Wound and Cutaneous Injury Healing with a Nucleic Acid Encoding a Proteoglycan Polypeptide

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CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation-in- part of US patent application no. 11/604,633, filed 11-27-2006, which is a continuation of US Patent Application No. 10/420,270, filed 04-22-03, now US Patent No. 7,141,551, issued 11-28-2006, which claims priority to and benefit of US Provisional Patent Application No. 60/374,553, filed 04-22-02.

FIELD OF THE DISCLOSURE

The present disclosure relates to biomolecules involved in wound healing and repair and methods of using and delivering such biomolecules in would healing and repair.

BACKGROUND

Proteoglycans are molecules that contain both a protein portion (which may be referred to as the protein core) and glycosaminoglycan portion. Glycosaminoglycans are the most widely present polysaccharides in the animal kingdom and are mainly found in the connective tissues. Glycosaminoglycans are biological polymers made up of linear disaccharide units containing an uronic acid and a hexosamine and are attached to the core proteins via a linking tetrasaccharide moiety. The major glycosaminoglycans are hyaluronic acid, chondroitin sulfates, heparan sulfate, dermatan sulfate and keratan sulfate.

Physiochemical properties such as, but not limited to, solvation and interaction with biological tissues and structures are related to, at least in part, the presence of carboxylic acid and/or sulfuric groups within the glycosaminoglycan chains. The glycosaminoglycan chains can impart a substantial negative charge to the proteoglycan proteins. The aligned sulfated glycosaminoglycans chains can sequester water through hydrogen bonding, holding many times their weight in water. Such properties determine, in part, the biological activity of the glycosaminoglycans in extracellular matrices. Glycosaminoglycans also help to maintain a favorable environment for cell growth. Because of these characteristics, glycosaminoglycans are used in many clinical and medical applications. The use of glycosaminoglycans in cosmetics is also due to their physicochemical and biological properties linked to their molecular weight and their water retaining capacity (Gagnieu, et al., Peau Seche et Hydratation, Lyon, France, Journees

Internationales de Dermocosmetologie de Lyon, 1998). The hydrating potential of recombinantly expressed proteoglycans has also been published (Huc, et al., Peau Seche et Hydration, Lyon, France, 1988).

Proteins that are membrane bound become either integral membrane proteins, with a transmembrane domain, or glycosylphosphotidylinositol (GPI) linked to the lipid bilayer. Within an integral membrane protein, a transmembrane helix is a segment that is alpha-helical in structure, roughly 20 amino acids in length, and is said to "span" the membrane.

Glycosaminoglycan chains are synthesized via similar routes involving the stepwise addition of four monosaccharides to serine residues followed by co-polymerization of disaccharide units. It has been shown that serine followed by glycine residues are heavily favored acceptors for xylosyltransferase, the key enzyme in the initial step of glycosaminoglycan glycosylation. The priming of glycosaminoglycan synthesis as well as determining the type of glycosylation is in part encoded by the core protein. The formation of heparan sulfate over chondroitin sulfate, for example, is favored when the core protein contains 2 or more serine-glycine (SG)-consensus sequences in close proximity to each other, a cluster of acidic amino acids is located nearby, and a tryptophan residue immediately follows the (SG) glycosaminoglycan attachment sites. However, acidic clusters are also found in chondroitin sulfate proteoglycans and thus seem to be necessary but not sufficient for the priming of heparan sulfate glycosylation. Therefore, while the sites for glycosaminoglycan attachment are known to some extent, the rules governing the type and extent of glycosaminoglycan modification are still not clear. The GAG attachment sites are known for a number of proteoglycans, including perlecan (Dolan et al, J. Biol. Chem., Vol. 272, p. 4316-4322, 1997), collagen XVIII (Dong et al., J. Biol. Chem., Vol. 278, p. 1700-1707,2003), syndecan-1 (Zhang et al., J. Biol. Chem., Vol. 270, p. 27127-27135, 1995), glypican (Chen et al., J. Biol. Chem., Vol. 276, p. 7507-7517, 2001) and agrin (Winzen et al., J. Biol. Chem., Vol. 278, p. 30106-30114, 2003).

Chronic sun exposure induces numerous changes in exposed skin; the most striking histopathologic change is the massive accumulation of material with the staining characteristics of elastin, termed solar elastosis, in the superficial dermis. Recently, the large chondroitin sulfate proteoglycan, versican, has been identified in the dermis in association with elastic fibers, and the smaller chondroitin sulfate proteoglycan, decorin, has been shown to codistribute with collagen fibers. Evidence was published for the close association of versican with elastic fibers and decorin with collagen fibers, even in the situation of abnormal fiber deposition occurring in photodamaged skin (Bernstein, et al., Lab Invest 72(6): 662-9, 1995). In addition, changes in versican and decorin immunostaining were accompanied by similar alterations in gene expression. In another study, the effect of UVB exposure on the distribution and synthesis of

dermal proteoglycans was measured in the skin of mice (Margelin, et al., Photochem Photobiol 58(2): 211-8, 1993). The results demonstrated that chronic doses of UVB altered proteoglycan metabolism through both quantitative and qualitative changes.

Numerous articles have been published about the necessity of moisturizers for patients with dermatological damage, such as dryness caused by rosacea, and the ability of moisturizers to hydrate the skin and reduce transepidermal water loss (TEWL), further improving the vigor of the stratum corneum (Draelos, Dermatol Clin 18(4): 597-607, 2000; Bikowski, Cutis 68(5 Suppl): 3-11, 2001; Rawlings, et al., Dermatol Ther 17 Suppl 1: 49-56, 2004; Draelos, Cutis 76(6 Suppl): 19-25, 2005). Such moisturizers may contain proteoglycans. Although these moisturizers have been shown to improve patient skin health and appearance, they are presently only delivered as pre-synthesized proteoglycans and so limited in their effectiveness.

Despite the widespread use and acceptance of proteoglycans and glycosaminoglycans in pharmaceuticals, the use of proteoglycans when delivered as polynucleotides has only been described for the proteoglycans decorin and biglycan in the scientific literature, and for decorin (US Patent No. 6,524,573) and perlecan (US Patent No. 7,141,551) in the patent literature. In addition, a patent has been issued describing in-situ delivery of nucleic acid encoding syndecan intracellular sequences as a fusion transmembrane protein that is expressed as a cell-bound molecule (US Patent No. 7,029,668). This is substantially different in scope and meaning from the present disclosure, which discloses a polynucleotide encoding a secreted proteoglycan. In managing skin homeostasis, secreting the proteoglycan into the extracellular matrix is an important aspect of the present invention and has not been demonstrated as obvious to experts in the field.

Due to their propensity to sequester water, the delivery of proteoglycan polypeptides to the sites of wounds or cutaneous injury caused by age, sun exposure, skin ailments, or trauma will visibly reduce wrinkling or surface irregularities as the sequestered water hydrates the area and cause conditions favorable for treatment and/or prevention of wounds and/or cutaneous injury. In addition, more highly hydrated skin should function better, possibly allowing for increased blood flow and elasticity, further improving appearance, and increasing patient health by allowing nutrients to be distributed more readily.

The present disclosure provides nucleic acid constructs encoding one or more polypeptides containing one or more sites for glycation by glycosaminoglycan chain, such as proteoglycan polypeptides, and methods for delivering to the site of a wound or cutaneous injury at least one nucleic acid construct encoding one or more such polypeptides, such that the expressed polypeptide is decorated by glycosaminoglycan chains through the normal physiological processes of the subject at the site of administration to produce a polypeptide for

the healing of the wound or other cutaneous injury. The delivered nucleic acid construct is transcribed, translated to produce a polypeptide, which is subsequently post-translationally modified by the addition of glycosaminoglycan chains (referred herein as "decoration" or "glycation") to produce a polypeptide. The glycated polypeptide is then secreted from the cell in which it was produced as directed by a sequence that is sufficient for secretion. During the secretion process, all or a portion of such sequence may be cleaved. After secretion, the glycated polypeptide is available to provide treatment of wounds and/or cutaneous injury in the subject and/or prevention of cutaneous injury in a subject. As a result, the glycated polypeptide released is decorated optimally by the normal physiological process of the subject to provide one or more glycosaminoglycan containing polypeptides based on the conditions prevailing at the site of administration in a particular subject. In a particular embodiment, the glycosaminoglycan containing polypeptide is a proteoglycan polypeptide.

BRIEF DESCRIPTION OF DRAWINGS

FIGS. 1A and 1B demonstrate that proteoglycan polypeptides comprising a signal sequence are secreted from fibroblast and endothelial cells.

FIG. 1A shows a 96-well dot-blot of 100 µl of the solubilized residual cell matrix samples and 100 µl of the conditioned medium (presented as duplicate samples). Immunoreactivity was assessed using the anti-D1 mAb A71. Columns 1 and 2 are solubilized residual cell matrix from primary human endothelial cells cultures following 9 days of culture after infection with perlecanD1-Ad and control RevD1-Ad, respectively. Columns 3 and 4 are conditioned medium from primary human endothelial cells cultures following removed following 5 days of culture after infection with perlecanD1-Ad and control RevD1-Ad, respectively. Columns 5 and 6 are conditioned medium from primary human endothelial cells cultures removed following 6-9 days of culture after infection with perlecanD1-Ad and control RevD1-Ad, respectively.

FIG. 1B shows a 96-well dot-blot of 100 µl of the solubilized residual cell matrix samples and 100 µl of the conditioned medium (presented as duplicate samples). Immunoreactivity was assessed using the anti-D5 mAb A74. Columns 1 and 2 are solubilized residual cell matrix from primary human endothelial cells cultures following 9 days of culture after infection with perlecanD1-Ad and control RevD1-Ad, respectively. Columns 3 and 4 are conditioned medium from primary human endothelial cells cultures following removed following 5 days of culture after infection with perlecanD1-Ad and control RevD1-Ad, respectively. Columns 5 and 6 are conditioned medium from primary human endothelial cells cultures following removed following 6-9 days of culture after infection with perlecanD1-Ad and control RevD1-Ad, respectively.

FIG. 2 shows a Western blot of fibroblast conditioned medium of perlecanD1-Ad and RevD1-Ad infected cells after 8 days of serum-free culture visualized using anti-D1 mAb A71. Lane 1

represents conditioned medium from fibroblast cultures infected with perlecanD1-Ad, and lane 2 represents control conditioned medium from fibroblast cultures infected with the RevD1-Ad. Immunoreactive material in lane 1 extends from 32 kDa to 42 kDa with the dominant band at 35 kDa.

FIG. 3A shows immunoblotting (dot blot) of conditioned medium from perlecan D1-Ad infected primary human endothelial cells using a panel of antibodies that recognize variations of sulfation within heparan sulfate glycosaminoglycan chains and an antibody that recognizes chondroitin sulfate. The 2Q546 anti-heparan sulfate mAbs recognize a highly sulfated heparan sulfate, while the Hep-SS1 antibody recognizes a low sulfated heparin sulfate. The mAb CS56 recognizes chondroitin sulfate. The top row of the dot blot contains a standard heparin sulfate proteoglycan as a control, while the bottom row is conditioned medium from perlecan D1-Ad infected primary human endothelial cells. The primary antibodies used were Hep-SS1 (panel A), 2Q546 (panel B), CS-56 (panel C), and none (panel D).

Fig. 3B shows immunoblotting (dot blot) of conditioned medium from perlecanD1-Ad (top) and RevD1-Ad (bottom) infected primary human endothelial cells after staining using mAB 2Q546.

FIG. 4 shows a Western blot rD1 from conditioned medium after to enzyme degradation 1 mU of heparatinase I (lane 2), which degrades regions of heparan sulfate which have low sulfate density, or with 20 mU of chondroitinase abc (lane 1), which removes chondroitin sulfate chains, or with only buffer (lane 3).

FIG. 5 shows the effect of recombinant perlecan D1 expression on wound healing as evaluated using the acute calvarial wound model. Excised calvarium from mouse 18 days after bilateral osseous defects were created and grafted with a gelatin gel containing HA particles and either perlecanD1-Ad (left side) or control RevD1-Ad (right side). Prior to flap closure, the grafts were covered with a 3 mm diameter barrier membrane (Biomend, a bovine collagen used in guided tissue regeneration).

FIG. 6 shows histological analysis of calvarial bone sections by immunochemistry and Masson's trichrome.

FIG. 7 shows a predicted model of perlecan D1.

DETAILED DESCRIPTION

The present disclosure provides nucleic acid encoding a proteoglycan polypeptide and methods for delivering to the site of a wound or cutaneous injury at least one nucleic acid encoding a proteoglycan polypeptide, such that the expressed polypeptide is decorated by glycosaminoglycan chains through the normal physiological processes of the subject at the site of administration to produce a functional glycated polypeptide for the healing of the wound or other cutaneous injury. In one embodiment, at least one of the one or more polypeptides is a

proteoglycan polypeptide. Furthermore, in one embodiment, such nucleic acid construct may further comprise a sequence sufficient for excretion as described below. The delivered nucleic acid construct is transcribed, translated and post-translationally modified by the addition of glycosaminoglycan chains (referred herein as "decoration" or "glycation") to produce a glycated polypeptide. The glycated polypeptide is then secreted from the cell in which it was produced as directed by a sequence that is sufficient for secretion. During the secretion process, all or a portion of such sequence may be cleaved. After secretion, the glycated polypeptide is available to provide treatment and/or prevention of wounds and/or cutaneous injury. As a result, the polypeptide released is glycated optimally by the normal physiological process of the subject to provide one or more glycosaminoglycan containing polypeptide molecules based on the conditions prevailing at the site of administration in a particular subject.

Approximately 30 proteoglycan polypeptides have been identified with sizes ranging from 10 to >500 kDa and the number of attached glycosaminoglycan chains ranging from 1 to >100. Exemplary proteoglycans are discussed in more detail below. Aggrecan is a large core protein decorated with numerous chondroitin sulfate and keratan sulfate chains (>100) and will likely sequester the most water per molecule of the discussed proteoglycans. Aggrecan is also known to interact with hyaluronic acid in cartilage, providing for the high water content in joints and increasing the osmotic swelling in the joint. The core protein is 225 kDa with 2162 amino acids. After addition of the 130 to more than 200 carbohydrate chains, the molecular weight is considerably higher with highly charged, hydrophilic moieties that could conceivably hold up to 75% of its weight in water. The keratan sulfate chains are generally localized to the N-terminus while the chondroitin sulfate chains are located more in the C-terminus section. Fragments of the aggrecan proteoglycan protein may be advantageously used since their production would be less energetically costly to produce and would still provide the beneficial physiochemical properties without the need for the full length protein.

Versican is a large proteoglycan of about 265 KDa with 12-15 chondroitin sulfate chains attached. This protein is a major component of the dermal layer of skin, and interacts with hyaluronan in the extracellular matrix through N-terminal contacts. Versican also interacts with numerous other signaling molecules through C-terminal contacts. The central domain of versican contains the glycosaminoglycan attachment points, but differential splicing in various tissues leads to a variety of glycosaminoglycan attachments and sulfation patterns, further yielding an assortment of glycosaminoglycan chain interactions with other molecules. In addition, since versican is known to interact with hyaluronan, increased versican production may increase hyaluronan production.

In addition to versican, dermis contains several small leucine-rich proteoglycans (SLRPs) such as decorin, biglycan and lumican. SLRPs seem to play an important role in the regulation of cell activity and in the organization and functional properties of skin connective tissue. A modification of their repartition might be involved in the alterations which occur in skin aging. It was shown that lumican expression decreased during aging whereas decorin expression tended to increase, resulting in a strong alteration of the decorin to lumican ratio. On the other hand, biglycan expression was not modified during aging. Alterations of SLRPs expression could be implicated in the functional impairment which affect aged skin (Vuillermoz, et al., Mol Cell Biochem 277(1-2): 63-72, 2005).

Lumican has a 38 KDa protein core that contains two keratan sulfate GAG attachment sites, and has been shown to affect the integrity of the extracellular matrix and skin structure. For instance, knockout mice that could not express lumican displayed abnormal collagen assembly and brittle skin, suggesting lumican plays a large role in ECM maintenance and in skin health (Wegrowski et al., Mol Cell Biochem 205(1-2): 125-31, 2000; Vuillermoz, et al., Mol Cell Biochem 277(1-2): 63-72, 2005). Periodontal health is also affected by lumican removal due to its interactions with collagen (Matheson, et al., J Periodontal Res 40(4): 312-24, 2005). In addition, Roughley et. al. indicated a role for lumican and other SLRPs in protecting collagen from degradation by collagenases, further suggesting a role for lumican in ECM maintenance and prevention of ECM degradation (Geng, et al., Matrix Biol., 25(8):484-91 2006). Further, Vuillermoz et. al. showed that lumican expression decreased in skin fibroblasts with increased age, suggesting a possible role of lumican in age-related damage to skin. In addition, several studies have suggested that lumican plays a role in corneal health, as decreased or knocked-out lumican expression resulted in poor corneal formation (Chakravarti, Glycoconj J 19(4-5): 287-93, 2002), further supporting a role in collagen fibril formation, but, also, purified lumican has been shown to promote corneal epithelial wound healing (Yeh, et al. Ophthalmol Vis Sci 46(2): 479-86, 2005). Therefore, it is likely that delivery of lumican encoding nucleic acids to skin as described in the present disclosure would facilitate collagen fibril formation and increase the water content due to the charge and hydrophilicity of the glycosaminoglycan chains, thereby increasing skin health and appearance. Other known proteoglycans include syndecans 1-4, glypicans 1-5, betaglycan, NG2/CSPG4, CD44/epican, fibromodulin, PRELP, keratocan, osteoadherin/osteomodulin, epiphycan, osteoglycin/mimecan, neurocan/CSPG3, brevican, bamacan, agrin, and serglycin.

In a first embodiment, the present disclosure provides an isolated nucleic acid molecule encoding one or more proteoglycan polypeptides. Such isolated nucleic acid molecule may be a part of a suitable vector for expression in a target cell of a subject. Alternatively, the isolated

nucleic acid molecules may be delivered as naked nucleic acid. Within the scope of the first embodiment are nucleic acid molecules coding for more than one proteoglycan polypeptide as well as individual nucleic acid molecules, each encoding one or more proteoglycan polypeptides, each being capable of being delivered as a part of a vector or a naked nucleic acid. In a further variation of the first embodiment, the nucleic acid molecules may code for other agents in addition to the proteoglycan polypeptides. In one example, the other agent is a growth factor molecule. The growth factor molecule may be encoded on the same nucleic acid as the proteoglycan polypeptide or on a distinct nucleic acid molecule and delivered together with the nucleic acid encoding the proteoglycan polypeptide. For example, a nucleic acid of the first embodiment may encode for one or more proteoglycan polypeptides and one or more growth factors. When a single nucleic acid codes for more than one proteoglycan polypeptide or one or more proteoglycan polypeptide and other agent, the nucleic acid may be polycistronic with the appropriate regulator elements required for transcription and translation of each encoded element.

In a second embodiment, the present disclosure provides for a composition comprising one or more of the nucleic acids of the first embodiment.

In a third embodiment, the present disclosure provides for a composition consisting essentially of one or more of the nucleic acids of the first embodiment.

In a fourth embodiment, the present disclosure provides for a composition consisting of one or more of the nucleic acids of the first embodiment.

The compositions of the second through fourth embodiments may be pharmaceutical compositions and may further contain a pharmaceutically acceptable carrier and/or accessory agents. Such compositions may be used in the treatment and prevention methods of the fifth and sixth embodiments.

In a fifth embodiment, the present disclosure describes a method for the effective treatment of a wound or a cutaneous injury in a subject in need of such treatment by administering to a site of the wound or cutaneous injury a composition or nucleic acid of the present disclosure, such as, but not limited to, the nucleic acid described in the first embodiment or the compositions described in the second through fourth embodiments above. Such administration to the site may be achieved by local administration or systemic administration. The at least one nucleic acid molecule encoding one or more proteoglycan polypeptides may be delivered using a vector or as naked nucleic acid, or other methods as are known in the art. In such treatment methods encompassed by the fifth embodiment, the nucleic acid or composition is administered so as to deliver a therapeutically effective amount of the nucleic acid encoding one or more proteoglycan polypeptides to treat the wound or cutaneous injury.

In a sixth embodiment, the present disclosure describes a method for the effective prevention of a cutaneous injury in a subject in need of such prevention by the administering to a site where it is desired to prevent such cutaneous injury a composition of the present disclosure, such as, but not limited to, the nucleic acid described in the first embodiment or the compositions described in the second through fourth embodiments above. Such administration to the site may be achieved by local administration or systemic administration. The at least one nucleic acid molecule encoding one or more proteoglycan polypeptides may be delivered using a vector or as naked nucleic acid, or other methods as are known in the art. In such prevention methods encompassed by the sixth embodiment, the nucleic acid or composition is administered so as to deliver a therapeutically effective amount of the nucleic acid encoding one or more proteoglycan polypeptides to prevent the cutaneous injury.

In the treatment and prevention methods of the fifth and sixth embodiments, the delivery of the at least one isolated nucleic acid molecule encoding one or more proteoglycan polypeptides allows the normal physiological processes of the subject at the site of administration to decorate the proteoglycan polypeptides with the appropriate glycosaminoglycan chains and release the glycated proteoglycan polypeptides from the cell. Because the glycation of the proteoglycan polypeptide with glycosaminoglycan elements proceeds in a differential manner depending on the site of the wound or cutaneous injury and/or the physiological environment at a particular site (which may change over time as a result of different environmental stressors, physiological process occurring at the site and/or the nature of the wound or cutaneous injury), the nature of the fully decorated proteoglycan molecule may change over time. The treatment and prevention methods of the fifth and sixth embodiments allows for the optimal glycosaminoglycan modification (i.e., glycation) to occur, resulting in one or more glycosaminoglycans with variations, such as, but not limited to, the extent of sulfation and the chain length of the glycosaminoglycan elements, that are optimal based on the conditions prevailing at the site of administration in a particular subject. Therefore, the specific nature of the expressed proteoglycan polypeptide is dictated by the normal physiological process of the subject at a particular time in response to a particular need (such as, but not limited to, wound healing or cutaneous injury).

Therefore, those methods of the prior art that apply a pre-manufactured proteoglycan molecule to the site of a wound or cutaneous injury may produce no or unsatisfactory results. Furthermore, delivery of the fully decorated proteoglycan molecules through the layers of the skin is difficult due to the size and charged nature of the proteoglycan molecules. Also, the likelihood of nucleic acid expression in the deeper layers of the skin has been demonstrated,

which is a significant improvement upon the penetration of pre-synthesized, exogenous proteoglycans applied to the skin in current cosmetic formulations.

In addition, using the treatment and prevention methods of the fifth and sixth embodiments, the delivery of at least one nucleic acid molecule encoding one or more proteoglycan polypeptides provides for an extended production of decorated proteoglycan molecules as described above as the delivered nucleic acid molecules will have a particular half-life in the subject. Another important aspect of the present disclosure, that is also a significant difference and improvement upon the current state of the art, lies in the fact that delivery of recombinant nucleic acid encoding proteoglycans for treatment and prevention of wounds and cutaneous injury will result in extended production of the recombinant proteoglycan polypeptide for several days, until expression dwindles and another application of the invention would be required for further expression.

When using the nucleic acids, compositions and/or methods of the first through sixth embodiments, a number of advantages are obtained. As discussed above, the methods of the present disclosure provide for the delivery of at least one nucleic acid molecule encoding one or more proteoglycan polypeptides, thereby allowing the normal physiological processes of the subject at the site of administration to glycate the expressed proteoglycan polypeptides with the appropriate glycosaminoglycan chains and release the decorated proteoglycan polypeptides from the cell. Therefore, the proteoglycan polypeptide released is synthesized by the normal physiological process of the subject to provide one or more proteoglycan polypeptides that are optimal based on the conditions prevailing at the site of administration in a particular subject. Such an application is not possible when administering pre-synthesized proteoglycan molecules. Furthermore, as the features of the proteoglycan core molecules that dictate the number and nature of glycosaminoglycan molecules are not completely understood, modification of a particular pre-synthesized proteoglycan molecule for a particular physiological requirement is not possible given the state of the art.

In addition, the delivery of at least one nucleic acid molecule encoding one or more proteoglycan polypeptides by the methods disclosed allows the ultimately produced proteoglycan molecules to be produced in a wider number of cell types. The methods of the present disclosure allow the proteoglycan polypeptides to be expressed at virtually any desired location.

Furthermore, using the methods of the present disclosure, an extended production of the desired proteoglycan molecules is realized since the at least one nucleic acid molecule encoding a proteoglycan polypeptide will allow for production of multiple proteoglycan polypeptides over time. Such advantages are impossible to realize using pre-synthesized proteoglycan molecules.

Definitions

As used herein, the terms "prevent", "preventing", "prevention", "suppress", "suppressing" and suppression as used herein refer to administering a nucleic acid or composition of the present disclosure prior to the onset of cutaneous injury so as to prevent any symptom, aspect or characteristic of the cutaneous injury. Such preventing and suppressing need not be absolute to be useful.

As used herein, the terms "treat", "treating" and treatment as used herein refers to administering a nucleic acid or composition of the present disclosure after the onset of cutaneous injury or appearance of a wound so as to reduce or eliminate any symptom, aspect or characteristic of the cutaneous injury or condition associated with the wound. In one embodiment, the treatment provides healing of the wound or cutaneous injury. Such treating need not be absolute to be useful.

As used herein, the term "in need of treatment" as used herein refers to a judgment made by a caregiver that a patient requires or will benefit from treatment. This judgment is made based on a variety of factors that are in the realm of a caregiver's expertise.

As used herein, the term "in need of prevention" as used herein refers to a judgment made by a caregiver that a patient requires or will benefit from prevention. This judgment is made based on a variety of factors that are in the realm of a caregiver's expertise.

As used herein, the terms "subject", "individual" or "patient" as used herein refers to any animal, including mammals, such as, but not limited to, mice, rats, other rodents, rabbits, dogs, cats, swine, cattle, sheep, horses, or primates, or humans. The term may specify male or female or both, or exclude male or female.

As used herein, the term "therapeutically effective amount", in reference to the treating, preventing or suppressing of a disease state/condition, refers to an amount of a compound either alone or as contained in a pharmaceutical composition that is capable of having any detectable, positive effect on any symptom, aspect, or characteristics of the disease state/condition. Such effect need not be absolute to be beneficial.

As used herein, the term "glycosaminoglycan" is meant to be broadly defined and includes known and, as yet, unknown glycosaminoglycans; exemplary glycosaminoglycans include, but are not limited to, hyaluronic acid, chondroitin sulfates, heparan sulfate, dermatan sulfate and keratan sulfate.

As used herein, the term "vector" means any mechanism for the transfer of a nucleic acid into a host cell of a subject. The term vector includes both viral and non-viral mechanisms for introducing the nucleic acid into a cell of a subject in vitro, ex vivo, or in vivo. Non-viral vectors include but are not limited to plasmids, liposomes, electrically charged lipids (such as cytofectins), DNA-protein complexes, and biopolymers. Viral vectors include but are not limited

to vectors derived from adenoviral vectors, retroviral vectors, lentiviral vectors, bovine papilloma viruses, Epstein-Barr virus, adeno-associated viruses, pox viruses, baculovirus, vaccinia virus, herpes simplex virus, and hybrids of two or more viral vector types. A vector may contain regulatory sequences required for expression of the nucleic acid encoding at least one proteoglycan polypeptide, such as, but not limited to, promoters and the like. The regulatory sequences may be optimized based on a particular cell type or tissue. In addition, a vector may contain one or more regulatory regions, and/or selectable markers useful in selecting, measuring, and monitoring nucleic acid transfer results (transfer to which cells, duration of expression, etc.).

As used herein, the term "secreted" or "secretion" refers to the release, export or excretion of a polypeptide from a cell.

As used herein, the terms "nucleic acid encoding a proteoglycan polypeptide" or "nucleic acid encoding one or more proteoglycan polypeptides" refers to a nucleic acid construct that comprises a first nucleic acid sequence encoding a sequence that is sufficient for secretion and a second nucleic acid sequence encoding one or more polypeptides having one or more sequences for the attachment of a glycosaminoglycan chain and lacking a transmembrane domain (or like domain). Alternatively, the term "nucleic acid encoding a proteoglycan polypeptide" or "nucleic acid encoding one or more proteoglycan polypeptides" may refer to a nucleic acid construct that consists essentially of or consists of the first and second nucleic acid sequences. When required, the described nucleic acid sequences may also comprise, consist essentially of or consist of a third, fourth, fifth etc nucleic acid sequences encoding one or more additional agents (such as but not limited to one or more growth factors).

As stated above, the nucleic acid encoding a proteoglycan polypeptide includes a first nucleic acid sequence encoding a sequence sufficient for secretion. Such sequences sufficient for secretion include, but are not limited to, leader sequences, export sequences, signal peptide signal sequences and other sequences that direct the secretion of a protein or polypeptide from a cell (collectively referred to as a signal sequence). The signal sequence usually contains 13-36 amino acids, which are predominantly hydrophobic in nature. The signal sequence is recognized by a multi-protein complex termed the signal recognition particle (SRP). This signal sequence is removed, at least partially, following passage through the endoplasmic reticulum membrane.

Any such signal sequence known in the art may be used as the signal sufficient for secretion. The sequence sufficient for secretion may be normally associated with the proteoglycan polypeptide in the subject or may be a recombinant or heterologous sequence not normally associated with that proteoglycan polypeptide in the subject. In a particular embodiment, the sequence sufficient for secretion is derived from the perlecan nucleic acid sequence and is as follows: atggggtggcgggcgccgggcgcgctgctggcgctgctgctg (SEQ ID NO: 27).

Other sequences sufficient for secretion are known to those of ordinary skill in the art. All or a part of the translated sequence sufficient for secretion may be removed during the secretion process.

In one embodiment, the proteoglycan polypeptide having one or more sequences for the attachment of a glycosaminoglycan chain is a polypeptide designed by the mind of man and the second nucleic acid sequence encodes such polypeptide; such a polypeptide may be a combination of segments from 1 or more naturally occurring proteoglycan polypeptides. Such a polypeptide may be designed to have particularly desired property/properties. In an additional embodiment, the polypeptide having one or more sequences for the attachment of a glycosaminoglycan chain is a proteoglycan polypeptide and the second nucleic acid sequence encodes one or more proteoglycan polypeptides. The term "proteoglycan polypeptide" is meant to be broadly defined and includes known and, as yet, unknown proteoglycans, proteoglycans created de novo and fragments of the foregoing, provided such proteoglycans created de novo, and fragments have at least one glycosaminoglycan chain. Therefore, the proteoglycan polypeptide may be a full length proteoglycan protein, or a fragment thereof that is naturally occurring. Exemplary proteoglycan proteins include, but are not limited to, aggrecan, versican, lumican, syndecan 1-4, glypican 1- 5, betaglycan, NG2/CSPG4, CD44/Epican, fibromodulin, PRELP, keratocan, osteoadherin/osteomodulin, epiphycan, osteoglycin/mimecan, neurocan/CSPG3, brevican, bamacan, agrin and serglycin. The nucleic acid sequences for such proteoglycans are provided in SEQ ID NOS: 1-26, respectively. In one embodiment, such proteoglycan polypeptide does not include decorin or biglycan. In an alternate embodiment, such proteoglycan polypeptide does not include perlecan. The term "fragment"" is meant to refer to any nucleic acid comprising at least 30 contiguous nucleic acid residues, provided that such fragment encodes for at least one site for glycosaminoglycan attachment. The nucleic acid encoding a proteoglycan polypeptide may be natural and synthetic. In an alternate embodiment, the second nucleic acid sequence is chimeric and contains nucleic acid encoding portions from more than one proteoglycan protein.

In a further embodiment, the second nucleic acid sequence can vary from the nucleic acid encoding the naturally occurring proteoglycan protein of fragment thereof, provided that the modified nucleic acid encodes a protein or polypeptide that functions to effect the healing of a wound or cutaneous injury as the naturally occurring proteoglycan protein or fragment thereof. These altered sequences include those caused by point mutations (referred to herein as mutants), those due to the degeneracies of the genetic code (referred to herein as degenerate variants) or naturally occurring allelic variants (referred to herein as allelic variants), and further modifications that have been introduced by genetic engineering (referred to herein as variants).

A variant or mutant includes, but is not limited to, those species engineered to have more or less sites for glycosaminoglycan attachment. The activity of the protein or polypeptide encoding such mutants, degenerate variants, allelic variants and variants may be assessed by the methods disclosed herein and as known in the art. All such modifications to the nucleic acid coding for a proteoglycan polypeptide are encompassed by this disclosure.

Techniques for introducing changes in a nucleic acid coding for a proteoglycan polypeptide such that the expressed proteoglycan polypeptide is different from a naturally occurring proteoglycan protein or fragment thereof are well known in the art. Such modifications include the deletion, insertion or substitution of bases which result in changes in the amino acid sequence. Changes may be made to increase the activity, to increase its biological stability or half-life, to change its glycosylation pattern, confer temperature sensitivity or to alter the expression pattern and the like.

In the present disclosure, the delivery of the glycosaminoglycan chains to the site of a wound or cutaneous injury may be desired. As such the exact structure of the protein/polypeptide may not be as critical as in other applications (such as receptor binding and the like). Therefore, the present disclosure contemplates that the various changes may be made in the nucleic acid encoding a proteoglycan polypeptide without appreciable loss of the ability of the expressed polypeptide to effectively deliver the glycosaminoglycan chains to the site of a wound or cutaneous injury and as such the modifications to the nucleic acid encoding a proteoglycan polypeptide are within the scope of the disclosure. In one embodiment, the site of glycosaminoglycan attachment is not altered.

Conservative substitutions of amino acids are well-known and may be made generally without altering the biological activity of the resulting protein or polypeptide. For example, such conservative substitutions are generally made by interchanging within the groups of polar residues, charged residues, hydrophobic residues, small residues, and the like. For example, certain amino acids may be substituted for other amino acids in a protein/polypeptide structure without appreciable alteration of the protein/polypeptide structure. In making such changes, the hydropathic index of amino acids may be considered. The importance of the hydropathic amino acid index in conferring interactive biologic function on a protein is generally understood in the art (Kyte and Doolittle, 1982, incorporated herein by reference). It is accepted that the relative hydropathic character of the amino acid contributes to the secondary structure of the resultant protein/polypeptide, which in part defines the activity of the protein/polypeptide.

Each amino acid has been assigned a hydropathic index on the basis of its hydrophobicity and charge characteristics (Kyte and Doolittle, 1982) as follows: isoleucine (+4.5); valine (+4.2); leucine (+3.8); phenylalanine (+2.8); cysteine/cystine (+2.5); methionine (+1.9); alanine (+1.8);

glycine (-0.4); threonine (-0.7); serine (-0.8); tryptophan (-0.9); tyrosine (-1.3); proline (-1.6); histidine (-3.2); glutamate (-3.5); glutamine (-3.5); aspartate (-3.5); asparagine (-3.5); lysine (-3.9); and arginine (-4.5).

It is known in the art that certain amino acids may be substituted by other amino acids having a similar hydropathic index or score and still result in a protein/polypeptide with similar structure and/or biological activity. In making such changes, the hydropathic indices of the substituted amino acids are within +/- 2, +/- 1 or +/- 0.5.

It is also understood in the art that the substitution of like amino acids can be made effectively on the basis of hydrophilicity. U.S. Pat. No. 4,554,101 states that the greatest local average hydrophilicity of a protein, as governed by the hydrophilicity of its adjacent amino acids, correlates with a biological property of a protein/polypeptide. The following hydrophilicity values have been assigned to amino acid residues: arginine (+3.0); lysine (+3.0); aspartate (+3.0.+-.1); glutamate (+3.0.+-.1); serine (.+-.0.3); asparagine (+0.2); glutamine (+0.2) glycine (0); threonine (-0.4); proline (-0.5.+-.1); alanine (-0.5); histidine (-0.5); cysteine (-1.0); methionine (-1.3); valine (-1.5); leucine (-1.8); isoleucine (-1.8); tyrosine (-2.3); phenylalanine (-2.5); tryptophan (-3.4).

It is understood that an amino acid can be substituted for another having a similar hydrophilicity value and still result in a protein/polypeptide with similar structure and/or biological activity. In making such changes, the hydrophilicity values of the substituted amino acids are within +/- 2, +/- 1 or +/- 0.5.

As outlined above, amino acid substitutions are generally therefore based on the relative similarity of the amino acid side-chain substituents, for example, their hydrophobicity, hydrophilicity, charge, size, and the like. Exemplary substitutions which take various of the foregoing characteristics into consideration are well known to those of skill in the art and include: arginine and lysine; glutamate and aspartate; serine and threonine; glutamine and asparagine; and valine, leucine and isoleucine.

As discussed herein the nucleic acid encoding a proteoglycan polypeptide may further comprise a nucleic acid sequence encoding at least one additional agent, such as a growth factor or fragment thereof. Alternatively, a second nucleic acid construct may be provided encoding at least one additional agent, such as a growth factor or fragment thereof. The growth factors or fragments thereof may be selected based on their ability to bind a glycosaminoglycan chain, such as a heparin sulfate chain. Alternatively, such growth factors or fragments thereof may be selected on their ability to aid in prevention or treatment of a wound or a cutaneous injury. Exemplary growth factors include, but are not limited to, fibroblast growth factor, keratinocyte growth factor, transforming growth factor-B, hepatocyte growth factor, vascular endothelial

growth factor, platelet-derived growth factor, epidermal growth factor, insulin-like growth factor, bone morphogenic protein and granulocyte-macrophage colony stimulating factor. In a specific embodiment, the growth factor is a member of the fibroblast growth factor family, such as fibroblast growth factor 2 or 7. The nucleic acid may also code for mutants, degenerate variants, allelic variants and variants of the described growth factors (as such terms are defined above). The teachings of the present disclosure regarding the substitution of amino acids are equally applicable here.

The nucleic encoding a proteoglycan polypeptide and other nucleic acid sequences disclosed herein may optionally contain and be operatively associated with one or more sequences necessary or desirable for expression. Alternatively, the nucleic acid encoding a proteoglycan polypeptide and other nucleic acid sequences disclosed herein may be a part of a vector as described herein and the vector may contain such sequences. Such sequences include, but are not limited to, a promoter, enhancer, transcription factor binding site and other gene expression regulatory sequences (referred to collectively as "expression elements"). The expression elements of these vectors may vary in their strength and specificity. Depending on the host and/or vector utilized, any one of a number of suitable expression elements may be used. The expression elements may be normally associated with the nucleic acid in the subject. Alternatively, the expression elements may be recombinant or heterologous elements that are not normally associated with that nucleic acid in the subject. In any event, the expression element(s) is/are "operably linked" to the nucleic acid, which refers to the situation of an expression element in such a manner as to influence the expression of the proteoglycan polypeptide from the nucleic acid encoding the proteoglycan polypeptide. Examples are: tissue specific expression elements, including distinct promoter and enhancer sequences that are derived from different sources and engineered to produce an expression element to regulate the expression of the transferred DNA in specific cell types. Expression elements isolated from the genome of viruses that grow in mammalian cells, (e.g., RSV, vaccinia virus 7.5K, SV40, HSV, adenoviruses MLP, MMTV LTR and CMV promoters) may be used, as well as promoters produced by recombinant DNA or synthetic techniques.

In some instances, the expression elements may be constitutive or inducible and can be used under the appropriate conditions to direct high level or regulated expression of the nucleic acid encoding a proteoglycan polypeptide. Specific initiation signals are also required for sufficient translation of the nucleic acid encoding a proteoglycan polypeptide. These signals include, but are not limited to, the ATG initiation codon and adjacent sequences. In cases where the entire coding sequence of a proteoglycan protein, including the initiation codon and adjacent sequences, are used (either alone or in combination with a vector), no additional translational

control signals may be needed. However, in cases where only a portion of the coding sequence of a proteoglycan protein (such as a fragment or a synthesized nucleic acid) is used, exogenous translational control signals, including, but not limited to, the ATG initiation codon may be provided. Furthermore, the initiation codon must be in phase with the reading frame of the coding sequences to ensure translation of the entire insert. These exogenous translational control signals and initiation codons can be of a variety of origins, both natural and synthetic. The efficiency and control of expression may be enhanced by the inclusion of transcription attenuation sequences, enhancer elements, and the like.

As used herein, the term "proteoglycan polypeptide" refers to a polypeptide expressed from a nucleic acid encoding a proteoglycan polypeptide that is secreted from a cell where said proteoglycan polypeptide is produced; as such a proteoglycan polypeptide has one or more attached glycosaminoglycan chains. The proteoglycan polypeptide may be a full length proteoglycan protein, or a fragment thereof. A proteoglycan polypeptide may contain one or more than one attached glycosaminoglycan chains; furthermore, it should be noted that the nature, identity and number of attached glycosaminoglycan chains can vary, even for the same proteoglycan polypeptide, depending on the post-translational glycation of the proteoglycan by the subject.

Compositions

Useful compositions comprising the nucleic acids of the present disclosure may be formulated according to methods known in the art. In one embodiment, such compositions are pharmaceutical compositions. The compositions disclosed may comprise one or more of the nucleic acids of the present disclosure, such as those nucleic acids of the first embodiment, in combination with a pharmaceutically acceptable carrier. Examples of such carriers and methods of formulation may be found in Remington: The Science and Practice of Pharmacy (20^{th} Ed., Lippincott, Williams & Wilkins, Daniel Limmer, editor). To form a pharmaceutically acceptable composition suitable for effective administration, such compositions will contain an effective amount of disclosed proteoglycan nucleic acid, and other protein, nucleic acid, or modulator compounds. The nucleic acid molecules may be used in combination with a suitable vector as described herein and the described compositions may comprise such vector.

The pharmaceutical compositions of the disclosure may be used in the treatment and prevention methods of the present disclosure. Such compositions are administered to a subject in amounts sufficient to deliver a therapeutically effective amount of the contained nucleic acids so as to be effective in the treatment and prevention methods disclosed herein. The therapeutically effective amount may vary according to a variety of factors such as, but not limited to, the

subject's condition, weight, sex and age. Other factors include the mode and site of administration. The pharmaceutical compositions may be provided to the subject in any method known in the art. Exemplary routes of administration include, but are not limited to, subcutaneous, intravenous, topical, epicutaneous, oral, intraosseous, and intramuscular. The compositions of the present disclosure may be administered only one time to the subject or more than one time to the subject. Furthermore, when the compositions are administered to the subject more than once, a variety of regimens may be used, such as, but not limited to, one per day, once per week, once per month or once per year. The compositions may also be administered to the subject more than one time per day. The therapeutically effective amount of the nucleic acid molecules and appropriate dosing regimens may be identified by routine testing in order to obtain optimal activity, while minimizing any potential side effects. In addition, co-administration or sequential administration of other agents may be desirable.

The compositions of the present disclosure may be administered systemically, such as by intravenous administration, or locally such as by subcutaneous injection or by application of a paste or cream. The production of proteoglycan polypeptides by the cells may be verified by sampling the tissues and measuring expression by conventional means, such as Northern blotting or Western blotting.

The compositions of the present disclosure may further comprise agents which improve the solubility, half-life, absorption, etc. of the nucleic acid molecules or the proteoglycan peptide molecules, either before or after secretion. Furthermore, the compositions of the present disclosure may further comprise agents that attenuate undesirable side effects and/or or decrease the toxicity of the nucleic acid molecules or produced proteoglycan peptides. Examples of such agents are described in a variety of texts, such a, but not limited to, Remington: The Science and Practice of Pharmacy (20th Ed., Lippincott, Williams & Wilkins, Daniel Limmer, editor).

The compositions of the present disclosure can be administered in a wide variety of dosage forms for administration. For example, the compositions can be administered in forms, such as, but not limited to, tablets, capsules, sachets, lozenges, troches, pills, powders, granules, elixirs, tinctures, solutions, suspensions, elixirs, syrups, ointments, creams, pastes, emulsions, or solutions for intravenous administration or injection. Other dosage forms include administration transdermally, via patch mechanism or ointment. Any of the foregoing may be modified to provide for timed release and/or sustained release formulations.

In the present disclosure, the pharmaceutical compositions contain at least one nucleic acid molecule encoding one or more proteoglycan polypeptides as an active ingredient, and are typically administered with a pharmaceutically acceptable carrier. The nucleic acid molecule may be administered with or as a part of a vector of the present disclosure. Such

pharmaceutically acceptable carriers include, but are not limited to, vehicles, adjuvants, surfactants, suspending agents, emulsifying agents, inert fillers, diluents, excipients, wetting agents, binders, lubricants, buffering agents, disintegrating agents and carriers, as well as accessory agents, such as, but not limited to, coloring agents and flavoring agents (collectively referred to herein as a carrier). Typically, the pharmaceutically acceptable carrier is chemically inert to the active compounds and has no detrimental side effects or toxicity under the conditions of use. The pharmaceutically acceptable carriers can include polymers and polymer matrices. The nature of the pharmaceutically acceptable carrier may differ depending on the particular dosage form employed and other characteristics of the composition.

For instance, for oral administration in solid form, such as but not limited to, tablets, capsules, sachets, lozenges, troches, pills, powders, or granules, the nucleic acid molecules of the present disclosure may be combined with an oral, non-toxic pharmaceutically acceptable inert carrier, such as, but not limited to, inert fillers, suitable binders, lubricants, disintegrating agents and accessory agents. Suitable binders include, without limitation, starch, gelatin, natural sugars such as glucose or beta-lactose, corn sweeteners, natural and synthetic gums such as acacia, tragacanth or sodium alginate, carboxymethylcellulose, polyethylene glycol, waxes and the like. Lubricants used in these dosage forms include, without limitation, sodium oleate, sodium stearate, magnesium stearate, sodium benzoate, sodium acetate, and the like. Disintegrators include, without limitation, starch, methyl cellulose, agar, bentonite, xanthum gum and the like. Tablet forms can include one or more of the following: lactose, sucrose, mannitol, corn starch, potato starch, alginic acid, microcrystalline cellulose, acacia, gelatin, guar gum, colloidal silicon dioxide, croscarmellose sodium, talc, magnesium stearate, calcium stearate, zinc stearate, stearic acid as well as the other carriers described herein. Lozenge forms can comprise the active ingredient in a flavor, usually sucrose and acacia or tragacanth, as well as pastilles comprising the active ingredient in an inert base, such as gelatin and glycerin, or sucrose and acadia, emulsions, and gels containing, in addition to the active ingredient, such carriers as are known in the art.

For oral liquid forms, such as but not limited to, tinctures, solutions, suspensions, elixirs, syrups, the nucleic acid molecules of the present disclosure can be dissolved in diluents, such as water, saline, or alcohols. Furthermore, the oral liquid forms may comprise suitably flavored suspending or dispersing agents such as the synthetic and natural gums, for example, tragacanth, acacia, methylcellulose and the like. Moreover, when desired or necessary, suitable and coloring agents or other accessory agents can also be incorporated into the mixture. Other dispersing agents that may be employed include glycerin and the like.

Formulations suitable for parenteral administration include aqueous and non-aqueous, isotonic sterile injection solutions, which can contain anti-oxidants, buffers, bacteriostats, and

solutes that render the formulation isotonic with the blood of the patient, and aqueous and non-aqueous sterile suspensions that can include suspending agents, solubilizers, thickening agents, stabilizers, and preservatives. The nucleic acid molecules of the present disclosure can be administered in a physiologically acceptable diluent, such as a sterile liquid or mixture of liquids, including water, saline, aqueous dextrose and related sugar solutions, an alcohol, such as ethanol, isopropanol, or hexadecyl alcohol, glycols, such as propylene glycol or polyethylene glycol such as poly(ethyleneglycol) 400, glycerol ketals, such as 2,2-dimethyl-1,3-dioxolane-4-methanol, ethers, an oil, a fatty acid, a fatty acid ester or glyceride, or an acetylated fatty acid glyceride with or without the addition of a pharmaceutically acceptable surfactant, such as, but not limited to, a soap, an oil or a detergent, suspending agent, such as, but not limited to, pectin, carbomers, methylcellulose, hydroxypropylmethylcellulose, or carboxymethylcellulose, or emulsifying agents and other pharmaceutical adjuvants.

Oils, which can be used in parenteral formulations, include petroleum, animal, vegetable, or synthetic oils. Specific examples of oils include peanut, soybean, sesame, cottonseed, corn, olive, petrolatum, and mineral. Suitable fatty acids for use in parenteral formulations include polyethylene sorbitan fatty acid esters, such as sorbitan monooleate and the high molecular weight adducts of ethylene oxide with a hydrophobic base, formed by the condensation of propylene oxide with propylene glycol, oleic acid, stearic acid, and isostearic acid. Ethyl oleate and isopropyl myristate are examples of suitable fatty acid esters. Suitable soaps for use in parenteral formulations include fatty alkali metal, ammonium, and triethanolamine salts, and suitable detergents include (a) cationic detergents such as, for example, dimethyldialkylammonium halides, and alkylpyridinium halides, (b) anionic detergents such as, for example, alkyl, aryl, and olefin sulfonates, alkyl, olefin, ether, and monoglyceride sulfates, and sulfosuccinates, (c) nonionic detergents such as, for example, fatty amine oxides, fatty acid alkanolamides, and polyoxyethylene polypropylene copolymers, (d) amphoteric detergents such as, for example, alkylbeta-aminopropionates, and 2-alkylimidazoline quaternary ammonium salts, and (e) mixtures thereof.

Suitable preservatives and buffers can be used in such formulations. In order to minimize or eliminate irritation at the site of injection, such compositions may contain one or more nonionic surfactants having a hydrophile-lipophile balance (HLB) of from about 12 to about 17. The quantity of surfactant in such formulations ranges from about 5% to about 15% by weight.

Topical dosage forms, such as, but not limited to, ointments, creams, pastes, emulsions, containing the nucleic acid molecule of the present disclosure, can be admixed with a variety of carrier materials well known in the art, such as, e.g., alcohols, aloe vera gel, allantoin, glycerine, vitamin A and E oils, mineral oil, PPG2 myristyl propionate, and the like, to form alcoholic

solutions, topical cleansers, cleansing creams, skin gels, skin lotions, and shampoos in cream or gel formulations. Inclusion of a skin exfoliant or dermal abrasive preparation may also be used. Such topical preparations may be applied to a patch, bandage or dressing for transdermal delivery or may be applied to a bandage or dressing for delivery directly to the site of a wound or cutaneous injury.

The compounds of the present disclosure can also be administered in the form of liposome delivery systems, such as small unilamellar vesicles, large unilamellar vesicles and multilamellar vesicles. Liposomes can be formed from a variety of phospholipids, such as cholesterol, stearylamine or phosphatidylcholines. Such liposomes may also contain monoclonal antibodies to direct delivery of the liposome to a particular cell type or group of cell types.

The compounds of the present disclosure may also be coupled with soluble polymers as targetable drug carriers. Such polymers can include, but are not limited to, polyvinyl-pyrrolidone, pyran copolymer, polyhydroxypropylmethacryl-amidephenol, polyhydroxyethylaspartamidephenol, or polyethyl-eneoxidepolylysine substituted with palmitoyl residues. Furthermore, the compounds of the present invention may be coupled to a class of biodegradable polymers useful in achieving controlled release of a drug, for example, polylactic acid, polyepsilon caprolactone, polyhydroxy butyric acid, polyorthoesters, polyacetals, polydihydro-pyrans, polycyanoacrylates and cross-linked or amphipathic block copolymers of hydrogels.

Methods of Treatment and Prevention

In one embodiment, the teachings of the present disclosure provide for the use of the nucleic acids and compositions of the present disclosure in a method of treating a wound or cutaneous injury. The method of treatment comprises the steps of providing such nucleic acid or composition containing such nucleic acid and administering the same in a therapeutically effective amount to effectively treat the wound or cutaneous injury in a subject in need of such treatment.

In one embodiment, the teachings of the present disclosure provide for use of such nucleic acids and compositions in a method of preventing a wound or cutaneous injury. The method of preventing or suppressing comprises the steps of providing such nucleic acid or composition containing such nucleic acid and administering the same in a therapeutically effective amount to effectively prevent the wound or cutaneous injury in a subject in need of such prevention.

Nucleic acid delivery methods

A variety of methods are currently known to enable delivery of the nucleic acid molecules of the present disclosure to a target cell in a subject. Any such methods may be used. It has long been an accepted idea that nucleic acid molecules can not be delivered across the stratum

corneum. However, studies in the last 10 years have shown that plasmid DNA can be delivered across the skin barrier and cause measurable protein expression through the use of a variety of lipid vesicles (Raghavachari, et al., J Pharm Sci 91(3): 615-22, 2002; Patil, et al., Aaps J 7(1): E61-77, 2005). In addition, virus incorporating the DNA of choice successfully transfects cells of many different tissue types and expresses the desired polypeptide (Patil, et al., Aaps J 7(1): E61-77, 2005). Viral infection of skin cells has been successful by subcutaneous injection (Setoguchi, et al., J Invest Dermatol 102(4): 415-21, 1994), through the use of gene guns or pressure delivery devices (Gaffal, et al., Eur J Cell Biol. , e-publication, Aug 21 2006), and by direct application after light abrasion (Shi, et al., J Virol 75(23): 11474-82, 2001). Delivery of nucleic acids through the stratum corneum has recently become a feasible and viable method for numerous therapies and vaccination techniques. These techniques are discussed to demonstrate applicability of the present invention.

The present disclosure envisions the delivery of the nucleic acid molecules of the present disclosure to living cells in a subject, such as, but not limited to, the cells of the epithelium. Such cell types include, but are not limited to, epidermal keratinocyte (differentiating epidermal cell), epidermal basal cell (stem cell), keratinocyte of fingernails and toenails, nail bed basal cell (stem cell), medullary hair shaft cell, cortical hair shaft cell, cuticular hair shaft cell, cuticular hair root sheath cell, hair root sheath cell of Huxley's layer, hair root sheath cell of Henle's layer, external hair root sheath cell, hair matrix cell (stem cell), prokaryotic cell (bacteria), eukaryotic cells (plant and animal cell), surface epithelial cell of stratified squamous epithelium of cornea, tongue, oral cavity, esophagus, anal canal, distal urethra and vagina, basal cell (stem cell) of epithelia of cornea, tongue, oral cavity, esophagus, anal canal, distal urethra and vagina, urinary epithelium cell (lining urinary bladder and urinary ducts), salivary gland mucous cell (polysaccharide-rich secretion), salivary gland serous cell (glycoprotein enzyme-rich secretion), Von Ebner's gland cell in tongue (washes taste buds), mammary gland cell (milk secretion), lacrimal gland cell (tear secretion), ceruminous gland cell in ear (wax secretion), eccrine sweat gland dark cell (glycoprotein secretion), eccrine sweat gland clear cell (small molecule secretion), apocrine sweat gland cell (odoriferous secretion, sex-hormone sensitive), gland of Moll cell in eyelid (specialized sweat gland), sebaceous gland cell (lipid-rich sebum secretion), Bowman's gland cell in nose (washes olfactory epithelium), Brunner's gland cell in duodenum (enzymes and alkaline mucus), seminal vesicle cell (secretes seminal fluid components, including fructose for swimming sperm), prostate gland cell (secretes seminal fluid components), bulbourethral gland cell (mucus secretion), Bartholin's gland cell (vaginal lubricant secretion), gland of Littre cell (mucus secretion), uterus endometrium cell (carbohydrate secretion), isolated goblet cell of respiratory and digestive tracts (mucus secretion), stomach lining mucous cell (mucus secretion), gastric

gland zymogenic cell (pepsinogen secretion), gastric gland oxyntic cell (hydrochloric acid secretion), pancreatic acinar cell (bicarbonate and digestive enzyme secretion), paneth cell of small intestine (lysozyme secretion), type II pneumocyte of lung (surfactant secretion), Clara cell of lung, anterior pituitary cells, somatotropes, lactotropes, thyrotropes, gonadotropes, corticotropes, intermediate pituitary cell, secreting melanocyte-stimulating hormone, magnocellular neurosecretory cells, secreting oxytocin, secreting vasopressin, gut and respiratory tract cells secreting serotonin, secreting endorphin, secreting somatostatin, secreting gastrin, secreting secretin, secreting cholecystokinin, secreting insulin, secreting glucagon, secreting bombesin, thyroid gland cells, thyroid epithelial cell, parafollicular cell, parathyroid gland cells, parathyroid chief cell, oxyphil cell, adrenal gland cells, chromaffin cells, secreting steroid hormones (mineralcorticoids and glucocorticoids), Leydig cell of testes secreting testosterone, theca interna cell of ovarian follicle secreting estrogen, corpus luteum cell of ruptured ovarian follicle secreting progesterone, kidney juxtaglomerular apparatus cell (renin secretion), macula densa cell of kidney, peripolar cell of kidney, mesangial cell of kidney, intestinal brush border cell (with microvilli), exocrine gland striated duct cell, gall bladder epithelial cell, kidney proximal tubule brush border cell, kidney distal tubule cell, ductulus efferens nonciliated cell, epididymal principal cell, epididymal basal cell, hepatocyte (liver cell), white fat cell, brown fat cell, liver lipocyte, type I pneumocyte (lining air space of lung), pancreatic duct cell (centroacinar cell), nonstriated duct cell (of sweat gland, salivary gland, mammary gland, etc.), kidney glomerulus parietal cell, kidney glomerulus podocyte, loop of Henle thin segment cell (in kidney), kidney collecting duct cell, duct cell (of seminal vesicle, prostate gland, etc.), blood vessel and lymphatic vascular endothelial fenestrated cell, blood vessel and lymphatic vascular endothelial continuous cell, blood vessel and lymphatic vascular endothelial splenic cell, synovial cell (lining joint cavities, hyaluronic acid secretion), serosal cell (lining peritoneal, pleural, and pericardial cavities), squamous cell (lining perilymphatic space of ear), squamous cell (lining endolymphatic space of ear), columnar cell of endolymphatic sac with microvilli (lining endolymphatic space of ear), columnar cell of endolymphatic sac without microvilli (lining endolymphatic space of ear), dark cell (lining endolymphatic space of ear), vestibular membrane cell (lining endolymphatic space of ear), stria vascularis basal cell (lining endolymphatic space of ear), stria vascularis marginal cell (lining endolymphatic space of ear), cell of Claudius (lining endolymphatic space of ear), cell of Boettcher (lining endolymphatic space of ear), choroid plexus cell (cerebrospinal fluid secretion), pia-arachnoid squamous cell, pigmented ciliary epithelium cell of eye, nonpigmented ciliary epithelium cell of eye, corneal endothelial cell, respiratory tract ciliated cell, oviduct ciliated cell (in female), uterine endometrial ciliated cell (in female), rete testis cilated cell (in male), ductulus efferens ciliated cell (in male), ciliated

ependymal cell of central nervous system (lining brain cavities), ameloblast epithelial cell (tooth enamel secretion), planum semilunatum epithelial cell of vestibular apparatus of ear (proteoglycan secretion), organ of Corti interdental epithelial cell (secreting tectorial membrane covering hair cells), loose connective tissue fibroblasts, corneal fibroblasts, tendon fibroblasts, bone marrow reticular tissue fibroblasts, other nonepithelial fibroblasts, pericyte, nucleus pulposus cell of intervertebral disc, cementoblast/cementocyte (tooth root bonelike cementum secretion), odontoblast/odontocyte (tooth dentin secretion), hyaline cartilage chondrocyte, fibrocartilage chondrocyte, elastic cartilage chondrocyte, osteoblast/osteocyte, osteoprogenitor cell (stem cell of osteoblasts), hyalocyte of vitreous body of eye, stellate cell of perilymphatic space of ear, red skeletal muscle cell (slow), white skeletal muscle cell (fast), intermediate skeletal muscle cell, nuclear bag cell of muscle spindle, nuclear chain cell of muscle spindle, satellite cell (stem cell), heart muscle cell, nodal heart muscle cell, purkinje fiber cell, smooth muscle cell (various types), myoepithelial cell of iris, myoepithelial cell of exocrine glands, red blood cell, erythrocyte (red blood cell), megakaryocyte (platelet precursor), monocyte, connective tissue macrophage (various types), epidermal Langerhans cell, osteoclast (in bone), dendritic cell (in lymphoid tissues), microglial cell (in central nervous system), neutrophil granulocyte, eosinophil granulocyte, basophil granulocyte, mast cell, helper T cell, suppressor T cell, cytotoxic T cell, B cells, natural killer cell, reticulocyte, stem cells and committed progenitors for the blood and immune system (various types), auditory inner hair cell of organ of Corti, auditory outer hair cell of organ of Corti, basal cell of olfactory epithelium (stem cell for olfactory neurons), cold-sensitive primary sensory neurons, heat-sensitive primary sensory neurons, merkel cell of epidermis (touch sensor), olfactory receptor neuron, pain-sensitive primary sensory neurons (various types), photoreceptor rod cell of eye, photoreceptor blue-sensitive cone cell of eye, photoreceptor green-sensitive cone cell of eye, photoreceptor red-sensitive cone cell of eye, proprioceptive primary sensory neurons (various types), touch-sensitive primary sensory neurons (various types), type I carotid body cell (blood pH sensor), type II carotid body cell (blood pH sensor), type I hair cell of vestibular apparatus of ear (acceleration and gravity), type II hair cell of vestibular apparatus of ear (acceleration and gravity), type I taste bud cell, cholinergic neural cell (various types), adrenergic neural cell (various types), peptidergic neural cell (various types), inner pillar cell of organ of Corti, outer pillar cell of organ of Corti, inner phalangeal cell of organ of Corti, outer phalangeal cell of organ of Corti, border cell of organ of Corti, hensen cell of organ of Corti, vestibular apparatus supporting cell, type I taste bud supporting cell, olfactory epithelium supporting cell, schwann cell, satellite cell (encapsulating peripheral nerve cell bodies), enteric glial cell, astrocyte (various types), neuron cells (large variety of types, still poorly classified), oligodendrocyte, spindle neuron, anterior lens epithelial cell, crystallin-

containing lens fiber cell, karan cells, melanocyte, retinal pigmented epithelial cell, oogonium/oocyte, spermatid, spermatocyte, spermatogonium cell (stem cell for spermatocyte), spermatozoon, ovarian follicle cell, Sertoli cell (in testis), and thymus epithelial cell. Such cells are typically mammalian cells and in one embodiment, human cells. Therefore, the vectors chosen for such delivery must be suitable for delivery of the nucleic acid molecules of the present disclosure to living cells of mammalian origin.

Vectors encompassed by the present disclosure are meant to include a broad range of mechanisms. Vectors include both viral and non-viral vectors. Non-viral vectors include, but are not limited to, plasmids, liposomes, electrically charged lipids (such as cytofectins), DNA-protein complexes, and biopolymers. Such non-viral vectors may be transferred into cells using any of the methods known in the art, including calcium phosphate coprecipitation, lipofection, protoplast fusion, receptor-mediated gene delivery, naked DNA injection, electroporation and bioballistic or particle acceleration.

Suitable plasmids for use as vectors include, but are not limited to, pcDNA3, pMC1neo, pXT1, pSG5, EBO-pSV2, pBPV-1, pBPV-MMTneo, pRSVgpt, pRSVneo, pSV2-dhfr, pUCTag, IZD35, pHB-Apr-1-neo, EBO-pcD-XN, pcDNAI/amp, pcDNAI/neo, pRc/CMV, pSV2gpt, pSV2neo, pSV2dhfr, pTk2, pMSG, pSVT7, pKoneo and pHyg. Such plasmids may contain an origin of replication for autonomous replication in host cells, selectable markers, a number of useful restriction enzyme sites, a potential for high copy number, and promoters active in a particular cell type. A promoter is defined as a nucleic acid sequence that directs RNA polymerase to bind to the nucleic acid and initiate RNA synthesis.

Viral vectors may be transferred into cells using any method known in the art, including infection and transfection. Viral vectors that may be used in the present invention include, but are not limited to, vectors derived from adenoviral vectors, retroviral vectors, lentiviral vectors, bovine papilloma viruses, Epstein-Barr virus, adeno-associated viruses pox viruses, baculovirus, vaccinia virus, herpes simplex virus, and hybrids of two or more viral vector types.

Adenoviruses are eukaryotic DNA viruses that can be modified to efficiently deliver nucleic acid to a variety of cell types. Various serotypes of adenovirus exist, including type 2 and type 5 human adenoviruses and adenoviruses of animal origin. In one embodiment, the adenovirus is replication defective and comprises the LTRs, an encapsidation sequence, and a nucleic acid molecule of the present disclosure. In a particular embodiment, at least the E1 region of the adenoviral vector is nonfunctional. Other regions may also be modified, including the E3 region (see WO95/02697), the E2 region (see WO94/28938), the E4 region (see WO94/28152, WO94/12649, and WO 95/02697), or in any of the late genes L1-L5.

Adenovirus vectors can be prepared by techniques known to a person skilled in the art. In particular they can be prepared by homologous recombination between an adenovirus and a plasmid which carries a nucleic acid molecule of the present disclosure. Homologous recombination is effected following cotransfection of the adenovirus and plasmid into an appropriate cell line. The cell line employed should be transformable by said components and contain sequences which are able to complement the defective regions in the replication defective adenovirus (if a replication defective adenovirus is used). Examples of cell lines which may be used are the human embryonic cell line 293 (Graham et al., J. Gen. Virol. 36, 59 (1977)) which contains the left-hand portion of the genome of an Ad5 adenovirus (12%) integrated into its genome, and cell lines which are able to complement the E1 and E4 functions, as described in WO94/26914 and WO95/02697. Recombinant adenoviruses are recovered and purified using standard biological techniques which are well known to those having ordinary skill in the art.

One class of useful adenovirus vectors may be prepared according to Bett et al., Proc. Natl. Acad. Sci. (USA) 91:8802-6 (1994), which describes a system for construction of adenovirus vectors with insertions or deletions in the E1 and E3 regions.

Adenoviral vectors can be produced at high titers (e.g. 10^{10}-10^{12} infectious units per ml), and can be used to transiently express the desired proteoglycan polypeptides in infected target cells in vitro or in vivo.

Retroviruses are integrating viruses which generally infect dividing cells. Lentiviruses are a type of retrovirus that is also capable of infecting non-dividing cells. The following discussion is applicable generally to retroviruses, including lentiviruses. The retrovirus genome includes two long terminal repeats (LTRs), an encapsidation sequence and three coding regions (gag, pol and env). The construction of recombinant retroviral vectors is known to those of skill in the art.

In recombinant retroviral vectors, the gag, pol, and env genes are generally deleted, in whole or in part, and replaced with a heterologous nucleic acid sequence of interest. These vectors can be constructed from different types of retrovirus, such as M-MuLV, MSV (murine Moloney sarcoma virus), HaSV (Harvey sarcoma virus), SNV (spleen necrosis virus), RSV (Rous sarcoma virus) and Friend virus.

In general, in order to construct recombinant retroviruses containing a nucleic acid molecule of the present disclosure, a plasmid is constructed which contains the LTRs, the encapsidation sequence and the coding sequence of a nucleic acid molecule of the present disclosure. This construct is used to transfect a packaging cell line, which cell line is able to supply in trans the retroviral functions which are deficient in the plasmid. In general, the packaging cell lines are thus able to express the gag, pol and env genes. Such packaging cell lines have been described in the prior art. In particular the cell line PA317 (U.S. Pat. No. 4,861,719),

the PsiCRIP cell line (WO90/02806), and the GP+envAm-12 cell line (WO89/07150) may be used. Recombinant retroviral vectors are purified by standard techniques known to those having ordinary skill in the art.

Retroviral vectors derived from lentiviruses such as HIV-1, HIV-2, and SIV can be used for delivery to nondividing cells. These viruses can be pseudotyped with the surface glycoproteins of other viruses, such as M-MuLV or vesicular stomatitis virus (VSV). The production of high titer HIV-1 pseudotyped with VSV glycoprotein has been disclosed by Bartz and Vodicka, Methods 12(4):337-42 (1997), and multiply attenuated lentiviral vectors have been disclosed by Zufferey et al., Nature Biotechnology 15:871-75 (1997). Such lentiviral vectors can infect nondividing cells, have a broad host range, and can be concentrated to high titers by ultracentrifugation.

Chimeric adenoviral/retroviral vector systems can also be used to achieve efficient gene delivery and long term expression. A chimeric viral system in which adenoviral vectors are used to produce transient retroviral producer cells in vivo, such that progeny retroviral particles infect neighboring cells, has been described by Feng et al., Nature Biotechnology 15:866-70 (September 1997).

Vectors encoding proteoglycan polypeptides of the present disclosure can be generated in several ways using standard techniques of molecular biology. The vector should be suitable for stable, high-level expression in mammalian cells. Retroviral vectors containing strong viral promoters, such as the immediate-early human cytomegalovirus (CMV)/enhancer, to drive the expression of the inserted nucleic acid, may be used.

Vectors encoding expression of the proteoglycan polypeptides of the present disclosure are administered to a subject as described herein.

Effective amounts may be determined by the physician or by another qualified medical professional. Recombinant viruses are generally formulated and administered in the form of doses of from about 10^4 to about 10^{14} pfu, from about 10^6 to about 10^9, or from about 10^6 to about 10^8.

In carrying out the nucleic acid manipulations described herein, many techniques for manipulating and modifying nucleic acids may be used. Merely exemplifying such techniques are the following: Gene Probes for Bacteria (Macario and De Marcario, editors, Academic Press Inc., 1990); Genetic Analysis, Principles Scope and Objectives (John R. S. Ficham, Blackwell Science Ltd., 1994); Recombinant DNA Methodology II (Ray Wu, editor, Academic Press, 1995); Molecular Cloning. A Laboratory Manual (Maniatis, Fritsch, and Sambrook, editors, Cold Spring Harbor Laboratory, 1982); PCR (Polymerase Chain Reaction), (Newton and Graham, editors,

Bios Scientific Publishers, 1994). Each of the foregoing references cited herein are incorporated by reference as if fully set forth in this disclosure.

The following examples illustrate certain embodiments of the present disclosure without, however, limiting the same thereto.

EXAMPLES

Example 1- Exemplary production of a nucleic acid sequence encoding a secreted proteoglycan polypeptide

The isolated nucleic acid molecule encoding one or more proteoglycan polypeptides comprises a first nucleic acid sequence encoding a sequence that is sufficient for secretion and a second nucleic acid sequence encoding a polypeptide having one or more sequences for the attachment of a glycosaminoglycan chain and lacking a transmembrane domain (or like domain). The proteoglycan polypeptide produced after transcription, translation and glycosylation is secreted from the cell in which it is produced due to the presence of the signal sufficient for excretion.

The signal sufficient for excretion may be any sequence that directs the secretion of a protein or polypeptide from a cell. As a specific example, the signal sequence from the perlecan proteoglycan may be used. The signal sequence from the perlecan proteoglycan has the sequence atggggtggcgggcgccgggcgcgctgctggcgctgctgctg (SEQ ID NO. 27). This signal sequence, as well as others known in the art, can be incorproated into the isolated nucleic acid molecule encoding one or more proteoglycan polypeptides by methods known in the art. The signal sequence is generally placed on the 5' end of the nucleic acid (the NH2-terminus of the proteoglycan polypeptide). Proteoglycan polypeptides having the signal sequence set forth in SEQ ID NO: 27 were secreted by fibroblasts and endothelial cells when expressed in these cell types.

The design and construction of an exemplary nucleic acid of the present disclosure is provided below to further illustrate the concepts of the disclosure. For the exemplary proteoglycan perlecan, a 20-mer antisense 3' perlecan domain 1 (D1) primer was made extending to base 639 of the NM 005529 GenBank sequence. Reverse transcription from total dermal microvascular endothelial cell mRNA was performed, and the resulting cDNA was amplified by PCR with an upstream 19-mer primer extending from base 38 of the NM 005529 sequence and included the signal sequence for secretion from cell. Subsequently, a Bgl2 restriction enzyme site was synthesized to extend from the 5' end of the 38 and 639 primers. PCR was repeated on the original D1 amplification product, and the PCR product was Bgl2 digested, producing the D1Bgl2 transgene. This product was subsequently ligated into the Bgl2 cloning site of the adenoviral expression system (Adenovator, Qbiogene) resulting in a forward perlecanD1-Ad

clone. By this method, a recombinant perlecan D1 expression product (rD1) was generated. A control RevD1-Ad clone with the D1 insert in reverse orientation relative to the CMV-5 promoter was also produced.

Primary human endothelial cells or dermal fibroblasts were seeded on plastic and infected with the perlecanD1-Ad or control RevD1-Ad. Infections were performed 16-24 h after seeding in DMEM, with 10% FBS with varying infectious doses inoculated into either 50 µl or 250 µl medium in 96-well or 24-well culture plates, respectively. Infections were allowed to proceed with constant rocking for 16-24 h at 37°C, 5% $C0_2$, at which time, media was changed to DMEM supplemented with F12 with, or without, 1% serum. Infected cell cultures were incubated for various time periods.

After several days of incubation, conditioned medium was removed and separated from any loose cell debris by centrifuge then saved frozen for assay. The residual cell and accumulated subcellular matrix were washed once in PBS, then either fixed with cold methanol, or solubilized with either 50 or 200 µl 0.1% SDS in water containing protease inhibitor cocktail (Product # P 2714, Sigma Aldrich Corp, St. Louis, MO), in 96-well or 24-well assays, respectively.

The solubilized residual cell matrix samples and conditioned media samples were stained with anti-D1 monoclonal antibody (mAb) A71 (FIG. 1A) or the anti-D5 mAb A74 (FIG. 1B). For each of FIGS. 1A and 1B, 100 µl of the solubilized residual cell matrix samples and 100 µl of the conditioned medium were applied to nitrocellulose in duplicate wells in a 96-well dot-blot format. The nitrocellulose was blocked with PBS containing Tween-20 detergent, 0.1% (PBS/Tween), and primary antibody was applied at 1 µg/ml. After overnight incubation with primary antibody, 1 µg/ml secondary anti-mouse AP conjugate was applied in PBS/Tween for 2 hours and the blots developed with BCIP. Columns 1 and 2 are solubilized residual cell matrix from primary human endothelial cells cultures following 9 days of culture after infection with perlecanD1-Ad and control RevD1-Ad, respectively. Columns 3 and 4 are conditioned medium from primary human endothelial cells cultures removed following 5 days of culture after infection with perlecanD1-Ad and control RevD1-Ad, respectively. Columns 5 and 6 are conditioned medium from primary human endothelial cells cultures removed following 6-9 days of culture after infection with perlecanD1-Ad and control RevD1-Ad, respectively.

In the solubilized residual cell matrix samples, there was some detectable mAb A71 immunoreactivity (FIG. 1A) from the infected cells (col. 1), and slightly more immunoreactivity in the control samples (col. 2), suggesting that this background was native perlecan, and that none of the recombinant had been retained in cell or subcellular matrix. Immunoreactivity of mAb A74 (FIG. 1B,), which binds domain 5 (D5) of native perlecan, confirmed that the probable

source of mAb A71 immunoreactivity was from native perlecan since it was of equal or greater intensity than the mAb A71 signal. Similar results were obtained with the fibroblast cultures (data not shown). Immunofluorescent analysis of fixed cells supported the evidence for the lack of accumulated rD1 in experimental wells, as neither the D1 or D5 signal was above background (not presented).

Using mAb A71 (FIG. 1A), the perlecanD1-Ad clone clearly accumulated immunoreactive product in the endothelial cell conditioned medium during 5 days of culture (col. 3), while no immunoreactivity above background was present in conditioned medium from the cultures infected with the control RevD1-Ad (col. 4). Similar results were seen in conditioned medium collected between the 5th and 9th day of culture (cols. 5-6). Background levels of anti-D5 immunoreactivity in conditioned medium with mAb A74 are shown in FIG. 1B cols. 3-6.

Conditioned medium from endothelial cells infected with perlecanD1-Ad or the control RevD1-Ad was subjected to SDS-PAGE on a 4-10% gradient gel, then transferred to nitrocellulose for Western blot analysis. Antibody concentrations and manipulations were as described in FIGS. 1A and 1B. The anti-D1 A71 antibody demonstrated a broad multimeric region of staining ranging from 32-42 apparent kDa in the perlecanD1-Ad sample (FIG. 2 lane 1), but no such species in the control sample (FIG. 2, lane 2), confirming dot blot results (FIGS. 1A and 1B), and suggesting that the rD1 is probably modified with at least 11-21 kDa of GAG chains attached.

The nucleic acid manipulations can be repeated with any suitable signal sequence and the leader sequences identified may be utilized with any desired nucleic acid sequence coding for a proteoglycan polypeptide to produce a recombinant proteoglycan polypeptide for use as described herein.

The design and construction of another exemplary nucleic acid of the present disclosure is provided below to further illustrate the concepts of the disclosure. For the exemplary proteoglycan lumican, human lumican cDNA, accession number U18728, is cloned first into the CMV-5 driven mammalian expression vector pcDNA3.1/V5-His (Invitrogen) and then into the CMV-5 driven adenoviral transfer vector (AdenoVator, Qbiogene). For cloning into the adenovirus transfer vector the necessary restriction enzyme site, Bgl2, will be cloned into the ends of the lumican-V5-His transgene by PCR utilizing primers as described above for the exemplary proteoglycan perlecan.

Example 2- Exemplary production of a heparan sulfate glycated proteoglycan polypeptide generated from a nucleic acid sequence encoding a secreted polypeptide

The endothelial conditioned medium produced as set forth in Example 1 above was subject to immunoblotting (dot blot) using a panel of antibodies that recognize variations of

sulfation within heparan sulfate glycosaminoglycan chains (FIG. 3A). The 2Q546 anti-heparan sulfate mAbs recognize a highly sulfated heparan sulfate, while the Hep-SS1 antibody recognizes a low sulfated heparan sulfate. The mAb CS56 recognizes chondroitin sulfate. The top row of the dot blot contains a standard heparan sulfate proteoglycan as a control, while the bottom row is conditioned medium from perlecan D1-Ad infected primary human endothelial cells. The primary antibodies used were Hep-SS1 (panel A), 2Q546 (panel B), CS-56 (panel C), and none (panel D); a secondary anti-mouse IgM-AP conjugate followed by BCIP was used for visualization. The procedure was performed as described for FIGS. 1A and 1B.

Conditioned medium from the perlecanD1-Ad infected endothelial cell cultures (FIG. 3A, bottom row) was poorly immunoreactive with the Hep-SS1 antibodies (panel A), relative to the strong signal from a standard aliquot of murine heparan sulfate proteoglycan 2. To the contrary, immunoreactivity of the conditioned medium with the 2Q546 antibodies (FIG. 3A, panel B) was strong relative to immunoreactivity with the standard HSPG.

FIG. 3B shows immunoblotting of perlecanD1-Ad (top) paired with control conditioned medium (bottom) visualized with mAb 2Q546; antibody concentrations and manipulations were as described in FIG. 3A. Given that the control conditioned medium contained significantly lower levels of immunoreactivity with the 2Q546 antibody (FIG. 3B), these data suggested that the rD1 expressed from endothelial cells *in vitro* was decorated with heparan sulfate which had been modified to a highly sulfated and charged state.

Immunoreactivity of the blotted conditioned medium with an anti-CS monoclonal antibody CS56 (FIG. 3A, panel C) showed slight reactivity (lower row) beyond background (panel D). However, the slight CS56 reactivity detected in the conditioned medium was at the background level also found in the control conditioned medium (data not shown). These data suggested that the rD1 from *in vitro* endothelial cell culture conditioned medium was not decorated with chondroitin sulfate.

rD1 from conditioned medium was subject to enzyme degradation to further determine the nature of the glycosaminoglycan chains (FIG. 4). Enzyme digestion of the rD1 with either 1 mU of heparatinase I (lane 2), which degrades regions of heparan sulfate which have low sulfate density, or with 20 mU of chondroitinase abc (lane 1), which removes chondroitin sulfate chains, or with only buffer (lane 3) was performed on the conditioned medium from perlecanD1-Ad infected endothelial cell cultures. Western blot analysis was performed on the samples after incubation at 37°C for 1 hour (FIG. 4). Using threshold image analysis of the blot it was clear that heparatinase digestion of the sample in conditioned medium (FIG. 4, lane 2) resulted in a significant loss of immunoreactive rD1 relative to the conditioned medium with buffer incubation (lane 3). Chondroitinase abc digestion of the rD1 (FIG. 4, lane 1) resulted in no less

immunoreactive rD1. These data taken together suggest that the rD1 is decorated primarily by heparan sulfate and little, if any, chondroitin sulfate. Incomplete heparan sulfate digestion can be attributable to the substrate specificity of the heparatinase I that was used, which supports the data suggesting the rD1 is highly sulfated.

Example 3- Effective wound healing by delivery of a nucleic acid sequence encoding a secreted proteoglycan polypeptide

The effect of expressing a delivered nucleic acid encoding a secreted proteoglycan polypeptide on wound healing was evaluated using the acute calvarial wound model. Two defects were created bilaterally on the calvaria of Balb C mice with a slowly rotating round 3 mm diamond bur and copious saline drip. Brief pressure was applied for hemostasis then approximately 15 µl of a hydroxyapatite (HA) slurry pre-loaded with either the perlecanD1-Ad, or the control RevD1-Ad, was applied to opposite paired defects in each mouse. Approximately 1.6 $x10^7$ viral particles of perlecanD1-Ad and 5.2 x 10^6 viral particles of RevD1-Ad per defect were delivered in the slurry of HA (calculated as approximately equal infectious doses). Crystals were lightly packed into the defect with a spatula and the defect was covered by replacing and securing the skin flap. After 18 or 22 days the animals were sacrificed and the calvarium removed for fixation in HistoChoice (Amresco, Solon, OH) for 24 hours, decalcification in 10% w/v EDTA for 6 days, and paraffin embedding. Deparaffinized sections were trichrome stained for collagen and bone.

A group of 8 mice were sacrificed at day 18. By gross observation of the collected calvaria, it was clear to a naïve observer which sites had received the proteoglycan construct, perlecanD1-Ad, and which sites were treated with the control delivery construct (RevD1-Ad); seven of the eight experimental sites were correctly identified, while the eighth was scored as even. FIG. 5 shows one example of the collected calvaria where the top left defect received the perlecanD1-Ad and the top right defect received the control adenovirus (RevD1-Ad). A greater level of vascularity appears in the center of the defect treated with perlecanD1-Ad and the borders surrounding the experimental graft are significantly denser.

Recombinant perlecan D1 expression was associated with accelerated regional new bone growth in the acute calvarial wound model. Adjacent deparaffinized sections of the calvarial bone allowed to heal for 22 days were incubated overnight with 20 µg/ml of either the anti-D1 mAb A71, or the anti-domain 3 (D3) mAb7B5 as a control. After washing and applying an AP-conjugated anti-mouse IgG antibody, BCIP visualization revealed significantly more perlecan D1 in the connective tissue associated with new bone growth (FIG. 6, anti-D1) than in the non-regenerating defect (anti-D1; mean pixel density mouse #4: 54 ± 19 vs. 15 ± 5, respectively; $p = .02$). At the same time, the perlecan D3 signal was relatively equal on either side of the

calvarium (FIG. 6, anti-D3). Control sections (secondary antibody only) were blank (data not shown). Ratio of anti-D1 to anti-D3 signal for the regenerative vs. the non-regenerative sides of mice #4 and #5 indicated that approximately 7 fold (± 5 fold) more rD1 than endogenous D1 was evident in the more fully regenerated graft site vs the lesser regenerated graft site at the 22 day time point.

Heparan sulfate was localized using the monoclonal antibody 2Q546, which recognizes highly charged regions of heparan sulfate. This antibody had the greatest affinity for the heparan sulfate-decorated recombinant *in vitro*, demonstrated above. In mouse #4, a greater density of heparan sulfate immunoreactivity was evident in association with higher levels of perlecan D1, and new bone (FIG. 6, anti-HS).

A dual stain with mAb A71 (blue) and mAb 7B5 (purple) was performed, and contrast-enhanced images highlight the greater abundance and intensity of blue signal from regions of bone regeneration than on the non-regenerating osseous defects (FIG. 6). These data suggested that recombinant perlecan D1 was expressed and accumulated in association with more rapid and complete bone regeneration of the calvarial defects. Further, by trichrome staining, the amount of new bone associated with the expressed recombinant perlecan D1 was striking (FIG. 6).

PROPHETIC EXAMPLES

Example 1- Use of nucleic acid encoding a secreted proteoglycan polypeptide in bone wounds

The present disclosure contemplates a variety of mechanisms and vectors to deliver a nucleic acid encoding a proteoglycan polypeptide. In one embodiment, a nucleic acid encoding a proteoglycan polypeptide is delivered to a bone wound. In this embodiment, the nucleic acid encoding the proteoglycan polypeptide, such as a cDNA, would be ligated into a replication–incompetent, E1/E3–defective human adenovirus serotype 5-derived vector under the transcriptional control of the human cytomegalovirus early promoter as described previously (Shi, et al., J Virol **75**(23): 11474-82, 2001). For *in situ* proteoglycan expression, 10^2 to 10^9 adenovirus particles would be delivered per cm^2 of wound surface area, or per cm^3 of a surgical grafting site.

For delivery, surgical grafting materials or implant materials would be pre-treated with this vector delivery system, preferably in a sterile buffer such as phosphate buffer, pH 7.4. The pre-treatment may be performed during surgery, or at any time prior to the surgery provided the coated surgical implant material is not subject to denaturing temperatures at any time after pre-treatment, and would involve immersion in the pre-treatment solution for a short period of time. The pre-treated grafting material or implant would then be surgically placed. Various growth factors may also be incorporated into the solution for incorporation into, and absorption onto, the

grafting materials and surgical implants. Once prepared, the grafting materials and surgical implants would be used according to standard procedures.

The adenoviral vector system delivers the nucleic acid to the site of the wound and the adenoviral vector system infects a plurality of target cells at the site of the wound. The nucleic acid encoding the proteoglycan polypeptide is then transcribed, translated, and the resulting polypeptide is then glycated with at least one glycosaminoglycan chain by the target cell. As the nucleic acid encoding the proteoglycan polypeptide contains a sequence sufficient for excretion, the produced proteoglycan polypeptide is secreted from the target cell and is available for effective treatment of the wound as discussed herein.

Example 2- Use of nucleic acid encoding a proteoglycan polypeptide for treatment of cutaneous injury

In an alternate embodiment, a nucleic acid of the present disclosure encoding a proteoglycan polypeptide is delivered to a site of cutaneous injury. In this embodiment, the nucleic acid encoding the proteoglycan polypeptide, such as a cDNA, would be ligated into a replication–incompetent, E1/E3–defective human adenovirus serotype 5-derived vector as described above or used in combination with another vector, such as but not limited to, a liposome.

For a 2 cm^2 area of cutaneous injury, the adenovirus or liposome vector system would be applied in a small volume (such as <50 μL) and allowed to dry after application. Adenovirus would be delivered in a phosphate buffered saline solution containing 10% glycerol as a thickening agent to aid in application and at an infectious dose of between 10^2-10^9 VP/ml. If the nucleic acid encoding the proteoglycan polypeptide is delivered across the stratum corneum as plasmid DNA, lipid vesicles will be used which have been shown to allow plasmid DNA to cross the stratum corneum, and transfect cells (Alexander, et al., Hum Mol Genet **4**(12): 2279-85, 1995; Raghavachari, et al, J Pharm Sci **91**(3): 615-22, 2002). Cationic lipids DOTAP (Avanti Polar Lipids) may be used as a lipid vesicle constituent of the liposomes. The ratio of DNA to liposome can vary from 1:1 to 1:100. The vector systems containing the nucleic acid encoding the proteoglycan polypeptide could be applied multiple times if required.

The vector system delivers the nucleic acid to the site of the cutaneous injury and the vector system infects a plurality of target cells at the site of the cutaneous injury. The nucleic acid encoding the proteoglycan polypeptide is the transcribed, translated and the resulting polypeptide is glycated with at least one glycosaminoglycan chain by the target cell. As the nucleic acid encoding the proteoglycan polypeptide contains a sequence sufficient for excretion, the produced proteoglycan polypeptide is secreted from the target cell and is available for effective treatment of the cutaneous injury as discussed herein.

Example 3- Creating a nucleic acid encoding a novel secreted proteoglycan

As discussed above, the present disclosure provides for a nucleic acid encoding a proteoglycan polypeptide. The nucleic acid encoding a proteoglycan polypeptide is delivered to a target, is transcribed, translated, and the resulting polypeptide is glycated with appropriate glycosaminoglycan chains as dictated by the physiological state of the target cell. The produced proteoglycan polypeptide is then secreted from the target cell. The definition of proteoglycan polypeptide is broad, covering proteoglycan proteins that are naturally occurring or that are synthesized de novo and which may not be naturally occurring, fragments of the foregoing, and modifications to the foregoing that have been altered to include new glycosaminoglycan attachment sites hence creating novel proteoglycans. Such proteoglycan polypeptides may be produced by modifying the nucleic acid encoding a proteoglycan polypeptide as discussed herein. An example is provided below.

An example of how any nucleic acid sequence could be utilized to establish new glycosylation sites is as follows. Using the proteoglycan perlecan as an example again, domain 1 (D1) usually is observed to contain 3 glycosaminoglycan chains, most often heparan sulfate. Currently, no structural data exists for perlecan or for perlecan D1. Computational modeling of perlecan D1 is somewhat problematic as the 21 kDa protein does not exhibit greater than 25% sequence identity with any known protein structures. The 25% cut-off for most modeling programs does not allow for modeling of the full protein. However, Geno3D allows for modeling of partial sections of the protein when the sequence identity is high enough (Combet, et al., Bioinformatics 18(1): 213-4, 2002). Perlecan D1 was modeled with Geno3D against the pdb 1MDC, an insect fatty acid binding protein, which displayed the highest sequence identity of the database at 24%. The predicted model of amino acids 53 to 144 suggested a β-sheet structure and encompassed the three glycosaminoglycan chain attachment sites, which are shown in FIG 7 by arrow 1 (S65, G66, D67), arrow 2 (S71, G72, D73), and arrow 3 (S76, G77, D78). A β-sheet structure would allow the glycosaminoglycan chains to project away from the protein core tertiary structure and possibly allow growth factors, such as but not limited to, FGF to bind the heparan sulfate chains on one face of the protein while the other face binds the FGF receptor for presentation of FGF. Additional sites for heparan sulfate attachment that are engineered on the same side of the protein as the natural attachment sites are likely to increase growth factor binding either in number or in affinity. Creating mutations that contain amino acids with similar physical properties reduces the possibilities of structural disruption due to the inclusion of the mutations as discussed herein. In addition, including the mutations in proposed loop regions would reduce the probability of structure disruption and allow for glycosaminoglycan chain flexibility for growth factor binding. Therefore, the two chosen mutation sites are L87S, V88G,

N89D and S97, P98G, Q99D, also shown in FIG. 7. The two amino acid triads were replaced with an SGD glycosylation sequence. These two sites are close to the three natural sites for glycosylation, and the amino acid changes are conservative enough to allow for proper structure formation. These mutations were made by site-directed mutagenesis in a single round of PCR for each site.

Similar approaches could be used for other proteoglycan protein/polypeptide structures.

The foregoing description illustrates and describes the nucleic acids, compositions, methods and other teachings of the present disclosure. Additionally, the disclosure shows and describes only certain embodiments of the nucleic acids, compositions, methods and other teachings disclosed, but, as mentioned above, it is to be understood that the teachings of the present disclosure are capable of use in various other combinations, modifications, and environments, and is capable of changes or modifications within the scope of the teachings as expressed herein, commensurate with the skill and/or knowledge of a person having ordinary skill in the relevant art. The embodiments described hereinabove are further intended to explain best modes known of practicing the methods and other teachings of the present disclosure and to enable others skilled in the art to utilize the teachings of the present disclosure in such, or other, embodiments and with the various modifications required by the particular applications or uses. Accordingly, the nucleic acids, compositions, methods and other teachings of the present disclosure are not intended to limit the exact embodiments and examples disclosed herein.

All references (including patent references) are hereby incorproated by reference as if fully set forth herein.

CLAIMS

1. A method for effective treatment or prevention of a wound or a cutaneous injury in a subject in need of such treatment or prevention via delivery of a glycosaminoglycan-decorated proteoglycan polypeptide, the method comprising administering to a target cell at a site of the wound or cutaneous injury a composition comprising a vector comprising a nucleic acid encoding a proteoglycan polypeptide, said nucleic acid comprising a first nucleic acid sequence encoding a sequence sufficient for secretion and a second nucleic acid sequence encoding at least one polypeptide having one or more sites for the attachment of a glycosaminoglycan chain, whereby a glycosaminoglycan-decorated polypeptide is generated in the target cell by the subject and subsequently secreted from the target cell to deliver an effective amount of glycosaminoglycan to the wound or the cutaneous injury resulting in an improvement in effective treatment of the wound or the cutaneous injury or prevention of the would or the cutaneous injury in the subject, said nucleic acid being delivered in therapeutically effective amount.
2. The method of claim 1 where the polypeptide having one or more sequences for the attachment of a glycosaminoglycan chain is a proteoglycan polypeptide.
3. The method of claim 2 where the proteoglycan polypeptide is a naturally occurring proteoglycan polypeptide.
4. The method of claim 3 where the naturally occurring proteoglycan polypeptide is selected from the group consisting of aggrecan, versican, lumican, syndecan 1-4, glypican 1- 5, betaglycan, NG2/CSPG4, CD44/Epican, fibromodulin, PRELP, keratocan, osteoadherin/osteomodulin, epiphycan, osteoglycin/mimecan, neurocan/CSPG3, brevican, bamacan, agrin, perlecan, decorin, biglycan and serglycin.
5. The method of claim 3 where the naturally occurring proteoglycan polypeptide is selected from the group consisting of aggrecan, versican, lumican, syndecan 1-4, glypican 1- 5, betaglycan, NG2/CSPG4, CD44/Epican, fibromodulin, PRELP, keratocan, osteoadherin/osteomodulin, epiphycan, osteoglycin/mimecan, neurocan/CSPG3, brevican, bamacan, agrin, and serglycin.
6. The method of claim 3 where the proteoglycan polypeptide is a degenerate variant or an allelic variant of a naturally occurring proteoglycan polypeptide.
7. The method of claim 3 where the proteoglycan polypeptide is a mutant or a variant of a naturally occurring proteoglycan polypeptide.
8. The method of claim 7 where the mutant or variant has been modified to include an additional site for glycosaminoglycan attachment.

9. The method of claim 1 where the proteoglycan polypeptide is not a naturally occurring polypeptide.
10. The method of claim 1 where the sequence sufficient for excretion is a signal sequence.
11. The method of claim 10 where the signal sequence has the sequence of SEQ ID NO. 27.
12. The method of claim 1 where the vector is a viral vector or a non-viral vector.
13. The method of claim 12 where the viral vector is an adenoviral vector, a retroviral vector, a lentiviral vector, a bovine papilloma viral vector, an Epstein-Barr viral vector, an adeno-associated viral vector, a pox viral vector, a baculovirus viral vector, a vaccinia viral vector, a herpes simplex viral vector, or a hybrid of two or more viral vector types.
14. The method of claim 12 where the non-viral vectors is a plasmid, a liposome, an electrically charged lipids, a DNA-protein complex or a biopolymers.
15. The method of claim 1 where the nucleic acid is a polycistronic nucleic acid.
16. The method of claim 1 where the nucleic acid encoding the proteoglycan polypeptide comprises at least one additional nucleic acid sequence, said additional nucleic acid sequence encoding at least one growth factor or a fragment thereof.
17. The method of claim 16 where the growth factor binds a glycosaminoglycan chain.
18. The method of claim 16 where the growth factor binds a heparin sulfate chain.
19. The method of claim 16 where the growth factor is selected from the group consisting of fibroblast growth factor, keratinocyte growth factor, transforming growth factor-B, hepatocyte growth factor, vascular endothelial growth factor, platelet-derived growth factor, epidermal growth factor, insulin-like growth factor, bone morphogenic protein and granulocyte-macrophage colony stimulating factor.
20. The method of claim 16 where the growth factor is fibroblast growth factor.
21. The method of claim 16 where the growth factor is fibroblast growth factor 2 or 7.
22. The method of claim 16 where the nucleic acid is a polycistronic nucleic acid.
23. The method of claim 1 further comprising adding a second vector comprising at least one accessory nucleic acid sequence encoding at least one growth factor or a fragment thereof.
24. The method of claim 23 where the growth factor binds a glycosaminoglycan chain.
25. The method of claim 23 where the growth factor binds a heparin sulfate chain.
26. The method of claim 23 where the growth factor is selected from the group consisting of fibroblast growth factor, keratinocyte growth factor, transforming growth factor-B, hepatocyte growth factor, vascular endothelial growth factor, platelet-derived growth factor, epidermal growth factor, insulin-like growth factor, bone morphogenic protein and granulocyte-macrophage colony stimulating factor.
27. The method of claim 23 where the growth factor is fibroblast growth factor.

28. The method of claim 23 where the growth factor is fibroblast growth factor 2 or 7.
29. The method of claim 1 where the composition further comprises a pharmaceutically acceptable carrier.
30. The method of claim 1 where said composition is administered to the target cell at the site of the wound or cutaneous injury via a systemic delivery or a local delivery.
31. The method of claim 30 where the local delivery is accomplished with a gene gun or a pressure delivery method.
32. The method of claim 1 where said wound is a bone wound.
33. The method of claim 1 where said cutaneous injury is the result of sun exposure or aging.
34. The method of claim 3 where the proteoglycan polypeptide is a fragment of a naturally occurring proteoglycan polypeptide.