(19) DANMARK

(10) DK/EP 3691649 T3

(12) Oversættelse af europæisk patentskrift

Patent- og Varemærkestyrelsen

(51) Int.Cl.: *A 61 K 31/519 (2006.01)* *A 61 K 9/00 (2006.01)* *A 61 K 9/06 (2006.01)*
A 61 K 31/728 (2006.01) *A 61 K 47/02 (2006.01)* *A 61 L 15/28 (2006.01)*
A 61 L 15/44 (2006.01) *A 61 L 17/00 (2006.01)* *A 61 L 26/00 (2006.01)*
A 61 P 17/02 (2006.01)

(45) Oversættelsen bekendtgjort den: **2022-12-12**

(80) Dato for Den Europæiske Patentmyndigheds bekendtgørelse om meddelelse af patentet: **2022-10-12**

(86) Europæisk ansøgning nr.: **18864379.5**

(86) Europæisk indleveringsdag: **2018-10-06**

(87) Den europæiske ansøgnings publiceringsdag: **2020-08-12**

(86) International ansøgning nr.: **US2018054776**

(87) Internationalt publikationsnr.: **WO2019071242**

(30) Prioritet: **2017-10-06 US 201762569025 P** **2018-06-13 US 201862684439 P**

(84) Designerede stater: **AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**

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(54) Benævnelse: **SAMMENSÆTNINGER OG FREMGANGSMÅDER TIL SÅRBEHANDLING**

(56) Fremdragne publikationer:
WO-A1-2017/173026
CN-A- 105 288 695
US-A1- 2012 318 262
US-A1- 2015 231 266
US-A1- 2017 128 271
BASTAKOTY DIKSHYA ET AL: "Inhibition of Wnt/[beta]-catenin pathway promotes regenerative repair of cutaneous and cartilage injury", THE FASEB JOURNAL, vol. 29, no. 12, 12 August 2015 (2015-08-12), pages 4881-4892, XP055806117, & EXPERIMENTAL BIOLOGY MEETING; SAN DIEGO, CA, USA; APRIL 21 -25, 2018 ISSN: 0892-6638, DOI: 10.1096/fj.15-275941 Retrieved from the Internet: URL:https://onlinelibrary.wiley.com/doi/fu ll-xml/10.1096/fj.15-275941>
JUNG et al.: "Nanographene OxideHaluronic Acid Conjugate for Photothermal Ablation Therapy of Skin Cancer", ACSNano, vol. 8, no. 1, 2014, pages 260-268, XP055588726,
LI et al.: "Hyaluronic acid-conjugated graphene oxide/photosensitizer nanohybrids for cancer targeted photodynamic therapy", Journal of Materials Chemistry B, vol. 1, no. 12, 28 March 2013 (2013-03-28) , pages 1678-1686, XP055588728,

Fortsættes ...

DESCRIPTION

Background

[0001] The invention described herein relates to compositions and uses of the compositions for wound treatment, and in particular, the prevention and/or reduction of scar formation during wound healing.

[0002] Wound healing is a complex process, involving an inflammation phase, a granulation tissue formation phase, and a tissue remodeling phase. These events are triggered by cytokines and growth factors that are released at the site of injury. Many factors can complicate or interfere with normal adequate wound healing. Chronic wounds, such as diabetic foot ulcers, venous leg ulcers, and pressure ulcers are particularly troublesome and challenging to treat.

[0003] A scar is the mark left in the skin by new connective tissue that replaces tissue which has been injured. Scarring in the skin after trauma, surgery, burn or sports injury can be a medical problem, resulting in loss of function, restriction of tissue movement and adverse psychological effects. Skin fibrosis, an irreversible pathological process that causes a loss of normal tissue structure and organ function, is associated with scarring. While the pathways and processes underlying scar formation have been better understood in the recent years, no effective therapeutic approaches for scar management are available, and there are no prescription drugs for the prevention or treatment of dermal scarring.

[0004] Currently available techniques for treating scarring (e.g., silicone sheeting (pressure therapy), topical ointments, resurfacing, peel, dermabrasion, lasers, cryosurgery, bleomycin and 5-fluorouracil injection, excision (revision surgery, radiotherapy), reconstruction possibly with skin grafts, flaps, etc.) focus on improving the aesthetics of existing scars, and have issues related to scarring recurrence and side-effects, such as dermal atrophy and hypopigmentation.

[0005] The Wnt pathway has been recently shown to play a key role in dermal fibrosis and scarring. The Wnt pathway is an evolutionary conserved pathway that regulates crucial aspects of cell fate determination, cell polarity, cell migration, neural patterning, and organogenesis during embryonic development. This pathway is instrumental in ensuring proper tissue development in embryos and tissue maintenance in adults. Wnt signaling is involved at the beginning stages of skin development. Following gastrulation, embryonic cells of the ectoderm and the mesoderm differentiate to form the epidermis and dermis, respectively.

[0006] Although there are at least three distinct Wnt signaling pathways involved in the signal transduction process, the canonical (or β-catenin dependent) Wnt pathway is the most understood. β-Catenin is the key effector molecule resulting from the signaling of the canonical Wnt pathway, and its protein levels are regulated through a "destruction complex". In the absence of a Wnt signal, the transcriptional activator β-catenin is actively degraded in the cell

by the actions of a protein complex, designated the "destruction complex". Within this complex, Axin-1 and -2 with adenomatous polypsis coli form a scaffold that facilitates β-catenin phosphorylation by casein-kinase 19α and glycogen synthase kinase 3β. Phosphorylated β-catenin is recognized and ubiquitinylated, resulting in its proteosomal degradation. Tankryase I and II (TNK1 and 2) are poly(ADP-ribose) polymerases (PARPs) that function to parsylate and destabilize Axin-1 and -2 proteins, thus destabilizing the β-catenin destruction complex. Once the destruction complex is destabilized, this allows β-catenin to be dephosphorylated, and subsequently stabilized and allowed to accumulate in the cytoplasm and enter the cell nucleus, where it interacts with members of the Tcf/Lef family. β-catenin converts the Tcf proteins into potent transcriptional activators by recruiting co-activator proteins, thus ensuring efficient activation of Wnt target genes. The Wnt pathway, once activated by the Wnt family of natural ligands, upregulates TNK1 and 2 to help destabilize the destruction complex. Studies have shown that TNK1 and 2 are critical regulators of canonical Wnt signaling.

[0007] Canonical Wnt signaling is over-activated in a variety of tumors where it plays a central role in cell growth and metastasis. In addition, the Wnt pathway has been shown to regulate cell proliferation in the adult epidermis, indirectly impacting the rate and extent of skin wound healing and fibrosis or scarring. Further, the Wnt/β-catenin pathway has been shown to cause overstimulation of dermal fibroblasts, which can give rise to myofibroblasts. Myofibroblasts are endowed with contractile function, which allows them to play a role in extracellular matrix (ECM) fibers to close open wounds. Overexpression of myofibroblasts causes excess collagen and ECM protein secretion, which in turn causes fibrosis and scarring. Sustained β-catenin activity in dermal fibroblasts promotes fibrosis by upregulating expression of ECM protein-coding genes. β-Catenin levels have been shown to regulate wound size and mediate the effect of TGF-β in cutaneous healing. The Wnt/β-catenin pathway has been shown to be upregulated in hypertrophic scars and keloid fibroblasts. Thus, the Wnt/β-catenin pathway induces β-catenin signaling in cutaneous mesenchymal cells, leading to their activation and induction of a sustained fibrotic response.

[0008] TNK1 and 2 have been shown to be druggable targets for modulation of the Wnt/β-catenin pathway. However, recently it has been demonstrated that systemic inhibition of TNK1 and 2 can cause intestinal toxicity due to inhibition of intestinal crypt cell renewal, a process primarily driven by the Wnt/β-catenin pathway.

[0009] XAV939 is a small molecule that selectively inhibits Wnt/β-catenin-mediated transcription through TNK 1 and 2 inhibition with an IC50 of 11nM/4nM in cell-free assays, regulates axin levels, and does not affect CRE, NF-κB, or TGF-β. Recently, topical application of XAV939 in a mouse ear punch assay demonstrated that XAV939 significantly increased rate of wound closure with reduced fibrosis (scarring). However, XAV939 was dissolved in DMSO and used only as a "research tool" compound due to its very low aqueous solubility (<1mg/mL). The problem with this approach is that humans cannot tolerate the use of DMSO. A soluble form of XAV939 suitable for humans is required for practical and medical use.

[0010] Bastakoty et al. ("Inhibition of Wnt/β-catenin pathway promotes regenerative repair of

cutaneous and cartilage injury," FASEB Journal 2015, 29(12), 4881-4892) reports that therapeutic Wnt pathway inhibition with topical application of two mechanistically distinct small-molecule Wnt pathway inhibitors (XAV939 and pyrvinium) can reduce fibrosis and promote regenerative cutaneous wound repair.

[0011] Jung et al. ("Nanographene Oxide-Hyaluronic Acid Conjugate for Photothermal Ablation Therapy of Skin Cancer," ACS Nano 2014, 8(1), 260-268) reports the application of transdermal nanographene oxide-HA conjugate (NGO-HA) in photothermal ablation therapy of melanoma skin cancers.

Summary of the Invention

[0012] In one aspect of the present invention, a composition for treating a wound is provided. The composition comprises: a matrix component comprising graphene oxide (GO) and hyaluronic acid (HA), wherein the GO and HA are covalently linked via a linker; XAV939; and water. The covalently linked GO and HA is also referred to herein as GO-HA or GO-HA conjugate. The composition can be in the form of a suspension, where the GO-HA can be present in the forms of dispersed microparticles suspended in the water.

[0013] In some embodiments, the composition further comprises a surfactant, which can be a polyethylene glycol (PEG). The PEG can have a molecular weight of about 200 to about 400 Daltons. The PEG can be in an amount of from about 0.1 wt % to about 20 wt % of the total composition.

[0014] In some embodiments, the composition further comprises a thickener, which for example, can be hydroxypropyl cellulose (HPC).

[0015] In some embodiments, the linker linking the GO and HA includes 2-25 carbons. In some embodiments, the linker can be straight-chained (or linear). In other embodiments, the linker can be branched. In some embodiments, the linker comprises a linear alkylene $-C_mH_{2m}-$ unit where m can be from 1 to 20. In some other embodiments, the linker can comprise one or more heteroatoms. For example, the linker can include one or more $-CH_2CH_2O-$ units. In certain embodiments, the linker comprises $-R^x-R^s-R^y-$, wherein R^x and R^y are each independently selected from the group consisting of -CO-, -COO-, -NH-, -NH-NH-, -NH-NH-CO-, -CS-, -S-, -O-, and wherein R^S is an unsubstituted or substituted linear alkylene group having 1-40, or 2-20 backbone carbons. In specific embodiments, R^x and R^y are each -NH-NH-CO-.

[0016] In some embodiments, the weight ratio of XAV939 to GO-HA can be from about 1:100 to about 100:1, for example, from about 1:2 to about 2:1. In some embodiments, XAV939 constitutes from about 0.001 wt% to about 5 wt% of the total composition. In certain embodiments, the GO-HA constitutes from 0.001 wt% to about 5 wt% of the total composition.

[0017] In another aspect, a medical device is provided. The medical device includes a substrate; and the composition(s) described herein which is applied on the substrate. The substrate can be a patch, a pad, a suture, a gauze, a tape, or a bandage.

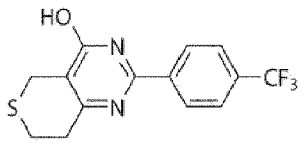
[0018] In a further aspect, provided is a composition for use in the treatment of a cutaneous wound in a subject (a human or non-human animal, such as a mammal) wherein the amount of the composition is effective for the treatment. The wound can be a surgical wound or a burn. In some embodiments, the wound can be a chronic wound such as an ulcer. In some embodiments, the composition for use in the treatment of a cutaneous wound in a subject (a human or non-human animal, such as a mammal) is for use with a second wound medication in the subject, the second wound medication comprising one or more of: corticosteroid, a cytotoxic drug, an antibiotic, an antiseptic, nicotine, an anti-platelet drug, an NSAID, colchicine, an anti-coagulant, a vasoconstricting drug or an immunosuppressive, a growth factor, an antibody, a protease, a protease inhibitor, an antibacterial peptide, an adhesive peptide, a hemostatic agent, living cells, honey, and nitric oxide.

[0019] Disclosed is a method of preparing a GO-HA conjugate. The method includes: modifying GO by converting at least some of the benzoxylic acid groups of the GO to terminal aliphatic carboxylic acid groups; derivatizing HA by reacting HA with a reagent having dual functional groups reactive to the terminal aliphatic carboxylic acid groups, the dual functional groups intervened by a spacer group; and reacting the modified GO and the derivatized HA to form the GO-HA conjugate. The disclosure provides that the spacer group can comprise a linear alkylene having 2-20 backbone carbons. The disclosure provides that the reagent for derivatizing HA is a dihydrazide. the disclosure provides that in the GO-HA conjugate, the weight ratio of GO:HA is from about 1:1 to about 1:20, or from about 1:6 to about 1:10.

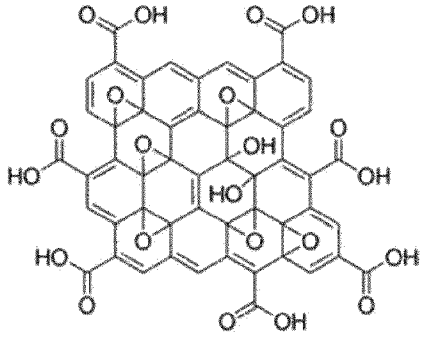
Detailed Description

[0020] In one aspect of the invention, a composition for treating a wound is provided, which includes: a matrix component comprising a conjugate of graphene oxide (GO) and hyaluronic acid (HA) where GO and HA are covalently linked via a linker; XAV939; and water. The covalently-linked GO and HA is also referred to herein as GO-HA conjugate or simply GO-HA.

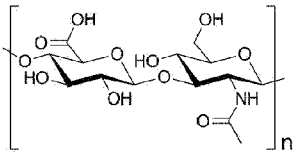
[0021] XAV939 is a potent tankyrase inhibitor, with a chemical name 3,5,7,8-Tetrahydro-2-[4-(trifluoromethyl)phenyl]-4H-thiopyrano[4,3-d]pyrimidin-4-one. The structure of XAV939 is shown below:



[0022] Graphene oxide (GO) as used herein refers to an oxidized form of graphene, which is a single layer form of graphite. GO can be obtained by treating graphite with strong oxidizers. GO contains carbon, oxygen, and hydrogen in various amounts, depending on how it is made. It can have several hundreds of nanometers, up to several micrometers, its planar direction, and about 0.7-1.2 nm in thickness. GO can include various oxygen containing moieties, such as oxygen epoxide groups, carboxylic acid (-COOH), phenol, etc., when prepared using sulphuric acid (e.g. Hummers method). An example GO structure is shown below.



[0023] Hyaluronic acid (HA) is an anionic, highly hydrophilic, non-sulfated glycosaminoglycan, occurring naturally throughout the human body. It can be several thousands of carbohydrate units long, and can bind to water giving it a gel of stiff viscous quality. An example structure of HA is provided below:



[0024] In the composition of present invention, the GO and HA are covalently linked to form a matrix component (or a carrier), which can serve to solubilize XAV939 as well as providing other simultaneous benefits to wound healing. The covalent linking can be accomplished by using a linker (or linker moiety). In some embodiments, the linker can include 2-25 carbons. In some embodiments, the linker is linear. In other embodiments, the linker is branched. The linker can be saturated or unsaturated.

[0025] In some embodiments, the linker can comprise a C_2-C_{25} alkylene group, where the carbons and hydrogens in the alkylene group can be substituted by oxygen or other atoms or groups such as hydroxy, carboxy, amino, alkyl, alkoxy, alkenyl, alkynyl, nitro, etc. In some embodiments, the linker can comprise one or more -CH_2CH_2O- units.

[0026] In some embodiments, the linker comprises -R^X-R^S-R^y-, wherein R^X and R^y are each independently selected from the group consisting of -CO-, -COO-, -NH-, -NH-NH-, -NH-NH-CO-, -CS-, -S-, and -O-, and wherein R^S (which is also referred to as the spacer group in this application) can be an unsubstituted or substituted, saturated or unsaturated linear alkylene group having 2-20 backbone carbons. In particular embodiments, both R^X and R^y are *-NH-

NH-CO- (* denoting the end of the linker distal to R^S).

[0027] In some embodiments of the composition, the weight ratio of XAV939 to GO-HA can be from about 1:100 to 100:1, e.g., from about 1:2 to about 2:1. In some embodiments, in the GO-HA conjugate, the weight ratio of GO:HA can be from about 1:1 to about 1:20, or from about 1:6 to about 1:10.

[0028] In general, the composition overall can appear as a slightly dark or black viscous liquid. XAV939 is evenly dispersed in the viscous suspension, which is stable at room temperature for months. In some embodiments, the composition further comprises a surfactant that enhances mixability or solubility of hydrophobic substances in water. In some examples, the surfactant can be a non-ionic hydrophilic material such as polyethylene glycol (PEG). The PEG can have a number-averaged molecular weight of from about 100 to about 10,000 Daltons, or about 200 to about 4000 Daltons, e.g., from about 200 to about 1000, from about 200 to about 800, from about 200 to about 500, from about 200 to about 400, from about 300 to about 400, from about 350 to about 450, about 200, about 250, about 300, about 350, about 400, about 450, about 500, about 550, about 600, about 650, about 700, about 750, about 800, about 850, about 900, about 950, about 1000 Daltons, etc. In some embodiments, the PEG can be present in the composition in an amount of from about 0.1 to about 20 wt % of that of the total composition. For example, the PEG can be from about 0.2 wt% to about 10 wt%, or from about 0.5 wt% to about 10 wt%, or from about 1 wt% to about 10 wt% of the total composition.

[0029] Other non-ionic hydrophilic material such as copolymers of PEG and PPG (polypropylene glycol), e.g., poloxamers, can also be used. In one example, Poloxamer-188 (which has an average molecular weight of about 8400 Daltons) can be used.

[0030] In some embodiments, the composition further comprises pharmaceutical carriers or excipients compounds or materials which enable the compositions to be presented in topically administrable semi-solid aqueous gel forms. For example, carboxymethylcellulose can be used as a gel-forming agent. However, other cellulose derivatives such as microcrystalline cellulose as well as polysaccharides such as alginate and agarose, tragacanth, guar gum, xanthum gum, are also suitable as gel-forming agents. The gel may, if required, be made thicker and/or stiffer by addition of a relatively resilient gel-forming material such as a cross-linked fibrous protein, e.g. gelatin or collagen cross-linked with formaldehyde.

[0031] In some embodiments, the composition can be in a form of a cream, which can include those excipients suitable for a cream formulation, such as paraffin oil, vaseline, wax, organic esters such as cetyl palmitate, etc.

[0032] In some embodiments, the composition of the invention further comprises a thickener for desired viscosity of the composition for skin delivery. For example, the thickener can include hydroxypropyl cellulose (HPC). HPC can make the composition into a smooth film for easy application. It also reduces evaporation and allows the wound to stay moist longer, a factor that has been shown to improve healing and result in decreased scarring. There are different

grades of HPC available according to molecular weights or viscosity of certain concentrations of HPC water solution.

[0033] In some embodiments of the composition, XAV939 can constitute from about 0.001 wt% to about 5 wt% of the total composition (including water). In some embodiments, XAV939 can constitute from about 0.01 wt% to about 2 wt%, from about 0.02 wt% to about 1 wt%, or from about 0.05 wt% to about 0.5 wt% of the total composition. In some embodiments, GO-HA constitutes from about 0.001 wt % to about 5 wt % of the total composition. In some embodiments, GO-HA can constitute from about 0.01 wt% to about 2 wt%, from about 0.02 wt% to about 1 wt%, or from about 0.05 wt% to about 0.5 wt% of the total composition.

[0034] In the compositions as described herein, other pharmaceutical or therapeutic compounds may be included in addition to XAV939. In other words, the compositions with XAV939 present can also serve as a base dispersion medium in which other pharmaceutical or therapeutic agents, especially those which are hydrophobic, may be dispersed, e.g., for topical administration to treat wound. These agents may include antifibrotic compounds such as pirfenidone, halofuginone, nintedanib, tocilizumab, rilonacept, etc., anti-cancer agents, anti-inflammatory agents, analgesics, antibiotics, etc.

[0035] In another aspect of the invention, a medical device is provided, which includes the composition as described herein, and a substrate upon which the composition is applied. The medical device can be in a form that facilitates topical administration of the composition, where the substrate can be constructed with suitable strength and flexibility for covering, securing and/or protecting the wound. For example, the substrate can be a patch, a pad, a tape, a bandage, a gauze, a suture, etc.

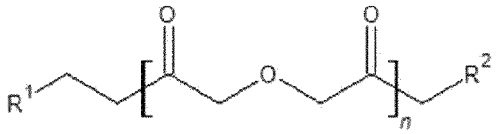
[0036] In yet another aspect of the invention, a composition for use in the treatment of a cutaneous or dermal wound in a subject (e.g., a human or a non-human animal) is provided. The amount of the composition for use is effective as described herein. The wound can be a type where its normal healing is accompanied by scar formation. The wound can be a surgical wound that is caused by a physical impact that disrupts the structure and function of the skin (such as a laceration, abrasion, cut, scratch or puncture by a knife, scalpel, bullet, or other sharp or blunt objects). The wound can also be caused by excessive (low or high) temperature, such as a burn. The wound can also be a chronic wound that does not heal in expected time due to the lack of one or more of the main requirements of healing, including a good supply of blood, oxygen and nutrients, and a clean and infection-free environment. Examples of chronic wounds include ischemic wounds where the wound area is not getting sufficient blood supply. Diabetic ulcers are a common type of ischemic wounds.

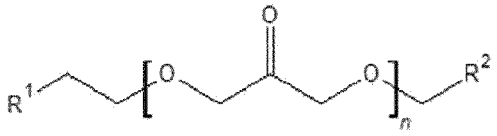
[0037] The composition(s) of the present invention described herein are topical composition(s) for use on the wound site. If the composition is included in a medical device described herein which includes a substrate such as a patch or a pad, the medical device can be secured to the wound site such that the composition contacts the wound.

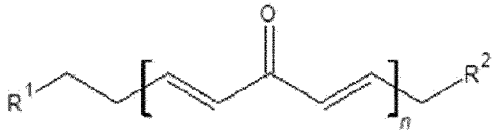
[0038] In some embodiments, the composition for use in the treatment is for use with a second wound medication or therapeutic agent in the subject, comprising one or more of: corticosteroid, a cytotoxic drug, an antibiotic, an antiseptic, nicotine, an anti-platelet drug, an NSAID, colchicine, an anti-coagulant, a vasoconstricting drug or an immunosuppressive, a growth factor, an antibody, a protease, a protease inhibitor, an antibacterial peptide, an adhesive peptide, a hemostatic agent, living cells, honey, and nitric oxide. These therapeutic agents can be compositions that are separate dosage forms from the compositions described herein, or may be included as additional components of the compositions described herein, hence in the same composition with XAV939.

[0039] Disclosed are methods for preparing the compositions described herein and the intermediate compounds. Disclosed is a method of preparing a GO-HA conjugate which includes: (a) modifying GO by converting at least some of the benzoxylic acid groups of the graphene oxide to terminal aliphatic carboxylic acid groups; (b) derivatizing HA by reacting HA with a reagent having dual functional groups reactive to the terminal aliphatic carboxylic acid groups, the dual functional groups being intervened by a spacer group; and (c) reacting the modified GO obtained in (a) and derivatized HA obtained in (b), thereby forming a GO-HA conjugate.

[0040] In the above preparation method, the spacer group can be an unsubstituted or substituted, saturated or unsaturated linear alkylene group having 2-20 backbone carbons. For illustration and not limitation, the reagent for derivatizing HA can be selected from the following:







where R^1 and R^2 can be independently -CONHNH$_2$, -SH, -NH$_2$, -OH, or other nucleophiles, and n is an integer and can be for example, 1-20, e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, etc. In this

disclosure, the reagent for derivatizing HA can be a dihydrazide, such as adipic acid dihydrazide.

[0041] According to this disclosure, a method for preparing a composition includes: obtaining GO-HA (e.g., by the methods above), dissolving the GO-HA conjugate in water to obtain a GO-HA water solution, and adding XAV939 to the GO-HA water solution to form a mixture. In some examples, this is accomplished by dissolving XAV939 first in a non-ionic hydrophilic polymer, e.g., PEG-400 (or PEG 400, having an average molar mass of about 400), and then the XAV939 solution is added into the GO-HA conjugate water solution.

[0042] The present invention provides a wound treatment strategy that simultaneously addresses several facets of wound healing by synergistically combining a multi-functional scaffold (GO) conjugated to a highly hygroscopic material (HA) traditionally beneficial in wound healing, and aqueous solubilization of a potent Wnt pathway inhibitor (XAV939) for improved healing of cutaneous wounds with reduced scarring. Without wishing to be bound by any particular theory, it is believed the compositions of the present invention can prevent, reduce, or inhibit dermal fibrosis and scarring in wound healing by inhibiting TNK1 and 2 via XAV939 targeting the Wnt/β-catenin in the skin, thereby directing wound healing toward a regenerative process rather than a fibrotic process. It is believed that XAV939 is coated onto the GO as a nanocarrier due to the ability of GO to complex (via π-π interactions) hydrophobic compounds, and with the hydrophilic HA linked to GO, rendering the hydrophobic compounds "water soluble". Also, GO may serve as a scaffold for cell growth and communication due to its good biocompatibility, and properties that influence cell-cell-communication, cell division and cell fate, as well as possible suppression of microbes.

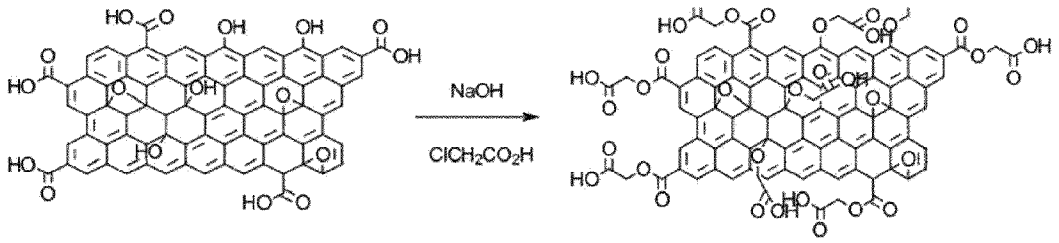
[0043] Additional benefits of the topical composition and topical administration of embodiments of the present invention is low toxicity and high bioavailability of the beneficial components to the site of injury/wound.

[0044] The invention is defined in the claims. Any aspects, embodiments and examples of the present disclosure which do not fall under the scope of the appended claims do not form part of the invention and are merely provided for illustrative purposes. For example, the following examples are provided for purpose of illustration of certain parts of the description herein.

[0045] The instrumentation used in the Examples: FT-IR: Thermo Nicolet 380 FT-IR with a SmartOrbi Diamond ATR accessory; 1H NMR: 500 MHz Bruker DRX500 or AV-500 NMR spectrometer; UV-Vis: Shimadazu Pharma Spec UV1700. Solvents: 99% pure, supplied by Sigma-Aldrich; Sonication was conducted at 42kHz in a bath sonicator.

Example 1: Modification of GO

[0046]



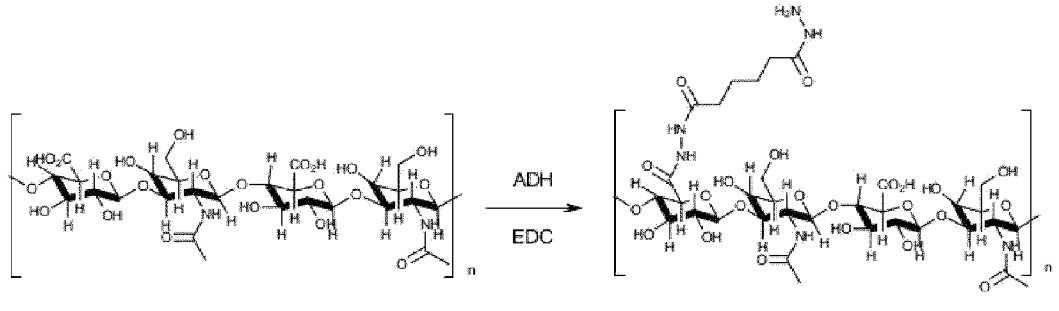
Scheme 1

[0047] Although GO includes many carboxylic acid groups on its edges, the reactivity of these aromatic carboxylic acid groups is not high. To improve its linking efficiency with HA, some of these aromatic carboxylic acid groups on GO are converted to aliphatic aromatic carboxylic groups. See Scheme 1. In this step, some hydroxyl groups of GO are also converted to carboxylic groups (as illustrated above).

[0048] Graphene oxide (1.25g, 250 mL of 5 mg/mL GO dispersion in de-ionized water; supplier: Goographene Inc.) was added to 250 mL of ultra-pure de-ionized water and stirred for 5 minutes. Sodium hydroxide pellets (3 g (0.075 moles; supplier: Sigma-Aldrich) were added in small solid portions to the mixture over 30 minutes. Once addition was complete, it was stirred for 1 hour at room temperature. Next the solution was ultrasonicated for 30 minutes, and then chloroacetic acid (3.54 g (0.0375 moles); supplier: Alfa Aesar) was added in small, solid portions over 20 minutes. The reaction mixture was then stirred for 18 hours at room temperature. The reaction mixture was acidified with hydrochloric acid (7 mL, 12 N). The solution was then transferred to centrifuge tubes and centrifuged for 15 minutes at 5,000 rpm. The water layer was then decanted and more ultra-pure deionized water (~30 mL) added to the tubes before re-centrifugation. This process was repeated 3 times. Methanol (-30 mL) was added to the precipitated, modified graphene oxide remaining in the centrifuged tubes and centrifuged at 5,000 rpm for 15 minutes. This process was repeated 3 times. Once the methanol was decanted, the tubes were put under vacuum for 48 hours at room temperature for drying. A total of 0.926 g of modified graphene oxide was obtained. ^{1}H NMR (500 MHz, D_2O) δ: 4.173 (-CH_2CO_2H) ppm (diagnostic peak). FT-IR: 1593 cm^{-1}, (C=C), UV-Vis λ: 268 nm.

Example 2: Derivatization of HA

[0049]



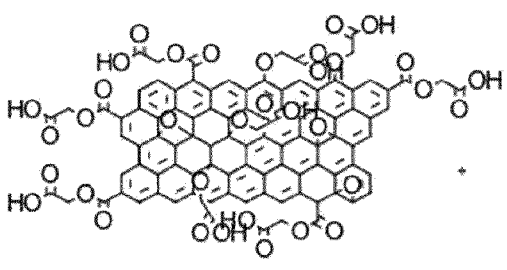
Scheme 2

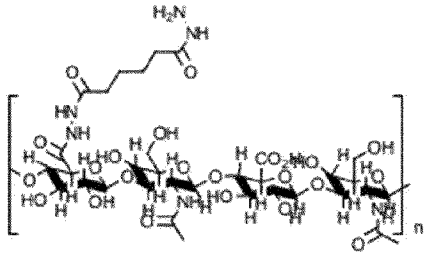
Scheme 2

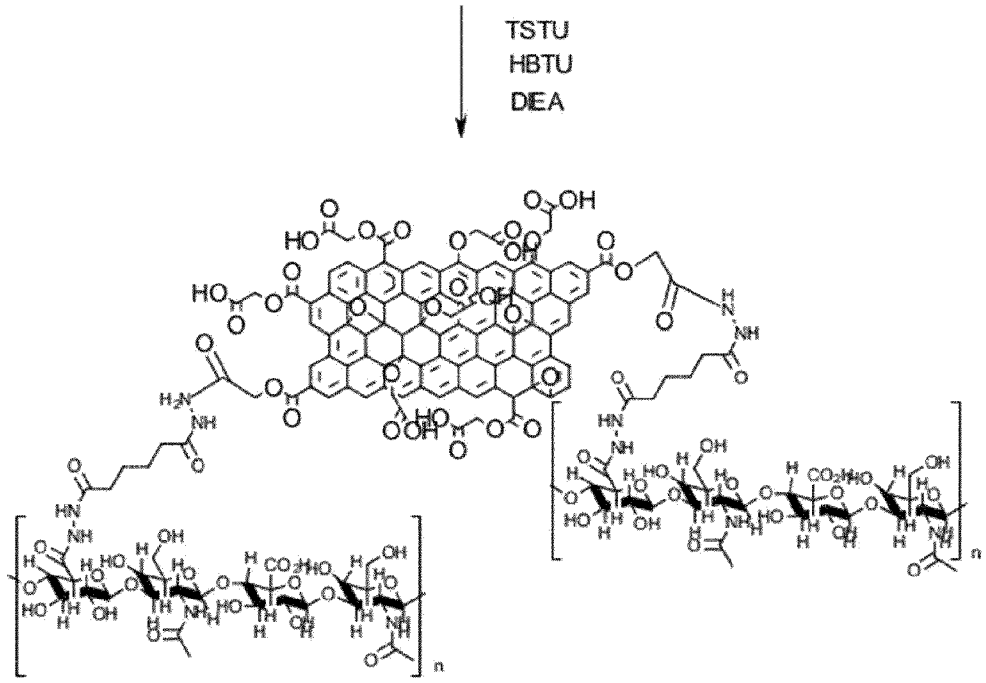
[0050] The general procedure of derivatizing HA is shown in Scheme 2. Hyaluronic acid (100mg, MW=10,000 (n=13.5 in the scheme), 0.00001 moles; supplier: Creativepegworks) in ultra-pure deionized water (20 mL) was stirred for 5 minutes at room temperature. 1-(3-Dimethylaminopropyl)-3-ethyl carbodiimide hydrochloride (EDC) (52mg, 0.00027 moles, supplier: Alfa Aesar) was added to the mixture and stirred for 3 hours at room temperature. During this time, the pH of the solution was maintained at approximately 5 to 6 by small additions of 0.1 N hydrochloric acid. This mixture was added dropwise to a separate mixture containing adipic dihydrazide (ADH) (17mg, 0.00027 moles; supplier: Alfa Aesar) in 5 mL of ultra-pure deionized water at room temperature. Once the addition was complete, it was stirred at room temperature for 18 hours. The solution was then subjected to dialysis (MWC=3500) for 24 hours. The mixture was then lyophilized to obtain a white powder (100 mg). ^{1}H NMR (500 MHz, D_2O) δ: 2.4 (2H), 2.26 (2H), 1.66 (4H) ppm (diagnostic peaks). The substitution/loading degree was determined by the ratio of methylene hydrogens of adipic hydrazide to acetyl methyl protons of the Hyaluronic acid moiety. Integration indicated 30% coupling, resulting in approximately 8 substitutions. Coupling ranges were commonly 6-30%. A 6% coupling resulted in ~1.6 carboxyl units substituted.

Example 3: Reaction between modified GO and derivatized HA to prepare GO-HA conjugate

[0051] The general procedure of preparing GO-HA is outlined in Scheme 3 below. The modified GO obtained in Example 1 (0.90 g) was added to ultra-pure deionized water (100 mL) and stirred for 5 minutes, followed by ultra-sonication for 15 minutes. 2-Succinimido-1,1,1,3-tetramethyluronium tetrafluoroborate (TSTU) (0.32g, 0.001 moles; supplier: Alfa Aesar), 2-(1H-benzotriazol-1-yl)-1,1,3,3-tetramethyluronium hexafluorophosphate, Hexafluorophosphate Benzotriazole Tetramethyl Uronium (HBTU) (0.41g, 0.001 moles; supplier: Aldrich) and diisopropylethyl amine (DIEA) (0.15 mL, 0.001 moles; supplier: Sigma-Aldrich) was added to the mixture at room temperature and stirred for 5 minutes. Then a solution of hyaluronic acid-adipic hydrazide (obtained from Example 2) (0.90 g in 150 mL of ultra-pure deionized water) was added dropwise to the activated graphene oxide solution at room temperature. The reaction mixture was allowed to stir for 18 hours and then subjected to dialysis (MWC = 20,000) for 2 days. The solution was then lyophilized to yield a black powder (1.13 g). ^{1}H NMR (500 MHz, D_2O) δ: 1.94 (2H), 1.90 (2H), 1.21 (4H) ppm (diagnostic peaks).



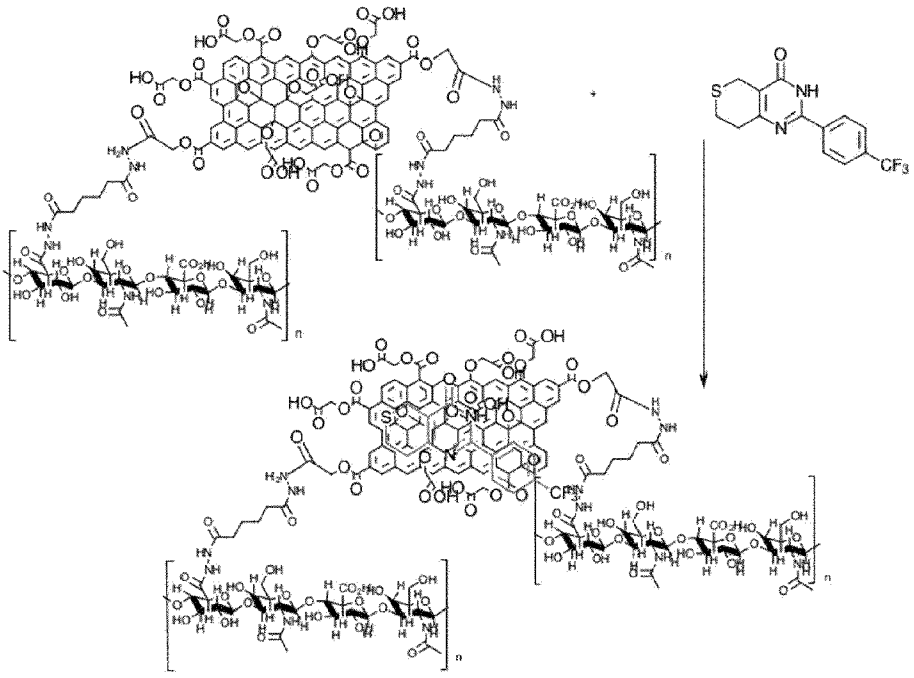




Scheme 3

Example 4: Preparation of wound-treating composition

[0052]



Scheme 4

[0053] The procedure of preparing the composition is schematically shown in Scheme 4. 11

mg of the GO-HA obtained in Example 3 was dissolved in 11 mL of ultra-pure water, to create an effective concentration of 1 mg/mL. The solution was ultrasonicated for 10 minutes. XAV939 (11 mg; supplier: APEBIO) was added to PEG-400 (0.5mL) and subjected to ultrasonication for 30 minutes. The XAV939 PEG-400 solution was added dropwise to the GO-HA and vigorously stirred for 5 minutes. The combined solution was then subjected to ultrasonication for 1 hour and then stirred at room temperature for 18 hours. Hydroxypropyl cellulose (0.2 g; supplier: Sigma-Aldrich) was added in small portions at room temperature with vigorous stirring. Once addition was complete, the solution was stirred at room temperature for 24 hours to form a viscous solution of the GO-HA / XAV939 complex. The complex was to be used as is.

Example 5. Animal Study 1

[0054] The objective of this study was to observe the wound healing effect of a composition of the present invention (STM42) in a dermal full thickness injury rat model following topical administration.

5-1: Test Article

[0055] STM42: the composition made according to the procedure described in Example 4. Vehicle: 96 vol % water and 4 vol % PEG-400.

5-2 Animal Husbandry

[0056] 16 Sprague-Dawley rats at age of about 6-8 weeks were used. Animal room was set to maintain a temperature of 23±2 °C, humidity of 40-70%, and a 12-hour light/12-hour dark cycle. SPF Rat Growth Breeding Feed was provided ad libitum throughout the in-life portion of the study. Reverse Osmosis water was available to the animals ad libitum. Animals were free to access both food and water during the whole course of study.

5-3 Animal Grouping and Test Procedure

[0057] Animals were housed 5 rats per cage and acclimated for 5-7 days. They were then each anesthetized with pentobarbital sodium (45 mg/kg, ip., 2% in saline) and shaved on both sides of the back with an electric clipper, disinfected by applying betadine followed by 70% ethanol wiping. A (3 to 4 cm^2) full thickness of elliptical excision wound was created using toothed forceps, Acupunch® (12mm, Acuderm Inc, USA) and scissors, skin was removed from the underlying muscle.

[0058] The animals were allocated to two groups according to the wound areas and body weight. Each group consists of 8 animals. Vehicle group: G1 (G1-1, G1-2, G1-3, G1-4, G1-5, G1-6, G1-7, G1-8); STM42 group: G2 (G2-1, G2-2, G2-3, G2-4, G2-5, G2-6, G2-7, G2-8). The grouping is summarized below.

Group	Number of animals	Treatment	Dosage (μL /rat)	Route of Adm.	Dosing Schedule
1	8	Vehicle	100	Topical	QD×14d
2	8	STM42	100	Topical	QD×14d

[0059] STM42 and vehicle were topically administered to the animals respectively via a syringe to drip the formulation directly into the wound bed to create an even and consistent layer over the wound to cover all of the wound area. The treatment was continued daily for 2 weeks (14 days) following injury.

[0060] The animal body weight was measured twice weekly. Wound area boundary was drawn on a transparency paper with a permanent marker on Day 1, Day 5, Day10 and Day 15 and the area will be measured with ImagePro Premier®. Photos of the wound of each rat were taken on Day 1, Day 5, Day 10 and Day 15.

[0061] For HE staining: Two 5 μm slides per wound was stained with H&E and Masson's Trichrome and digitally scanned for pathology analysis. The pathology analysis included: (1) Evaluation of Scar resolution and rete ridges formation (dermal-epidermal junctions) in healing skin: Create Massons trichrome stained sections of skin from the full-thickness excisional wounds and evaluate "linear" extracellular matrix (scar-like) for all articles. (2) Evaluation of fiber thickness of healing skin by Massons trichrome stained sections imaged with circular polarized light for each article. (3) Evaluate rete-ridge for each article by H&E staining for each article.

5-4 Pathology testing:

[0062] Materials: Skin samples, 10% formalin, hematoxylin, Eosin staining solution, acid fuchsin, Aniline Blue, dimethylbenzene, 70% alcohol, 95% alcohol, 100% alcohol, etc.

[0063] Instruments: Tissue hydroextractor (Shandon Excelsior ES™ Tissue Processor Fisher/Thermo A78400006); Tissue Embedder (Shandon Histocentre™ 3 Tissue Embedding Center Fisher/Thermo B64100010); Leica automatic slicing machine (Leica RM2255); Automatic staining machine (Automatic Slide Stainer Fisher/Thermo A74200010, Shandon Varistain® 24-4)

[0064] Tissue processing & slicing: (1) Tissue processing by tissue hydroextractor: gradient

alcohol dehydration, transparentizing by dimethylbenzene, paraffin infiltration, embedding. (2) The samples are cut into 5 μm thick slides by Leica automatic slicing machine (3) H&E staining, Masson staining.

[0065] Evaluation parameters: re-epithelialization, neovascularization, Rete Ridge, scabbing, granulation. Scoring criteria are summarized in the below table:

1. Re-epithelialization		
New epithelium attempting to bridge over the wound gap	0	No ingrowth of epithelium into the wound gap
	1	Small stumps of growth from the edge
	2	Large gap between the bridging epithelium
	3	Small gap between the bridging epithelium
	4	Complete bridging over the wound
2.N eovascularization		
Newly formed vascular network in the wound bed	0	Relatively normal
	1	Mildly increased in number in the wound bed
	2	Moderately increased in number in wound bed
	3	Moderately to markedly increased in number in wound bed
	4	Markedly increased in number in wound bed
3.Rete-ridge		
Newly formed columns of epithelium extending downward to dermis of the wound bed	0	No formation of rete ridge
	1	Few columns formed
	2	Mildly increased in number
	3	Moderately increased in number
	4	Markedly increased in number
4. Scabbing		
Formation of scab on the cornified layer or on the wound bed	0	Relatively normal
	1	Small amount of scabbing
	2	Moderate amount of scabbing
	3	Moderate to marked amount of

4. Scabbing		
		scabbing
	4	Marked amount of scabbing
5. Granulation		
Accumulation of inflammatory cells in the matrix of fibrotic/scar tissues in the wound bed of dermis	0	Relatively normal
	1	Small amount scattered in the wound bed
	2	Moderate amount across the wound bed
	3	Dense fibrotic tissues with heavy infiltration of inflammation
	4	Fibrinoid formation in the dermis

5-5 Observation & analysis

[0066] Clinical signs: all clinical signs were recorded for individual animals, once before commencement of treatment and once daily during the study; observations were performed at the same time interval each day.

[0067] Terminal Studies: Animals in extremis or disposed for humane reasons and those that have completed the scheduled test period would be euthanized by carbon dioxide.

[0068] Statistical Analysis: The results (individual and group) were analyzed using Student's unpaired t-test. Data were given as Mean ± SD or Mean ± SEM. $P<0.05$ was considered significant.

5-6 Results

[0069] Clinical signs: Mortality, morbidity and the abnormal behavior were not found during the treatment period of the experiment. During the course of the experiment, the following signs did not occur: suffering (cachexia, weakening, difficulty to move or to eat, pain, cryings); toxicity (hunching, convulsions); 25% body weight loss for three consecutive days or 20% body weight loss on any day. There was no significant difference between groups in wound areas during the experiment ($p>0.05$).

[0070] On Day 15, 3 rats in each group (vehicle group: G1-4, G1-5, G1-8; STM42 group: G2-3, G2-4, G2-6) with an average wound healing rate were euthanized with carbon oxide, and

wound tissue were excised and fixed neutral formalin buffer then embedded in paraffin for histology.

[0071] The scores of the STM42 group and the vehicle group are represented in Figure 1. From Figure 1 it can be seen that STM42 had a significant effect on re-epithelization (essential component of wound healing used as a defining parameter of a successful wound closure), improved neovascularization (the natural formation of new blood vessels, usually in the form of functional microvascular networks, capable of perfusion by red blood cells, that form to serve as collateral circulation in response to local poor perfusion or ischemia), improved rete ridge formation (epithelial extensions that project into the underlying connective tissue in both skin and mucous membranes-improved rete ridge formation is a sign of tissue regeneration rather than fibrosis / scarring (reduced rete ridge formation), decreased scabbing (wounds with scabs take longer to heal and a sign of fibrosis/scarring) and decreased granulation (granulation tissue is composed of extracellular matrix proteins such as fibrin and type III collagen that can be quickly laid down by the initial surge of fibroblasts that is recruited to the wound site-causing a scar).

[0072] The total effect of STM42 toward wound healing with scar reduction can be evaluated using the following formula: Total = (Re-epithelization + Neovascularization + Rete ridge formation) - (Scabbing + Granulation)). Using mean measured values for each category: STM42 = 4.66. Vehicle = -1.33. Under this metric, there is a 5.99-fold increase in scar reduction using STM42 in this study as compared to the control group.

Example 6. Animal Study 2

[0073] The objective of this study was to observe the wound healing effect of STM-52 in a dermal full thickness injury STZ induced diabetic rat model with topical administration.

6-1 Compound and preparation

[0074] STM-52 (or STM52): same as STM42, the composition made according to the procedure described in Example 4.

[0075] Vehicle: 96 vol % water and 4 vol % PEG-400.

6-2 Test article preparation procedure

[0076] Admixing the STM-52 well by sonicating for 10 minutes before injecting via syringe 100uL of sample onto the wound.

6-3 Animal husbandry

[0077] 14 male Spargue-Dawley rats, grade SPF of an age of about 6-8 weeks were used. The rats had a blood glucose of > 16.7mM

[0078] Weight at initiation of treatment: Within the range of 200~300g.

[0079] Acclimation period: 7 days.

[0080] Environmental controls for the animal room were set to maintain a temperature of 23 ± 2°C, humidity of 40~70%, and a 12-hour light/12-hour dark cycle. The 12-hour dark cycle may be temporarily interrupted to accommodate study procedures.

[0081] Food and water: SPF Rat Growth Breeding Feed (BEIJING KEAO XIELI FEED CO. LTD.) was provided ad libitum throughout the in-life portion of the study. Reverse Osmosis water was available ad libitum.

[0082] Animal selection and fasting: Animals to be used in this study were selected based on overall health and acclimation to caging. Animals were free to access both food and water during the whole course of study.

6-4 Experimental design

[0083] Upon arrival at the animal facility, the animals were housed 5 rats per cage and acclimated for seven days. Prior to the experiments, food was withdrawn for about 16 hours. The rats were rendered diabetic by an i.p. injection of STZ (65mg/kg) dissolved in sodium citrate buffer, pH 4.5. The rats with a final blood glucose level>16.7 mM (300 mg/dL) were included in the study. All the selected rats were anesthetized with pentobarbital sodium (45mg/kg, i.p. 2% in saline) and shaved on both sides of the back with an electric clipper, disinfected by iodophor followed by 75% ethanol wiping. A (3 to 4cm^2) full thickness of elliptical excision wound was created using Acupunch® (12mm, Acuderm Inc, USA). The skin was removed from the underlying muscle using scissors and toothed forceps.

[0084] The animals were divided into two groups according to the wound area and the body weight.

Group	Number of Animals	Treatment	Dosage(μL/rat)	Route of Adm.	Dosing Schedule
1	7	Vehicle	100	Topical	QD×21d
2	7	STM-52	100	Topical	QD×21d

[0085] The wound was topically administrated (via a syringe to drip the formulation directly into the wound bed to create an even and consistent layer over the wound making sure to cover all of the wound area) with STM-52 or vehicle (100µL/rat). The treatment was continued daily for 21 days following injury.

[0086] Figure 2 is a plot showing the average area size of the wounds of the Vehicle group and the STM-52 group during the course of the 21-day treatment. The results indicate that topical administration of STM-52 increased the rate of healing of the diabetic rat impaired healing animal model as compared to vehicle. Primarily, the rate increase was observed on days 10-18 of the 21 day study. Also during this time, there were no signs of overt toxicity as indicated by body weight measurements.

[0087] The word "about" as used herein in association with a numeric value or a numeric range mean "approximately" and refers to a result that can be obtained within a tolerance and the skilled person knows how to obtain the tolerance, for example, ± 10% of the given value or range.

[0088] The term "effective amount" or the phrase "the amount of the composition effective for" as used herein means the amount of a composition that, when administered to a subject for treating an undesirable or diseased condition (e.g., treating a wound) of the subject, is sufficient to ameliorate or improve such condition. The "effective amount" may vary depending on the composition, the condition and its severity, and the age, physical condition, and responsiveness of the subject to be treated.

REFERENCES CITED IN THE DESCRIPTION

Cited references

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Non-patent literature cited in the description

- **BASTAKOTY et al.**Inhibition of Wnt/β-catenin pathway promotes regenerative repair of cutaneous and cartilage injuryFASEB Journal, 2015, vol. 29, 124881-4892 [0010]

- **JUNG et al.**Nanographene Oxide-Hyaluronic Acid Conjugate for Photothermal Ablation Therapy of Skin CancerACS Nano, 2014, vol. 8, 1260-268 [0011]

SAMMENSÆTNINGER OG FREMGANGSMÅDER TIL SÅRBEHANDLING

PATENTKRAV

1. Sammensætning, der omfatter:

en matrixbestanddel omfattende et graphenoxid-(GO)- og hyaluronsyre-(HA)-konjugat (GO-HA), hvor GO og HA er kovalent bundet via en linker;

3,5,7,8-tetrahydro-2-[4-(trifluormethyl)phenyl]-4H-thiopyrano[4,3-d]pyrimidin-4-on (XAV939); og

vand.

2. Sammensætning ifølge krav 1, der endvidere omfatter polyethylenglycol (PEG), hvor PEG fortrinsvis har en molekylvægt på fra ca. 200 til ca. 400 Dalton, og hvor PEG fortrinsvis er i en mængde på fra ca. 0,1 vægt-% til ca. 20 vægt-% af den totale sammensætning.

3. Sammensætning ifølge krav 1, hvor linkeren omfatter 2-25 kulstoffer.

4. Sammensætning ifølge krav 1, hvor linkeren omfatter én eller flere $-CH_2CH_2O-$enheder.

5. Sammensætning ifølge krav 1, der endvidere omfatter et fortykkelsesmiddel.

6. Sammensætning ifølge krav 5, hvor fortykkelsesmidlet omfatter hydroxypropylcellulose (HPC).

7. Sammensætning ifølge krav 1, hvor linkeren omfatter $-R^x-R^s-R^y-$, hvor R^x og R^y hver uafhængigt er valgt fra gruppen bestående af -CO-, -COO-, -NH-, -NH-NH-, -NH-NH-CO-, -CS-, -S-, og -O-, og hvor R^s er en ikke-substitueret eller substitueret, lineær alkylengruppe med 2-20 skeletkulstoffer.

8. Sammensætning ifølge krav 7, hvor R^x og R^y hver er -NH-NH-CO-.

9. Sammensætning ifølge krav 1, hvor vægtforholdet mellem XAV939 og GO-HA er fra ca. 1:2 til ca. 2:1.

10. Sammensætning ifølge krav 1, hvor XAV939 udgør fra ca. 0,001 vægt-% til ca. 5 vægt-% af den totale sammensætning, fortrinsvis fra ca. 0,01 vægt-% til ca. 2 vægt-% af den totale sammensætning.

11. Medicinsk anordning, der omfatter:

et substrat, der fortrinsvis er en patch, en pude, en sutur, gaze, et bånd eller en bandage; og

sammensætning ifølge et hvilket som helst af kravene 1-10 påført substratet.

12. Sammensætning ifølge et hvilket som helst af kravene 1-10 til topisk anvendelse i behandling af et kutant sår hos et menneske.

13. Sammensætning til anvendelse ifølge krav 12, hvor såret er et kirurgisk sår.

14. Sammensætning til anvendelse ifølge krav 12, hvor såret er en forbrænding.

15. Sammensætning til anvendelse ifølge krav 12, hvor såret er et kronisk sår.

DRAWINGS

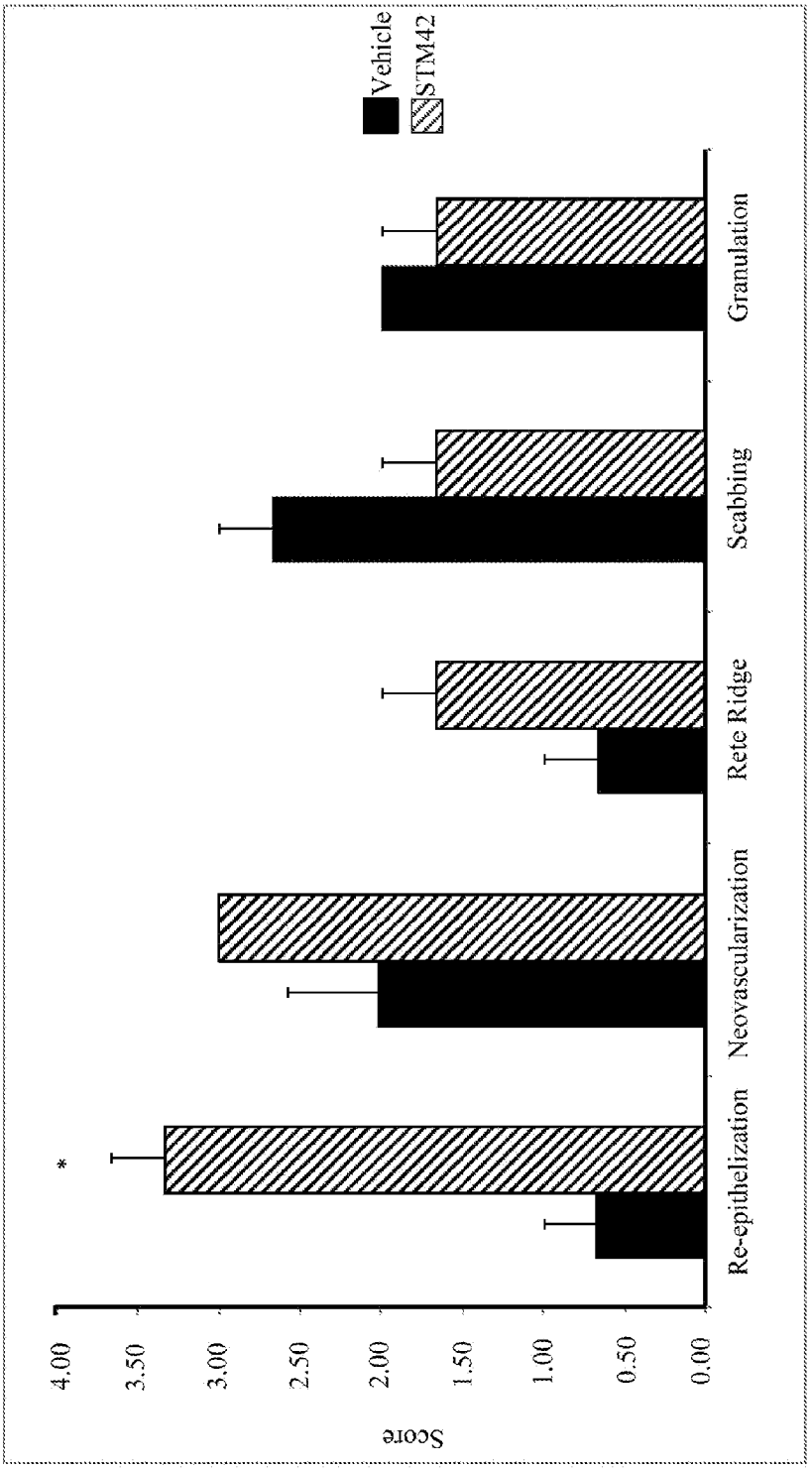


FIG. 1

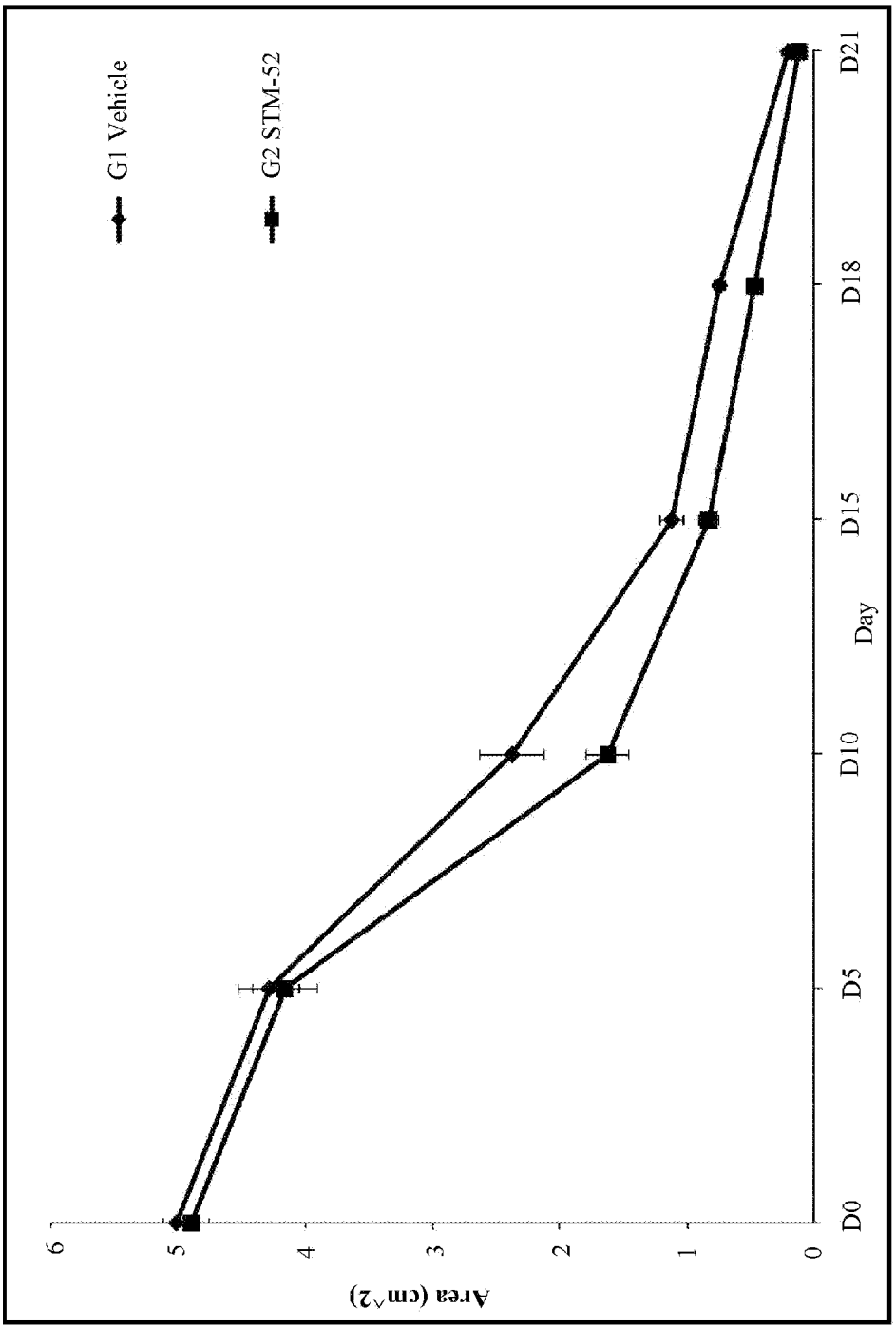


FIG. 2