.g., U.S. Patent 6,475,757. Using the ADFAST™ procedure, a plasmid was constructed that encodes an entire serotype 5 adenovirus vector genome. Isolation of a single genetic clone of the final vector genome was achieved by two

sequential colony-growth steps in bacteria. This AdFAST™ plasmid was converted to a viral vector upon introduction into mammalian cells that complement for adenovirus vector growth. Subsequent expansion via serial passaging was then performed to generate adenovirus vector stocks. The steps to construct the Hath1-expressing serotype 5 adenoviral vector are summarized below.

Construction of Plasmids

A plasmid denoted pAd3511gfa2.HATH1.sv was digested with restriction enzymes to gel extract a GFAP.HATH1 expression cassette. A base plasmid comprising a serotype 5 adenoviral genome with deletions in the E1, E3, and E4 regions and a transcriptionally inert spacer containing an SV40 poly(A) and transcription termination sequences, a β -glucuronidase gene, and a bovine growth hormone gene (BGH) poly(A) and transcription termination sequences (denoted pAdE1 (BN) E3 (10) E4 (TIS1)) was linearized and purified. The pAdE1 (BN) E3 (10) E4 (TIS1) plasmid was homologously recombined with the GFAP.HATH1 expression cassette in *E. coli*, resulting in the plasmid pAdE1(GFAP.Hath1)E3(10)E4(TIS1).

[0061] To ensure clonality of the full length adenovirus vector plasmid, an aliquot of pAdE1(GFAP.Hath1)E3(10)E4(TIS1) ADFAST™ plasmid DNA was used to transform DH10B *E. coli* by limiting serial dilutions. Well-defined and isolated colonies were selected from the highest dilution plate containing the fewest colonies. Miniprep plasmid DNA was prepared and digested with Hind III+SpeI to confirm plasmid integrity via RFLP analysis. Positive corresponding miniprep DNA was used to generate another series of limiting dilutions, which were then used to transform DH10B *E. coli*. An aliquot of liquid culture from a single colony on the plate containing the fewest colonies was used to generate miniprep DNA, whereupon ApaI was used to further confirm plasmid integrity. Remaining liquid culture of the positive clone was used to streak an LB-kanamycin plate. A single bacterial transformant was expanded for preparation of EndoFree ADFAST™ plasmid DNA by the HISPEED™ Plasmid Maxi Kit (Qiagen, Venlo, The Netherlands) following the manufacturer's protocol. The resulting plasmid preparation was confirmed by BglI, EcoRV, HindIII, KpnI, and BamHI+PacI restriction endonuclease digestion. A map of the pAdE1(GFAP.Hath1)E3(10)E4(TIS1) is shown in Figure 1. The DNA sequence of pAdE1(GFAP.Hath1)E3(10)E4(TIS1) was then determined.

Vector Conversion

[0062] 18 µg of the endotoxin-free pAdE1(GFAP.HATH1)E3(10)E4(TIS1) was digested in 300µL with Pac I restriction endonuclease and purified by Phenol Chloroform Isoamylalcohol (PCI). Briefly, 100uL of PCI was added to the restriction reaction, mixed by vigorous inversion, spun at 13,000RPM for two minutes in a microfuge, and the upper aqueous phase was transferred to a new tube. The DNA was precipitated by the addition of 30µL (0.1 volume) of 5M NaCl and 800µL of absolute ethanol, incubated on ice for 10 minutes, and then spun in a microfuge at 13,000RPM for 10 minutes, and the supernatant was decanted. The pellet was washed with 500µL of 70% ethanol, centrifuged and decanted as above, and the DNA pellet air-dried. The DNA was resuspended in 30 µL TE and the DNA concentration was determined by absorbance at 260 nm. 293-ORF6 cells were transfected with 4µg of the Pac I-digested and -purified DNA using POLYFECT™ reagent (Qiagen, Venlo, The Netherlands), and incubated at 37 °C, 5% CO₂, for three days. The transfection lysate (generated by three freeze-thaw cycles) was used to initiate serial passaging to generate high titer lysate. After confirmation by PCR, the high titer lysate was used to expand the AdGFAP.HATH1.11D adenovector.

Construction of the AdGFAP.HATH1.11D Adenoviral Vector

[0063] To construct the adenoviral vector AdGFAP.HATH1.11D, also referred to as GV501A (a map of which is shown in Figure 2) and CGF166, the ADFAST™ plasmid pAdE1(GFAP.HATH1)E3(10)E4(TIS1) was digested with the restriction endonuclease PacI and transfected into 293-ORF6 cells using standard procedures. The adenovector lysate from the transfected cells was serially passaged five times to expand the titer and volume of the AdGFAP.HATH1.11D/GV501A lysate and produce a high titer (HT2) stock. The 293-ORF6 cells used for the GV501A transfection and construction were maintained in a limited access cell culture room to ensure separation from other activities. In addition, the transfection, serial passaging, and production of the AdGFAP.HATH1.11D/GV501A vector were conducted in a separate virus culture room under procedures to maintain separation and limited access. The identity and integrity of the AdGFAP.HATH1.11D/GV501A vector was confirmed by PCR

analysis at the HT2 passage. The HT2 lysate was then used to generate adenovector stock expansions.

Hath1 Transgene Expression Assays

[0064] The AdGFAP.HATH1.11D vector was certified for functional transgene expression based on HATH1-driven sensory cell regeneration in a mouse utricle model. Results of this experiment showed that the AdGFAP.HATH1.11D vector was capable of inducing sensory cell regeneration, and therefore produced functional HATH1 protein. In addition, AdGFAP.HATH1.11D was tested for expression of Hath1 transgene mRNA using a modified Hath1 mRNA expression assay. The assay involved infecting 293 cells with AdGFAP.HATH1.11D and isolating total RNA 24 hours post-infection. Hath1-specific mRNA expression was measured by a semi-quantitative RT-PCR method. The results of this assay showed evidence of Hath1 expression based on the RNA/DNA- and DNA-only primers and probes observed.

[0065] The results of this example confirm the generation of a serotype 5 adenoviral vector in which one or more endogenous nucleotides of the E1 region and the E4 region have been deleted, and which comprises an SV40 early polyadenylation sequence, a Hath1-encoding nucleic acid sequence operably linked to a human GFAP promoter, and a transcriptionally inert spacer (TIS).

EXAMPLE 2

[0066] This example describes a clinical study designed to evaluate the safety, tolerability, and the potential ability of CGF166 (AdGFAP.HATH1.11D) delivered through intra-labyrinthine (IL) infusion to improve hearing and vestibular function in humans.

[0067] The clinical trial will be a three part study utilizing an open label, single dose, sequential cohort in patients with severe-to-profound bilateral hearing loss with intact vestibular function in the non-operative ear. Patients will be required to have documented non-fluctuating severe-to-profound bilateral hearing loss prior to enrollment. A maximum of 45 patients may be enrolled in this three-part, six-cohort trial

[0068] Part A of the trial will assess the safety and tolerability as well as potential efficacy following a single IL dose of 20 μL CGF166 concentration (5.0×10^{11} viral particles (vp)/mL). Patient enrollment will be staggered so that a safety data review can be completed after each treated patient (about 4 weeks after treatment) prior to dosing each subsequent patient.

[0069] Part B of the trial will include a volumetric escalation design to evaluate up to four possible infusion volumes (between 20 μL and 90 μL) of the same CGF166 concentration (5.0×10^{11} vp/mL) in four cohorts of patients ($n=3/\text{cohort}$; total of 12 patients). All dose volumes will be subject to change based on trial safety data.

[0070] Each subsequent cohort will be dosed only after the volume delivered in the prior cohort is deemed to be safe and tolerable as determined by a Safety Review Committee (SRC). In addition, the scheduling and dosing of the first patient in each cohort will be staggered to allow at least a four week interval in between treating the remaining two patients in each cohort.

[0071] The highest safe and tolerable volume determined in Part B will be used for IL infusion in Part C patients. A total of 20 patients will be required for Part C of the current study. A safety review analogous to that described for parts A and B will take place whenever a block of five subjects completes the first four weeks of study assessments.

[0072] Patients will undergo the same protocol-required assessments and visit schedule in all Parts of the trial (A-C). Part C of the study will only commence once preliminary safety and tolerability has been established for CGF166 and the associated delivery methods in patients in Parts A and B.

[0073] The trial duration will consist of a 63 day screening period followed by a 1-3 day baseline assessment period and in-house surgical dose/post operation assessment period (approximately 6-14 days) followed by a 6-month post-dose assessment period. In addition, all dosed subjects in Parts A-C will be advised of the opportunity to enroll in a separate 5-year safety follow-up trial.

[0074] During the screening period, eligibility of potential patients will be verified at the study centers.

[0075] Potential patients will be evaluated for fitness prior to undergoing protocol-required surgery and for the planned therapy based on physical exam, MRI, past/current medical history,

and laboratory testing. During the screening period, potential patients will also undergo pre-treatment quality of life, auditory, and vestibular function tests.

[0076] At least two outpatient visits during the screening period are anticipated in order to complete the required verification and assessments. If all screening assessments can be completed in one visit, that is allowed. Additional outpatient screening visits (i.e., more than two visits) are permitted pending patients' and clinic schedule and the need for re-verifications and potential re-testing.

[0077] Based on the screening assessments, one ear will be selected as the study ear and will undergo the study required surgery. Criteria for the selection of the study ear include: (1) the ear with more severe hearing loss as determined by pure tone audiometry and speech recognition score and (2) if both ears have equal severity in hearing loss, then the study ear will be selected by the investigator's preference.

[0078] Upon completing the screening visits, eligible patients will be scheduled for a baseline visit and surgery.

Baseline (Day -3 to -1)

[0079] Eligible patients will return to the study center at baseline (Day -3 to -1) and undergo pre-operative preparation as well as pre-treatment functional assessments.

Day 1 visit

[0080] On Day 1, study patients will undergo the required protocol assessments and the stapedotomy for delivery of the study drug to the scala vestibuli perilymphatic space of the inner ear. At the completion of the surgery and study drug infusion, study patients will recover in the surgical center's post-op facility and undergo post-surgery evaluations and assessments. Study patients may be transitioned to either the inpatient unit of the surgical center or pre-arranged temporary housing close to the surgical center.

Day 2 to Day 6 visits

[0081] Study patients will be followed up for the next 5 post-surgery days (Day 2 to Day 6) and will undergo the protocol-required safety follow up evaluations. Study patients will be discharged home if there are no significant adverse events requiring prolonged monitoring.

Patients will have the option to remain in the provided housing until the completion of the Day 14 visit. Subsequent visits will be scheduled with the study patients prior to being discharged.

Day 14 visit

[0082] Study patients will return to the study center to have surgical packing removed from their ear and will also undergo study required assessments. Patients will be discharged home or to their local housing at the end of all study required evaluations. Patients will be reminded of their next scheduled visit.

Follow up and end of study visits (every four weeks)

[0083] During each monthly visit to the study center, post-operative recovery of the study ear will be monitored and evaluated. Study patients will also undergo the study-required safety, quality of life, auditory, and vestibular function tests during each visit. Biodistribution blood samples will also be collected during each visit. Samples for immunogenicity testing will be collected as per the blood log. At completion of the six-month post-surgery visit (end of study visit), if there are no significant adverse events requiring prolonged monitoring, study patients will be considered to have completed the study and will be discharged to their home.

[0084] All dosed patients will be expected to participate in a separate extension/follow-up trial.

Safety Data Reviews

[0085] Prior to dosing each patient in Part A (cohort 1) and prior to dosing the two remaining patients in Part B (cohorts 2-5), a review of all safety and tolerability data as well as a review of selected auditory and vestibular function data will be conducted. Data considered for review will be those available up to four weeks post-dose, as outlined in the SRC Charter. Safety and tolerability must be assessed as satisfactory in order to proceed with the remaining patients in the cohort. For cohorts 2-5, the decision to dose the remaining two patients will be made by the SRC. If notable adverse events or safety concerns are found at one of the planned dose levels, the next planned dose level may be changed.

[0086] After completion of one cohort and prior to proceeding to the next cohort, a review of all safety and tolerability data, as well as limited auditory and vestibular data will be performed for all patients who received a dose of CGF166 and have completed at least 4 weeks of study assessments. Safety and tolerability must be assessed as satisfactory in order to proceed to the

next cohort. This decision will be made by the SRC. Should notable adverse events or safety concerns be found at one of the planned dose levels, the next planned dose level may be changed.

[0087] For Part C, the safety review described above will be performed as each five subjects complete their first four weeks of study assessments.

[0088] Findings

[0089] The first patients treated with 20 to 40 uL of the composition of the invention under cohorts A, B, and C have reported between 0 and 3 adverse events each - all classified as mild to moderate- over 2-6 months of follow-up. Most adverse events, including all events classified as moderate, were not suspected to be associated with the treatment. In addition, there have been no clinically significant changes in laboratory values following treatment with the composition. These results indicate that the inventive composition invention is safe when administered to a human.

[0090] This example describes a clinical protocol designed to evaluate the safety and efficacy of the inventive adenoviral vector for treating hearing loss in humans.

[0091] All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

[0092] The use of the terms “a” and “an” and “the” and “at least one” and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The use of the term “at least one” followed by a list of one or more items (for example, “at least one of A and B”) is to be construed to mean one item selected from the listed items (A or B) or any combination of two or more of the listed items (A and B), unless otherwise indicated herein or clearly contradicted by context. The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms (i.e., meaning “including, but not limited to,”) unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is

incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[0093] Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

CLAIMS:

1. An adenoviral vector comprising:
 - (a) a serotype 5 adenoviral genome, except that two base pairs are deleted in the VA RNA I region, one or more endogenous nucleotides of the E1 region are deleted to render an endogenous gene in the E1 region functionally deficient, one or more endogenous nucleotides of the E3 region are deleted, and one or more endogenous nucleotides of the E4 region are deleted to render an endogenous gene in the E4 region functionally deficient, wherein a right side inverted terminal repeat (ITR), an E4 region polyadenylation sequence, and an E4 region promoter are retained,
 - (b) an SV40 early polyadenylation sequence,
 - (c) a nucleic acid sequence encoding a human atonal homolog-1 (Hath1) protein comprising SEQ ID NO: 1,
 - (d) a human glial fibrillary acidic protein (GFAP) promoter, and
 - (e) a transcriptionally inert spacer (TIS),wherein elements (b), (c), and (d) are located in sequence from 3' to 5' relative to the adenoviral genome in the E1 region of the adenoviral genome, and wherein element (e) is located in the E4 region of the adenoviral genome between the E4 polyadenylation sequence and the E4 promoter.
2. The adenoviral vector of claim 1, wherein the adenoviral genome does not comprise the endogenous promoters and coding regions of the E1A and E1B genes.
3. The adenoviral vector of claim 2, wherein the adenoviral genome does not comprise endogenous nucleotides 356-3510, inclusive, of the E1 region of the serotype 5 adenoviral genome.
4. The adenoviral vector of any one of claims 1-3, wherein the adenoviral genome does not comprise endogenous nucleotides 28,593-30,471, inclusive, of the E3 region of the serotype 5 adenoviral genome.
5. The adenoviral vector of any one of claims 1-4, wherein the adenoviral genome does not comprise any of the E4 region coding sequences.

6. The adenoviral vector of claim 5, wherein the adenoviral genome does not comprise endogenous nucleotides 32,827-35,563, inclusive, of the E4 region of the serotype 5 adenoviral genome.

7. The adenoviral vector of any one of claims 1-6, wherein the two base-pair deletion in the VA RNA I region is the deletion of endogenous nucleotides 10,594 and 10,595 of the serotype 5 adenoviral genome.

8. The adenoviral vector of any one of claims 1-7, wherein the human glial fibrillary acidic protein (GFAP) promoter comprises SEQ ID NO: 2.

9. The adenoviral vector of any one of claims 1-8, wherein the transcriptionally inert spacer (TIS) comprises in sequence from 5' to 3' relative to the adenoviral genome (i) a polyadenylation (poly(A)) sequence and transcription termination sequence from simian virus 40 (SV40), (ii) a nucleic acid sequence encoding a β -glucuronidase gene, and (iii) a polyadenylation (poly(A)) sequence and transcription termination sequence from the bovine growth hormone (BGH) gene.

10. The adenoviral vector of any one of claims 1-9, which comprises the nucleic acid sequence SEQ ID NO: 3.

11. A composition comprising the adenoviral vector of any one of claims 1-10 and a pharmaceutically acceptable carrier.

12. A method of generating sensory cells in the inner ear of a human in need thereof, which method comprises administering the composition of claim 11 to the inner ear of the human, whereupon the nucleic acid sequence encoding the Hath1 protein is expressed and sensory cells in the inner ear are generated.

13. The method of claim 12, wherein the composition is administered to a human suffering from hearing loss.

14. The method of claim 12, wherein the composition is administered to a human suffering from a balance disorder.

15. The method of any one of claims 12-14, wherein the composition is administered once to the inner ear of the human.