UROLOGICAL DEVICES INCORPORATING COLLAGEN INHIBITORS

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ABSTRACT
Provided herein are implantable or insertable biomedical devices comprising a substrate and a collagen inhibitor or in said substrate, and methods of treatment using the same. In some embodiments, the device is a urethral, ureteral, or nephroureteral catheter or stent. Kits comprising the same are also provided.
Rat Halofuginone Levels in vivo

Figure 3

Rat Halofuginone Levels *in vivo*

Figure 4
Figure 5
UROLOGICAL DEVICES INCORPORATING COLLAGEN INHIBITORS

RELATED APPLICATIONS

[0001] This application is a continuation-in-part of application Ser. No. 11/948,335, filed Nov. 30, 2007, which claims the benefit of U.S. Provisional Patent Application Ser. No. 60/868,217, filed Dec. 1, 2006, the disclosure of each of which is incorporated by reference herein in its entirety.

[0002] This application is related to application Ser. No. 11/948,294, filed Nov. 30, 2007, and application Ser. No. ______, filed May 30, 2008, the disclosures of each of which is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

[0003] The present invention concerns medical devices, including implantable devices such as catheters and stents.

BACKGROUND OF THE INVENTION

[0004] Luminal strictures, such as urethral or ureteral strictures, represent a vexing problem for urologists. Urethral strictures result from spongiofibrosis, most of which is composed of type I collagen, and are due to the imbalance of collagen formation and destruction following urethral injury (Baskin et al. J Urol. 1993 Aug. 150(2 Pt 2):642-7). Urethral strictures are commonly treated with dilation and/or incision followed by stenting, but such techniques have suffered from high failure rates. The use of pharmacologic agents to prevent stricture formation (e.g., MMC, steroids, colchicine) have improved treatment results only marginally.

[0005] Short urethral strictures are typically treated with a direct visual internal urethrotomy (DVIT), or incision of the stricture, followed by catheter stenting for approximately 4 days, in hopes that the new scar will heal around the stent, leaving a large caliber urethra. Unfortunately, wound healing cannot be well controlled, and the new incision heals via the deposition of type-I collagen, which may contract, causing a high rate of stricture recurrence.


[0007] However, oral administration or administration by injection is not ideal. There is need for new approaches to alleviate urethral strictures and other problems associated with medical interventions.

SUMMARY OF THE INVENTION

[0008] Provided herein are implantable or insertable biomedical devices comprising a substrate and a collagen inhibitor on or in said substrate. In some embodiments, the device is a urethral, ureteral, or nephroureteral catheter or stent. In some embodiments, the substrate includes a material selected from the group consisting of vinyl, polyethylene, poly(vinyl chloride) (PVC), ethylene vinyl acetate (EVA), silicone, latex, and polypropylene. In some embodiments, the collagen inhibitor is selected from the group consisting of: mithramycin, mitomycin-c, tranilast, halofuginone and analogs thereof.

[0009] Methods of treating urethral or ureteral strictures in a subject in need thereof are also provided, including topically administering a collagen inhibitor in an amount effective to treat the urethral strictures. In some embodiments, the administering step is carried out by stenting with a catheter (e.g., a silicone catheter) coated with the collagen inhibitor. In some embodiments, the collagen inhibitor is selected from the group consisting of: mithramycin, mitomycin-c, tranilast, halofuginone and analogs thereof.

[0010] Methods of preventing or reducing capsule formation in a subject undergoing implantation of a medical device (e.g., breast implants, pacemakers, orthopedic joint prosthetics, etc.) are provided, including providing a collagen inhibitor on or in said medical device.

[0011] Kits including the implantable or insertable biomedical devices are also provided.

[0012] The present invention is explained in greater detail in the specification set forth below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1. SEM image of HFBr coating on silicone urethral stent used in rat model.

[0014] FIG. 2. Masson’s Trichrome Stain of 2-Week Rat Urethra. A: Samples had HF-coated stent. B: Samples had uncoated stent. In slides A1 (2.5x) and A2 (10x), there is no new collagen deposition (no spongiofibrosis), but only an inflammatory response. In slides B1 (2.5x) and B2 (10x), there is obvious new collagen deposition (spongiofibrosis).

[0015] FIG. 3. Masson’s Trichrome Stain of 3-month Rabbit Urethra. A: Sample had HF-coated stent. B: Sample had uncoated stent. In slide A, there is less collagen deposition (less blue stain) with normal urethral architecture. In slide B, there is greater collagen deposition (more blue stain), but note that at 3 months the collagen has become more organized, unlike the amorphous collagen seen at 2 weeks.

[0016] FIG. 4. Rat Halofuginone Levels in vivo. The concentration of HF was determined in both the penile tissue and blood serum. There is almost a ten-fold difference between HF levels in the serum vs. the penile tissue. Standard error bars are included.

[0017] FIG. 5. HF Elution.

[0018] FIG. 6. Halofuginone coated PLGA was placed subcutaneously in the rat model. The PLGA has completely dissolved and there is no new collagen, but hemorrhage and inflammation.

[0019] FIG. 7. Uncoted PLGA is still present and surrounded by a collagen capsule.

[0020] FIG. 8. Rabbit urethra at two weeks with scar, uncoated stent.

[0021] FIG. 9. Rabbit urethra with no scar, collagen inhibitor coated stent.

[0022] FIG. 10. Rat urethra at 2 weeks following scar induction with mithramycin coated stent. The site of the scar is known, as there is a marking permanent suture visible which was placed at the site of the scar. There is no new scar visible.

[0023] FIG. 11. Rat urethra at 2 weeks following scar formation with uncoated stent, the site of new scar. Increased collagen deposition is clearly seen.
FIG. 12. Silicone discs coated with halofuginone have a paucity of new collagen surrounding the subcutaneous implantation site at two weeks in the rat model.

FIG. 13. Uncoated silicone disks show significantly more collagen surrounding the implantation site.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The disclosures of all United States Patent references cited herein are to be incorporated by reference herein as if fully set forth.

Healing through the deposition of scar (fibrous) tissue is the normal response to injury. In humans, the wound healing response is divided into three phases: inflammation, fibroplasias and maturation. The steps of the process overlap broadly and are best understood as a continuum rather than a series of discrete steps.

Without wishing to be bound to any particular theory, the wound healing process begins with a disturbance of blood vessel integrity that exposes the subendothelial collagen to blood platelets. This event is the initiating step that leads to blood extravasation and triggers the acute inflammatory response. This response activates local and systemic factors that lead to an orderly and predictable migration of cells into the wound. The first cells to appear in the wound are neutrophils, followed by monocytes and fibroblasts. Fibroblasts are the dominant cell type during fibroplasia. This phase is characterized by fibroblast proliferation and migration. The major function of the fibroblast during this stage is to elaborate interstitial matrix and collagen type-1. It is this collagen that makes up the fibrous tissue that characterizes the clinical entity referred to as scar tissue. When the fibroplasia stage is complete, the final stage of maturation occurs during which the wound becomes acellular and undergoes remodeling over months to years. During the remodeling phase the wound gathers tensile strength. Under the influence of various mediators and enzymes, remodeling is thought to represent the interplay between matrix synthesis and degradation.

Provided herein are compositions, devices and methods of treatment to improve wound healing after medical procedures such as surgery, or other trauma. In some embodiments, the present invention provides collagen inhibitors topically administered to the wound or site of injury.

“Stenosis” or “stricture” refers to the narrowing of a bodily canal, passageway or tubular structure or organ. Similarly, “restenosis” is the recurrence of a narrowing of a bodily canal, such as a blood vessel.

A “capsule” is a cover or envelope partially or wholly surrounding a structure in the body. Capsules containing collagen fibers form a normal reaction around a foreign substrate implanted in the body (e.g., breast implants, pacemakers, orthopedic joint prosthetics), tending to wall it off. However, certain implants may function better with less capsule formation. See, e.g., U.S. Pat. No. 5,564,439 to Picha.

“Subjects” that may be treated by the present invention include both human subjects for medical purposes and animal subjects for veterinary and laboratory purposes. Other suitable animal subjects are, in general, mammalian subjects such as primates, bovines, ovines, caprines, porcines, equines, felines, canines, lagomorphs, rodents (e.g., rats and mice), etc. Human subjects are the most preferred. Human subjects include fetal, neonatal, infant, juvenile, adult and geriatric subjects.

“Treat” as used herein refers to any type of treatment or prevention that imparts a benefit to a subject afflicted with or at risk of developing scarring or complications involving scar tissue production and/or collagen production, including improvement in the condition of the subject (e.g., in one or more symptoms), delay in the progression of the scarring, delay the onset or slow the progression of collagen deposition, capsule formation, stricture, restenosis, scarring, etc. Also, the term “treatment” also includes prophylactic treatment of the subject to prevent the onset of symptoms. As used herein, “treatment” and “prevention” are not necessarily meant to imply cure or complete ablation of symptoms, but refer to any type of treatment that imparts a benefit to a patient afflicted with a disease, including improvement in the condition of the patient (e.g., in one or more symptoms), delay in the progression of the disease, etc.

“Treatment effective amount”, “amount effective to treat” or the like as used herein means an amount of the collagen inhibitor sufficient to produce a desirable effect upon a patient afflicted with wounds or site of injury. This includes improvement in the condition of the patient (e.g., in one or more symptoms), delay in the progression of the disease, etc.

“Pharmaceutically acceptable” as used herein means that the compound or composition is suitable for administration to a subject to achieve the treatments described herein, without unduly deleterious side effects in light of the severity of the disease and necessity of the treatment.

I. Collagen Inhibitors

“Collagen inhibitors” useful for carrying out the present invention are known and include all agents that inhibit the synthesis of collagen. See, e.g., U.S. Pat. Nos. 6,046,340 and 5,902,841; PCT Publication No. WO/2005/112990. Collagen is the major protein component of the extracellular matrix in organisms. There are at least 12 types of collagens, with types I, II and III being the most common. They are primarily synthesized in the body by fibroblasts during healing, and are formed by processing of the precursor procollagen proteins.

In some embodiments, inhibitors of type-1 collagen (also known as type I collagen) are preferred. The primary component of scar tissue, collagen type-1 alpha, typically forms a protein rod 300 nm long composed of 3 subunits: two alpha1(I) chains and one alpha2(I) chain. Within the fibroblast, elaboration of type-1 collagen is controlled by activation of the alpha-1 collagen gene. Therefore, in some embodiments, inhibitors of the alpha-1 collagen gene expression are preferred.

Examples of “collagen inhibitors” as used herein include, but are not limited to, minomycin, mitomycin-c, tranilast, halofuginone, d-penicillamine, beta-aminopropionitrile, okadaic acid, LY294002 (PI-3K inhibitor), 5-fluorouracil, analogs thereof, etc.

Mitomycin (MIT or pilcamycin) is an aureolic acid polyketide antibiotic that binds to GC-rich areas of DNA. See, e.g., U.S. Pat. No. 5,723,448. It is a parental cell cycle phase nonspecific antineoplastic agent derived from Streptomyces plicatus, a gram-positive soil bacterium. Mitomycin was originally developed as an antibiotic with activity primarily against gram-positive bacteria (Grundy et al., “Aureolic acid, a new antibiotic.” *Antibiotics and Chemotherapy.* III (12)(Dec. (1953)):1215-1220). Since then, it has been used as
a chemotherapeutic agent to treat testicular cancer and to manage malignant and other causes of hypercalcemia.
Mithramycin acts as an intercalating agent, inserting between base pairs and causing the double helix to uncoil, thus preventing DNA synthesis and transcription from taking place (“Plicamycin.” Online drug information (WFUSM). Gold Standard Inc. 2007). It is currently administered to patients via intravenous infusion only. More recently, mithramycin has been suggested as a treatment for Huntington’s disease (Ferrante, et al. “Chemotherapy for the Brain: The Antitumor Antibiotic Mithramycin Prolongs Survival in a Mouse Model of Huntington’s Disease.” J.Neurosci., 2004; 24(46): 10335-10342).


Systemic (high) dosing of mithramycin in humans (e.g., 25-50 mg/kg) can interfere with systemic collagen homeostasis and is associated with grave side effects (bleeding, tissue necrosis and death) and has necessitated a black box warning by the U.S. Food and Drug Administration (U.S. Food and Drug Administration• Center for Drug Evaluation and Research FDA Oncology Tools Product Label Details in Conventional Order for plicamycin, mithramycin. Supplement number: 050109). To avoid systemic side effects, in some embodiments of the present invention, mithramycin is administered topically at the site of injury/stenting, in low (e.g., microgram) doses to achieve minimum concentrations in vitro and in vivo in the range of 10^{-9} to 10^{-5} M.

Mithramycin-c is a known fibroblast inhibitor with known scar inhibitory effects in the eye, sinus, larynx, trachea and pharyngoesophagus.

Tramulast (2-(2,3-dimethoxyxycinnamoyl)aminobenzoic acid) is also known and described in, for example, U.S. Pat. Nos. 5,385,935; 6,259,177; and 6,576,543.

“Halofuginone” or halofuginone bromide (7-bromo-6-chloro-3-[3-(3-hydroxy-2-piperidinyl)-2-oxopropyl]-4H-1,3-benzodiazepin-4-one) is known and described in, for example, U.S. Pat. Nos. 5,449,678; 6,420,371; 6,028,078; 6,090,814; and 6,159,488. Halofuginone is a quinazolinone compound that has been used in the cattle and poultry industries as an anticoagulant agent. Serendipitously, it was discovered that dermal thinning was occurring in chickens that were administered the drug systemically. Further study of this phenomenon led to the discovery that the mechanism of action of halofuginone was inhibition of the alpha-1 collagen gene promoter (Gnanot et al. Poult Sci. 1991 July; 70(7):1559-63). The pharmacology of this compound has been extensively studied for veterinary use and has FDA orphan drug approval for use in humans to treat scleroderma.

II. Substrates

Substrates include any biocompatible substrate, and may be biodegradable or non-biodegradable.

Biodegradable or bioabsorbable substrates may be formed of biodegradable polymers. Any suitable polymer may be employed, including, but not limited to, poly(lactic acid), poly(glycolic acid), poly(lactic-co-glycolic acid), poly(acrylic acid), poly(glycolic acid), poly(lactic acid-co-glycolic acid), poly(caprolactone), polycarbonates, polyesters, polyanhydrides, poly(ester amides), poly(ortho ester)s, poly(anhydrides), poly(caprolactone), polycarbonates, polyanhydrides, poly(amino acids), poly(ortho ester)s, poly(ether ester)s, copolymers of poly(ethylene glycol) and poly(ortho ester)s, poly(dioxanone), poly(alkylene alkylate)s, biodegradable polyurethanes, as well as blends and copolymers thereof. See, e.g., U.S. Pat. No. 7,097,857.

According to some embodiments, the present invention provides a wound closure device comprising a substrate and a collagen inhibitor on or in said substrate. The substrate may comprise, consist of or consist essentially of a biodegradable substrate (such as albumin, collagen, synthetic polypeptide acids, prolamines, polysaccharides, etc., or biodegradable polymers such as polyesters, polyglycolic acids, poly(lactide-co-glycolides), polycaprolactones, polycarbonates, polyanhydrides, polyanhydride acids, polyortho esters, polycetans, polyanhydrides, and degradable polyurethanes) or a non-biodegradable (inert) substrates such as silicone and silk or polyvinyl alcohol, polyethylene, polyurethane, polypropylene, polycaprolactone, polycarbonate, ethylene-vinyl acetates, polystyrene, polyvinyl oxides, polyvinyl fluorides, poly(vinyl imidazole), chlorosulphonated polylefins, polyethylene oxides, polystyrenechloroethylenes, nylons, and copolymers and combinations thereof. The device may take any suitable form, such as a suture, staple, tape, or bandage. In some embodiments the collagen inhibitor is carried in a biodegradable polymer which is coated on an inert or non-biodegradable substrate.

In some embodiments the device is a suture. Sutures may be formed of biodegradable polymers as described above (which may be in the form of a unitary solid), or may be formed from braided, woven, or non-woven fiber material (e.g., silk, cotton, rayon, linen, wool, satin, nylon, polyester or mixtures thereof). See, e.g., U.S. Pat. Nos. 5,685,860 and 6,224,630. In some embodiments, sutures include polypropylene (e.g., prolene or marlex) and/or polytetrafluoroethylene (PTFE) (e.g., Gore-Tex).

The present invention also provides surgical packings (e.g., suture packings) that include a substrate and a collagen inhibitor on or in said substrate. The packing may take any suitable form, including, but not limited to, those described in U.S. Pat. Nos. 5,263,927 and 4,291,687.

The substrate material for the packing may be formed of any suitable material, including but not limited to methylcellulose, hydroxypropylmethylcellulose, hydroxybutylmethylcellulose, hydroxyethylmethylcellulose, ethylhydroxyethylcellulose, hydroxyethylcellulose, hydroxypropylcellulose, carboxymethylcellulose, microcrystalline cellulose, xanthan gum, silicon dioxide, and mixtures thereof. See, e.g., U.S. Pat. No. 7,135,197. Oxycellulose is currently used as a wound packing to achieve hemostasis. In some embodiments the substrate may be provided in the form of a dry, preferably sterile, powder (e.g. with which the collagen inhibitor may be mixed).

In some embodiments, a barrier material is used for preventing adhesions in a subject, comprising in combination, a preformed or in situ formable barrier substrate and a collagen inhibitor on or in said substrate. The substrate may be any suitable material, and when formed in situ any suitable cross-linking agent may be employed. Suitable examples include but are not limited to those described in U.S. Pat. No. 6,638,917. The substrate or material may be biodegradable.
(e.g., a hemostatic material) or non-bioabsorbable (e.g., a non-absorbable mesh, such as is currently used in hernia repair).

[0052] A further aspect of the invention is an implantable or insertable biomedical device comprising a substrate and a collagen inhibitor on or in said substrate. In some embodiments, the device is a urethral, ureteral, or nephroureteral catheter or stent. Various nasal, esophageal and tracheal stents are also known. Cranial, maxillary and mandibular bone plates include bioabsorbable substrates (such as poly-L-lactic-co-glycolic acid [PLLA/PGA]) and non-bioabsorbable substrates (such as titanium).

[0053] In some embodiments, a non-bioabsorbable stent (i.e., a tube designed to prevent luminal strictures) anywhere in the body. Examples include, but are not limited to, Ureteral catheter, Ureteral stent, Nephroureteral catheter, Esophageal stent, Tracheostomy stent, Gastric feeding tube, Nasogastric tube, Laryngeal/tracheal/pulmonary stent, Myringotomy tube, Nasal stent, Salivary duct stent, Biliary stent, Enteric stent, Nasolacrimal stent.

[0054] Still other examples are described below. The substrate may be comprised of any suitable biodegradable or non-biodegradable material. In some embodiments the substrate (e.g., from which the catheter is formed) comprises a material such as vinyl, polyethylene, poly(vinyl chloride) (PVC), ethylene vinyl acetate (EVA), silicone, latex, or polypropylene. See, e.g., U.S. Pat. No. 7,025,753. The collagen inhibitor may be coated on such a substrate material, with or without a carrier (such as a biodegradable polymer), by any suitable technique as discussed further below.

[0055] Specific examples of devices or products that can be used to carry out the present invention by including a collagen inhibitor on or in a substrate from which the product or device is formed include, but are not limited to (for various fields):

- Urology:
  - [0081] Coated Urethral Catheter
  - [0082] Coated Ureteral Stent
  - [0083] Coated Nephroureteral Catheter

- ENT:
  - [0084] ENT
  - [0085] Coated Sinus Packing Material
  - [0086] Injectable sinus packing material
  - [0087] Coated Esophageal Stent
  - [0088] Coated Tracheostomy Tube
  - [0089] Coated Gastric Feeding Tube
  - [0090] Coated Nasogastric Tube

- Cardiovascular:
  - [0091] Coated Laryngeal/Tracheal/Pulmonary Stent
  - [0092] Injectable Material for Vocal Fold Augmentation
  - [0093] Coated Myringotomy Tube
  - [0094] Coated Nasal Septal Splat
  - [0095] Coated Nasal Stent

- Oral Care:
  - [0096] Coated Salivary Duct Stent
  - [0097] Coated Laryngeal Implant
  - [0098] Injectable gel for salivary radiation fibrosis

- Plastic Surgery/Dermatology:
  - [0099] Coated Cranial, maxillary, mandibular absorbable and nonabsorbable bone plates
  - [0100] Injectable silicone implants (or coated implants of other Composition)

- Other:
  - [0101] Injectable material for cosmetic augmentation
  - [0102] Coated Silicone Implants (or Coated Implants of other Composition)
  - [0103] Coating agent
  - [0104] Injectable material for cosmetic augmentation

III. Formulations

[0105] In some embodiments, collagen inhibitors of the present invention are provided as a coating on a substrate. Collagen inhibitors may be coated on a substrate by any suitable technique, such as dipping, spraying, spray drying, etc. The collagen inhibitor may be applied per se or concurrently with a carrier material or film-forming material, such as a biodegradable polymer (e.g., as described above). Collagen inhibitors may be combined into materials (such as powders or biodegradable materials) by any suitable technique, such as mixing, co-extruding, etc. In some embodiments, the collagen inhibitor is included in an amount effective to inhibit scarring and/or collagen formation on or adjacent to the implanted or inserted substrate.

[0106] According to some embodiments, for suture and/or packing materials the coating process includes one or more of the following steps: (a) prepare materials to desired size and shape for implantation; (b) prepare a solution of a collagen inhibitor (e.g., HFB at 0.5 μg/ml); (c) modify surface of material by flash freeze in liquid nitrogen, microwave heat (15-30 seconds) or plasma reactor to enhance adherence properties; (d) materials are then dipped and immediately frozen at −80°F for approximately 24 hours; (e) frozen materials are then lyophilized (i.e., vacuum dried); (f) materials are sterilized, e.g., using ethylene oxide or gamma irradiation.

[0107] According to some embodiments, coating and/or impregnating stent materials (e.g., for esophagus, trachea, vascular, etc.) with a collagen inhibitor includes one or more of the following steps: (a) dry collagen inhibitor (e.g., HFB, mithramycin, etc.) in powder form is mixed (e.g., in a 50:50
ratio) with stent material also in powder form (e.g., PLLA, PGA, Vicryl (polygalactin)); (b) powder material is solubilized in a suitable solution and electrospun into desired shape (in some embodiments, this process results in a collagen inhibitor impregnated stent that allows freedom to make the desired shape for implantation); (c) stent is sterilized, e.g., using ethylene oxide or gamma irradiation.

[0106] According to some embodiments, wound glue including a collagen inhibitor includes one or more of the following steps: (a) the collagen inhibitor (e.g., HFBr at 0.5 μg/ml) is mixed 50:50 with a suitable glue material (e.g., acrylate material); and (b) applied directly to the wound. In other embodiments, collagen inhibitor is mixed with carboxymethylcellulose and applied directly to the wound.

[0107] According to some embodiments, coating of stents (e.g., permanent catheters) with a collagen inhibitor includes one or more of the following steps. (a) Weigh stent; (b) Modify surface of the stent with a plasma reactor; or alternatively microwave water wet stent for about 30-60 seconds; (c) Immerse stent in collagen inhibitor (e.g., halofuginone) and freeze in liquid nitrogen or −80°C; (d) Lyophilize stent (e.g., overnight); (e) Weigh stent; 69% Immerser stent in 1% PEG (5,000-50,000) g/mol filtered in 0.2 um filter; (g) Freeze PEG in liquid nitrogen or −80°C, and lyophilize overnight; (h) Immerge stent in collagen inhibitor (e.g., halofuginone) and freeze and lyophilized overnight; (j) Weigh stent; and (j) Sterilize.

[0108] According to some embodiments, coating of stents (e.g., permanent catheters) with a collagen inhibitor includes one or more of the following steps. (a) Weigh stent (b) Modify surface of the stent with a plasma reactor, or alternatively microwave water wet stent (e.g., wet with PBS and covered with PBS soaked gauze) for about 30-60 seconds; (c) Dip stent in 2% PLGA-COOH to cool; (d) Dry under hood; (e) Cover with soaked gauze (e.g., with PBS) and microwave for about 30-60 seconds (or use plasma reactor); (f) Coat stent with halofuginone (e.g., immerse) and freeze in liquid nitrogen and lyophilize overnight; (g) Weigh stent to estimate drug content; and (h) Sterilize.

[0109] Those of skill in the art will appreciate that all of the above methods can be modified and optimized as desired by routine methods without departing from the spirit of the invention disclosed herein.

IV. Dosages and Routes of Administration

[0110] In preferred embodiments, collagen inhibitors of the present invention are administered topically (i.e., locally) to the wound or site of injury. In some embodiments, compositions including collagen inhibitors may be administered via a coated suture, via combination with a gel or suitable wound glue, via coatings and/or impregnating collagen inhibitors onto a suitable substrate as described herein.

[0111] In some embodiments, topical application of one or more collagen inhibitors in nano (10−6) or pico (10−12) molar doses is sufficient to inhibit collagen type-1 production in an open wound. In some embodiments, collagen inhibitors is used topically as a packing material (e.g., in the sinus after paranasal sinus surgery) to prevent post-operative scar tissue formation.

[0112] In some embodiments, collagen inhibitors are administered by elution/absorption of the drug in less than 30 minutes. In some embodiments, administration is performed over a longer period of time, e.g., substantial elution over 30 minutes, 1, 2 or 3 hours, and up to 5, 6, 7 or 8 days. In some embodiments, collagen inhibitors are eluted over time to capture as much of the early fibroplasia stage of wound healing as possible (e.g., over 3-7 days). In some embodiments, elution occurs at a differential rate, with early elution independent of substrate degradation and later elution that is dependent upon substrate degradation.

[0113] For example, in some embodiments, the collagen inhibitor is administered in a single or total dosage over time of less than 1 mg. In some embodiments, the collagen inhibitor is administered in a range of 10−8, 10−7, 10−6, or 10−5 to 10−10, 10−11 or 10−12 molar doses.

[0114] In some embodiments, formulations containing a collagen inhibitor (e.g., HF, mithramycin, etc.) may be applied as a topical ointment or cream containing the active ingredient(s) in an amount of, for example, 0.005 to 5% w/w (including active ingredient(s)) in a range between 0.01% and 1% in increments of 0.05% w/w such as 0.05% w/w, 0.1% w/w, 0.5%, etc.), preferably 0.1 to 1% w/w, and most preferably 0.05 to 0.5% w/w. In some embodiments, formulations contain a collagen inhibitor in sufficient amount/concentration to deliver a target tissue dose in the microgram range with molar concentrations of 10−9 M to 10−7 M.

[0115] In some embodiments, collagen inhibitors are administered at a dosage level such that collagen inhibition is achieved with little to no cell toxicity. In some embodiments, collagen inhibitors are administered at a dosage sufficient to achieve a tissue level for the days of drug elution between 10−7 to 10−12 molar doses.

[0116] In other embodiments (e.g., paranasal sinus), collagen inhibitors (e.g., HF, mithramycin, etc.) is delivered topically as a single dose of between 50 and 500 micrograms (e.g., 100-300 micrograms) to achieve tissue effect (e.g., while achieving in vitro molar concentrations between 10−5 M and 10−7 M in 3 cc PBS). In yet other embodiments (e.g., trachea) up to 500 micrograms of collagen inhibitor is given topically to achieve tissue effect (e.g., while achieving in vitro molar concentrations between 10−4 M and 10−5 M in 3 cc PBS). In other embodiments (e.g., skin) 10 micrograms is sufficient to achieve tissue effect without affecting tensile strength of dermal wounds (e.g., while achieving in vitro molar concentrations between 10−7 M and 10−9 M in 3 cc PBS).

[0117] Some embodiments of present invention are explained in greater detail in the following non-limiting examples.

EXAMPLES

Example 1

Coated Ureteral and Urethral Catheter Material

[0118] A collagen inhibitor coated catheter could be inserted following stricture incision, preventing recurrence by delivering a small amount of collagen inhibitor to the specific area of interest.

[0119] Halofuginone bromide (HF) is a substance known to be a potent Collagen Type I inhibitor, and previous studies have demonstrated that oral and local halofuginone administration can prevent luminal strictures, including urethral strictures. However, no previous studies have demonstrated the ability of HF coated stents to prevent urethral stricture formation. The objectives of this study were to successfully coat urethral stents with HF, and then to test whether HF coated stents could prevent spongiform fibrosis in a small animal model of urethral stricture disease.
Halocuran® (Oral Halofuginone. 0.5 mg/mL) was obtained from Intervet International BV of Norway. The rat stents were made of silicone tubing (0.30 mm x 0.64 mm) from SMI, while the rabbit stents were 8f silicone Foley catheters (Hard). The stents were coated as follows: 1. Wet stent with PBS and cover with PBS, soaked gauze and microwave for 40 sec; 2. Dip stent in 2% PlGA-COOH to cool; 3. Dry under hood; 4. Cover with PBS soaked gauze and microwave (or plasma) for 30 sec; 5. Coat stent with halofuginone (immers) and freeze in liquid nitrogen and lyophilize overnight; 6. Weight should be measured before and after coating to estimate drug content. The presence of halofuginone on the catheters was documented by measuring changes in stent weight, gross and SEM imaging studies, and elution kinetics.

The simplest method of measuring drug coating, namely determinations of changes in weight, was performed first. Silicone tubing of 3 cm in length was weighed before and after coating with Halocuran. The average weight change following coating was approximately 1 mg, demonstrating the coating of a small amount of drug on the tubing. Visual inspection of the coated catheters also demonstrated a yellow coating over the usual white appearance of the silicone, providing further evidence that the yellow Halocuran had adhered to the tubing.

Scanning electron microscopy of the silicone tubing was also performed before and after coating with Halocuran (FIG. 1). The coated tube clearly demonstrates a layer of drug on its surface, while the uncoated tube is completely smooth. This provides further evidence that the Halocuran was successfully coated on the silicone tubing.

Drug release studies were then performed to determine the amount of halofuginone released by the coated stents, and the timing of drug release. Stents approximately 3 cm in length were coated with halofuginone using our proprietary technique. These stents were then placed in PBS solution at room temperature for 24-hour intervals. After each 24-hour interval, the stents were placed in a new PBS solution, and the previous solution was analyzed for halofuginone concentration using UV spectroscopy (absorption at 243 nm). This process was continued daily until the amount of halofuginone in the PBS dropped to imperceptible levels. There was a sustained release of halofuginone from the stents for approximately 4 days, with a large burst release the first 24 hours, and progressively less the following 3 days (FIG. 5). These results provided further evidence that the silicone stents had been successfully coated with Halocuran, and that this coating provided a sustained release of drug over a several day period.

Animal Surgeries (Rat and Rabbit): Urethral scars were formed in the urethra via electrocautery using an established animal model (Jaidane et al. J. Urol. 2003 Nov. 170 (5):2049-52). Uncoated (control) or HF-coated (experimental) stent was inserted into the urethra and secured with permanent suture. The rabbits had perineal urethrostomies. The rats were euthanized at 2 weeks and the rabbits at 3 months post-surgery, at which point the penes (containing the urethral stents) and surrounding subcutaneous tissues were excised.

The specimens were fixed in 10% paraformalin and embedded in paraffin blocks. The specimen was then sectioned (5 μm), made into slides, and stained with Masson’s trichrome and alpha 1 collagen antibody staining.

HF Analysis in Local Tissues and Serum (in Rat): The tissue specimens were morcellated, incubated for 24 hours in 40 mL of PBS, centrifuged, and a sample was taken for HF concentration analysis via spectrophotometry. Blood was also drawn (1 mL) from the heart post-mortem, added to 5 mL of PBS, centrifuged, and the serum analyzed for HF concentration via spectrophotometry.

Results: The silicone stents were successfully coated with halofuginone. Scars were effectively induced in both animal models, utilizing the electrocautery technique, and scar formation was characterized by increased collagen deposition within damaged tissues (see FIG. 2 and FIG. 3). On gross examination, there was obvious collagen deposition (spongiosis) seen in the penes with the uncoated stents, while there was no new collagen deposition in the spongiosal tissue of the penes with the HF-coated stent. This result was observed in both the rat and rabbit animal model (FIG. 2 and FIG. 3, respectively). HF was detected in both the surrounding penile tissues and in the bloodstream serum, but the level of HF was significantly higher in the tissues than in the serum (FIG. 4).

Conclusions: HF coated stents resulted in no new periurethral collagen deposition in response to injury, thereby causing less scarring of the insulted area. This may correlate to reduced stricture formation. HF is present in both tissues adjacent to the drug-eluting stent and in the blood serum, and significantly higher concentrations are seen in local tissues than in the blood serum.

Example 2

Human Testing

Ten male patients with comparable urethral strictures amenable to treatment by DUUI therapy (<2 cm length) are recruited and divided into 2 treatment groups. Group A (5 men) are treated with DUUI and then stented for 4 days with a silicone urethral Foley catheter. Group B (5 men) are treated with DUUI and then stented for 4 days with a type-I collagen inhibitor coated silicone catheter.

The type-I collagen inhibitor coated silicone urethral catheter consists of a Bard All-Silicone 16 1/2 French Foley catheter (already in widespread use in humans), coated with the specific type-I collagen inhibitor halofuginone, approximately 0.375 mg of halofuginone in the form of the solution. The catheters used will be Bard 16 1/2 French silicone Foley catheters, purchased for hospital use through the usual vendors, and therefore packaged sterilely. The catheter will then be removed from its packaging and coated with the drug Halocuran (0.5 mg/ml halofuginone solution) as described above. The Halocuran is obtained from the Intervet Corporation, which produces Halocuran in large quantities with excellent quality control for use in the treatment of Cryospiridium parvum in newborn calves. Once the catheter is coated, it is packaged and sterilized under UV or gamma irradiation in preparation for patient use.

Immediately following removal of the catheter (and then every 3 months for a year), the patients undergo uroflowmetry evaluation in the standard fashion. At the end of the year, all patients undergo a retrograde urethrogram to evaluate urethral patency.

Qualitatively, the safety of the type-I collagen inhibitor coated catheter is assessed, as patients are observed for any untoward effects from the use of the stent. Quantitatively, recurrence of the urethral stricture is assessed by measuring uroflow rates as well as urethral caliber on retrograde urethromgrams. The uroflowmetry results will be objectively
compared by measuring the maximal flow rate (or Qmax), and subjectively compared by analyzing the shape of the flow curve (unimodal with normal monotonically increasing, stable period, and monotonically decrease indicating normal flow, versus a multimodal extended pattern signifying obstructed flow). The retrograde urethrography studies will be objectively compared by measuring the urethral width at its most narrow point to evaluate for stricture recurrence in each case.

Example 3
Catheter Coating

The following is a list of ureteral and urethral catheter material that we have demonstrated the ability to coat with halofuginone using imaging studies (microscopic and gross), weight changes, and elution data over 4 days:

- General device material: Silicone, Silastic, Latex, Polyurethane, Nitinol, PLGA.
- Boston Scientific products: Percuflex stents, Flexima stents, Pebax material.
- Cook stents: Polyurethane, Sof-flex, AQ stents, Endo-soft stents.
- Bard stents: Polyurethane, Latex, Woven stents, Lubricath Foley, Inlay stent, Elastomer coated catheters, Silver coated catheters.

The stents were coated as follows: 1. Wet stent with PBS and cover with PBS soaked gauze and microwave for 40 sec; 2. Dip stent in 2% PLGA-COOH to cool; 3. Dry under hood; 4. Cover with PBS soaked gauze and microwave (or plasma) for 30 sec; 5. Coat stent with halofuginone (immersed) and freeze in liquid nitrogen and lyophilize overnight; 6. Weight should be measured before and after coating to estimate drug content.

Example 4
PLGA Sheets, Uncoated Versus Coated with Halofuginone

The ability of collagen inhibitor coated biodegradable products to prevent scar is demonstrated. FIG. 6: halofuginone coated PLGA was placed subcutaneously in the rat model. The PLGA has completely dissolved and there is no new collagen, but hemorrhage and inflammation. FIG. 7: uncoated PLGA is still present and surrounded by a collagen capsule.

Example 5
Collagen Inhibitor (Halofuginone) Coated Dissolvable Stent in a Rabbit

Halofuginone coated PLGA stents prevent urethral stricture in rabbit model at two weeks. FIG. 8: Rabbit urethra at two weeks with scar, uncoated stent. FIG. 9: Rabbit urethra with no scar, collagen inhibitor coated stent.

Example 6
Mithramycin Coated and Uncoated Urethral Stents

The ability of mithramycin coated stents to prevent new collagen deposition (i.e., scar) in 2-week rat model. FIG. 10: Rat urethra at 2 weeks following scar induction with mithramycin coated stent. The site of the scar is known, as there is a marking permanent suture visible which was placed at the site of the scar. There is no new scar visible. FIG. 11: Rat urethra at 2 weeks following scar formation with uncoated stent, the site of new scar. Increased collagen deposition is clearly seen.

Example 7
Collagen Inhibitor Coated Silicone Disks in Rats Subcutaneous Tissue

The following data represents the ability of collagen inhibitor (halofuginone) coated silicone disks to prevent capsule formation. FIG. 12: silicone discs coated with halofuginone have a paucity of new collagen surrounding the subcutaneous implantation site at two weeks in the rat model. FIG. 13: uncoated silicone disks show significantly more collagen surrounding the implantation site.

That which is claimed is:

1. A non-biodegradable medical device comprising a substrate and a collagen inhibitor on or in said substrate.
2. The medical device of claim 1, wherein said collagen inhibitor is mithramycin.
3. The medical device of claim 1, wherein said substrate is comprised of a material selected from the group consisting of vinyl, polyethylene, poly(vinyl chloride) (PVC), ethylene vinyl acetate (EVA), silicone, latex, and polypropylene.
4. The medical device of claim 1, wherein said medical device is selected from the group consisting of: a stent, a ureal implant, a pacemaker and an orthopedic joint prosthesis.
5. The medical device of claim 1, wherein said medical device is a stent.
6. The medical device of claim 1, wherein said medical device is a ureal, ureteral, or nephroureteral stent.
7. A method of treating strictures in a subject in need thereof comprising topicaly administering a collagen inhibitor in an amount effective to treat said strictures in said subject, wherein said collagen inhibitor is mithramycin.
8. The method of claim 7, wherein said strictures are ureal or ureteral strictures.
9. The method of claim 7, wherein said administering step is carried out by stenting said strictures with a catheter coated with said collagen inhibitor.
10. The method of claim 9, wherein said stenting is carried out following stricture incision in said subject.
11. The method of claim 9, wherein said catheter comprises silicone.
12. The method of claim 9, wherein said catheter releases said collagen inhibitor for a time of from 1 to 4 days.
13. A method of preventing or reducing capsule formation in a subject undergoing implantation of a medical device, said method comprising providing a collagen inhibitor on or in said medical device.
14. The method of claim 13, wherein said medical device is selected from the group consisting of: breast implants, pacemakers and orthopedic joint prosthetics.
15. The method of claim 13, wherein said collagen inhibitor comprises mithramycin.
16. A kit comprising:
   (a) a substrate coated with a collagen inhibitor; and
   (b) a container in which said substrate is packaged in sterile form, wherein said collagen inhibitor is mithramycin.
17. The kit of claim 16, wherein said container comprises a plastic or foil container.

18. The kit of claim 16, wherein said container is vacuum-packed.

19. The kit of claim 16, wherein said substrate is coated with a single unit dose of said collagen inhibitor.

20. The kit of claim 16, wherein said substrate is selected from the group consisting of: stents, breast implants, pacemakers and orthopedic joint prosthetics.

21. The kit of claim 16, wherein said substrate is a stent.

22. The kit of claim 16, wherein said substrate is a urethral, ureteral, or nephroureteral catheter or stent.

23. The kit of claim 16, wherein said substrate is comprised of a material selected from the group consisting of vinyl, polyethylene, poly(vinyl chloride) (PVC), ethylene vinyl acetate (EVA), silicone, latex, and polypropylene.