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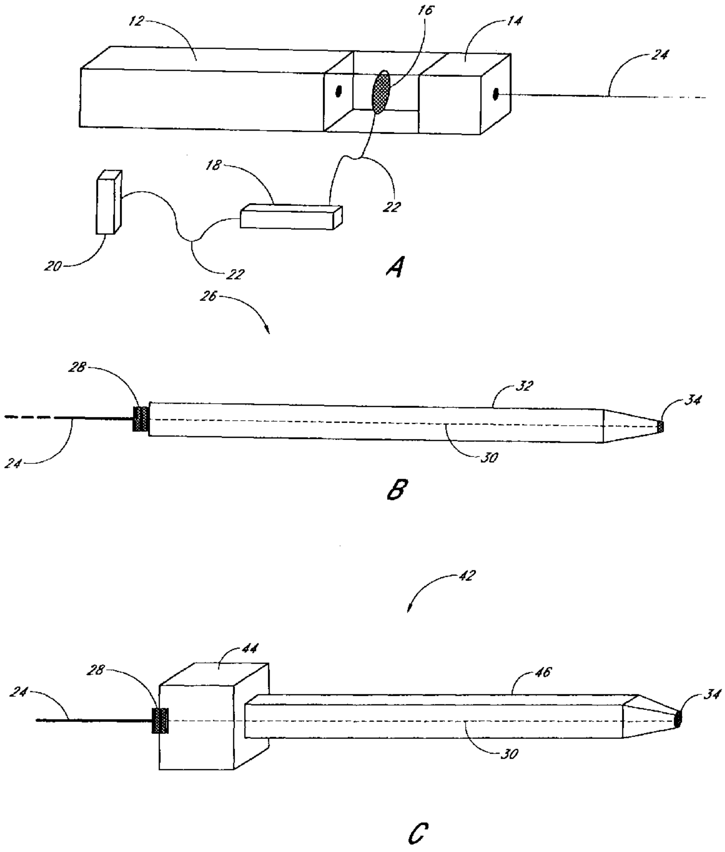
(54) Title: LIGHT ACTIVATED GENE TRANSDUCTION USING ULTRAVIOLET LIGHT FOR CELL TARGETED GENE DELIVERY



(57) Abstract: In accordance with the present invention, kits are provided for treating a patient through the use of ultraviolet light activated gene therapy. Embodiments of the present invention include kits useful for the utilization of light activated gene therapy to repair and/or rebuild damaged functional spinal unit (FSU) components or cartilage by introducing a desired gene into a patient's tissue.

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LIGHT ACTIVATED GENE TRANSDUCTION USING ULTRAVIOLET LIGHT FOR CELL TARGETED GENE DELIVERY

Government Interest

[0001] This invention was made with support by the United States Government under NIH Contract #AR45972, an RO1 grant awarded by NIAMS. The United States Government has certain rights in the invention.

Background of the Invention

Field of the Invention

[0002] The invention relates generally to the field of gene therapy. According to the present invention, medical kits are provided for the combined use of light activated gene transduction (LAGT) employing ultraviolet light and recombinant adeno-associated virus (r-AAV) for the purpose of introducing a desired gene into a patient's tissue.

Description of the Related Art

[0003] Currently, treatment for injured spines often involves "fusion" or inciting the biological union of bones by inserting bone grafts or devices within the functional spinal units (FSU), e.g., between two vertebra. In addition, the effective manipulation of certain osteobiologic molecules via gene therapy can be used to incite bone fusion within a functional spinal unit (FSU). A FSU is composed of two vertebra, a nearby nerve root, and a human interverterbral disc between the two vertebra. This disc, which cushions shock to the spine and lends stability to the FSU, is composed of water, collagen (Type I and II), and glycosaminoglycans (GAG).

[0004] An aging or degenerate disc is often characterized by reduced water, increased Type I collagen, decreased Type II collagen, and decreased GAG. This aging or degenerating, which is incompletely understood, generally results in decreased biomechanical shock absorption, increased range of motion and pain and/or disability.

[0005] Somatic cell gene therapy is a form of treatment, applicable to the spine as well as other areas, in which the genetic material of a target cell is altered through the administration of nucleic acid, typically in the form of DNA. In pursuit of effective *in vivo* administration routes, scientists have harnessed the otherwise potentially deleterious ability of viruses to invade a target cell and "reprogram" the cell through the insertion of viral DNA. By encapsulating desirable genetic material in a viral particle, or "vector," minus some of the viral DNA, the effective and targeted delivery of genetic material *in vivo* is possible. As applied to specific treatments, gene therapy offers the ability to adjust the expression of desirable molecules, including both intracellular and extracellular proteins, to bring about a desired biological result.

[0006] In particular, the desirable qualities of adeno-associated viruses (AAV) have led to further study of potential gene therapy uses. As a vehicle for gene therapy recombinant forms of AAV, or r-AAV, offer many advantages including the vector's ability to infect non-dividing cells (e.g., chondrocytes, cells within cartilage), the sustained target gene expression, the low immune response to the vector, and the ability to transduce a large variety of tissues. The AAV contains a single strand DNA (ssDNA) genome. Under normal conditions AAV is present in humans in a replication incompetent form, due to the fact the AAV alone does not encode the enzyme required for replication of the second DNA strand. Successful r-AAV transduction often requires the presence of a co-infection with an adenovirus or the exposure of the host cell to DNA damaging agents, such as γ-irradiation. The introduction of either the co-infection or the DNA damaging agents dramatically induces the rate limiting step of second strand synthesis, i.e. the second strand of DNA which is synthesized based on the vector inserted first strand. However, making use of these DNA damaging agents is impractical because the administration of an adenovirus co-infection to a patient is not practical or desirable and the site specific and safety issues involved with using γ-irradiation undesirable as well.

[0007] In the past, attempts have been made to induce r-AAV transduction *in vitro* using UV radiation having a wavelength of 254 nm. Unfortunately, no effective therapeutic method or apparatus was developed based on these experiments due to the long exposure times involved with using 254 nm UV radiation, the difficulties of delivering 254 nm UV radiation to a surgical target site, and the inability to position the 254 nm UV light source so as to allow effective penetration of a target cell.

Summary of the Invention

[0008] Preferred embodiments of the present invention provide structures for treating a patient using light activated gene therapy.

[0009] In accordance with an embodiment of the present invention, a kit for introducing a desired gene into a patient's tissue is provided. The kit includes an ultraviolet light activated viral vector and a light source capable of producing an ultraviolet light beam. The kit also includes a light probe operatively connected to the light source, the light probe being capable of delivering ultraviolet light having a wavelength from about 255 nm to about 400 nm.

[0010] In accordance with another embodiment of the present invention, an implant kit for introducing a desired gene into a patient's tissue is provided. The kit includes an implant configured to be inserted into a patient's tissue in a minimally intrusive surgical procedure and an ultraviolet light activated viral vector integrated with the implant. The kit also includes a light probe configured to access the implant, when inserted in a patient's tissue, and locally administer long wavelength ultraviolet light to the vector.

[0011] A feature of certain preferred embodiments of this invention is the avoidance of the problems involved with using UV and γ-irradiation through the use of locally administered, long wavelength UV (i.e., greater than or equal to 255 nm) radiation in order to induce the target cell to more effectively stimulate the transduction of a UV activated viral vector, such as recombinant adeno-associated virus (r-AAV).

Brief Description of the Drawings

[0012] Figure 1 is flowchart of a method of treating target cells in a patient's tissue by activating the transduction of a UV light activated viral vector using a light probe, in accordance with an embodiment of the present invention.

[0013] Figure 2A is a side view schematic of a component of a long wavelength UV radiation system, including a light source and user interface.

[0014] Figures 2B is a schematic of another component of the long wavelength UV radiation system, including a light probe, which in conjunction with the light source and user interface shown in Figure 2A, forms the *in vivo* UV radiation delivery system, in accordance with another embodiment of the present invention.

[0015] Figure 2C is perspective schematic of an external light probe which, in conjunction with the component having the light source and user interface shown in Figure

2A, forms the *ex vivo* UV radiation delivery system configured for external applications, in accordance with an alternate embodiment of the present invention.

[0016] Figure 3 is a schematic of an injecting device for introducing a UV activated vector into a patient's tissue, in conjunction with the long wavelength UV radiation system, shown in Figures 2A and 2B.

[0017] Figure 4 is a method of treating a patient's cartilage using a UV activated viral vector and a long wavelength UV radiation system, in accordance with yet another embodiment of the present invention.

[0018] Figure 5A-5D are perspective schematics of implants for use in conjunction with the long wavelength UV radiation systems and method provided herein, in accordance with another embodiment of the present invention.

[0019] Figure 5E is a cross-section schematic of the expanded implant of Figure 6D, the expanded implant shown located between two vertebra.

[0020] Figure 6 is a flowchart of a method of treating a patient's tissue using a UV light activated viral vector and a solid platform, in accordance with an embodiment of the present invention.

[0021] Figure 7 is flowchart of a method of treating a patient's spinal tissue using a UV light activated viral vector and a UV light probe, in accordance with a further embodiment of the present invention.

[0022] Figure 8 is flowchart of a method of treating a patient's spinal tissue including a spinal implant, in accordance with yet a further embodiment of the present invention.

[0023] Figures 9-11 are graphs of the results of the proof of principle experiment of Example 1.

Detailed Description of the Preferred Embodiment

[0024] The term "AAV" refers to adeno-associated virus, while "r-AAV" refers to recombinant adeno-associated virus. Preferably, r-AAV includes only the desired gene to be introduced into the patient's tissue and the flanking AAV inverted terminal repeats (ITRs) that serve as the packaging signals.

[0025] "Ultraviolet radiation" and "ultraviolet light," also known as "UV", refer to the portions of the electromagnetic spectrum which have wavelengths shorter than visible light. The range of wavelengths considered to be ultraviolet radiation, from about 4 nanometers to about 400 nanometers, is further subdivided into three subgroups, UVA, UVB, and UVC. "UVA" is the portion of ultraviolet radiation which includes wavelengths from 320 nm up to and including 400 nm. "UVB" is the portion of ultraviolet radiation which includes wavelengths from 280 nm up to and including 320 nm. "UVC" is the portion of ultraviolet radiation having a wavelength less than 280 nm.

[0026] The term "long wavelength UV" refers to ultraviolet radiation or light having a wavelength equal to or greater than 255 nm, but not more than 400 nm.

[0027] A "viral vector" refers to a virus, or recombinant thereof, capable of encapsulating desirable genetic material and transferring and integrating the desirable genetic material into a target cell, thus enabling the effective and targeted delivery of genetic material both *ex vivo* and *in vivo*. A "UV activated viral vector" "UV light activated viral vector" is any virus, or recombinant thereof, whose replication is regulated by ultraviolet light. Recombinant adeno-associated virus (r-AAV) is included in the group of viruses labeled UV activated viral vectors. A "solid platform" is any structure designed to be inserted into the body for the purpose of aiding the treatment of the target site proximate to where the solid platform is inserted.

[0028] The term "LAGT" refers to light activated gene transduction, while "LAGT probe" or "light probe" or "long UV wavelength light probe" refers to the medical device which delivers long wavelength ultraviolet light to the target site and effectuates the transduction of the desired gene carried by the vector.

[0029] With reference to Figure 1, a method of treating a patient's tissue is shown. A light probe is located 100 proximate to target cells. Long wavelength ultraviolet (UV) light is then transmitted 110 through a light delivery cable to the light probe. The transduction of the viral vector is activated 120 by locally administering ultraviolet light to the target cells using the light probe. Preferably, the wavelength of the UV light ranges from about 255 nm up to and including about 400 nm. A UV activated viral vector containing a desired gene is delivered 130 proximate to target cells in a patient's tissue. In other preferred embodiments, the wavelength of the UV light ranges from about 280 to about 330. More preferably, the locally administered UV radiation has a wavelength from about 315 nm to about 355 nm, most preferably about 325 nm. In an alternate embodiment the ultraviolet radiation has a wavelength of about 4 nm to about 400 nm, while in another alternate embodiment the ultraviolet radiation has a wavelength of 290 nm.

[0030] It should be noted that the method of Figure 1 may be performed in other preferred embodiments in a different order than the textually outlined above. For example, in another preferred embodiment the vector is delivered prior to locally administering the ultraviolet light.

[0031] Figures 2A-2C illustrate separate components of a UV radiation delivery system, with Figure 2A showing the UV light generator 10, user interface system, and Figure 2B and Figure 2C showing *in vivo* and *ex vivo* versions, respectively, of the light probe 26, 42. Note the light probe 26, 42 is operatively connected to the UV light generator 10 by the light delivery cable 24.

[0032] Figure 2A shows a UV radiation delivery system including a light source 12 with sufficient long wavelength UV output. In addition, light channeling optics, such as an optical coupler 14, transmit the light from the light source 12 into a light delivery cable 24, such as an optical fiber cable or bundle that transmits the light to the target site, for *in vivo* purposes, via a light probe 26 (Figure 2B). A timed shutter 16 is located in the path of the light beam between the light source 12 and the optical coupler 14 in order to control the length of time the patient is exposed to UV light via the light probe 26 (Figure 2B). The timed shutter 16 is operatively connected via connectors 22 to a shutter controller 18 and a shutter control interface 20. Note that the components disclosed in Figure 2A are, in alternate embodiments configured for *ex vivo* treatments, used in conjunctions with the *ex vivo* light probe components shown in Figure 2C.

[0033] Figure 2B shows a light probe 26 as part of an *in vivo* UV radiation delivery system for use with the light source and user interface, such as those shown in Figure 2A. The light probe 26 is configured to locally irradiate target cells, infected by a UV activated viral vector, with long wavelength ultraviolet (UV) light. The light probe 26 is joined to the light delivery cable by an optical connector 28. The light probe 26 is configured to fiber-optically transmit an appropriate UV wavelength light, which originates from the light source 12, through a light guide 30 to a light guide terminator 34, such as a microlens tip or cylindrical diffusing lens tip, in order to "activate" r-AAV transduction in target cells. The light probe 26 is preferably both shaped in the form of an arthroscope and interchangeable with alternate light probes having a differing configurations. For example, the light probe can be configured to have different forms in order to more effectively access different treatment sites. Preferably, the optical connector 28 also allows the light probe 26 to be selectively detached from the light delivery cable 24 when desired. The light probe 26 is also preferably configured to be sterile and disposable. In certain alternate embodiments, the UV radiation delivery system also includes a targeting laser beam (not shown) to enable accurate delivery of the light. Standard surgery tools as recognized by those skilled in the art, for example cannulas and trochars, may also be incorporated into the disclosed method.

[0034] In the embodiment shown in Figure 2A, the light source 12 is contained within a housing, while in certain alternate embodiments the light source 12 is operatively joined to the housing. It should be understood that the exact shape and size of the light probe 26 shown in Figure 2A, and especially the light probe tip, will vary depending on the particular application and target site as would be understood by one skilled in the art. For example, the light probe 26 can be configured to access an intervertabral disc in a patient's spine or the cartilage in a patient's joint. The preferred embodiments include a light source comprising a laser tuned to the appropriate long UV wavelength. In preferred embodiments, the UV radiation delivery system, whether it be a lamp or laser based system, will be optimized based on considerations such as cost and technical simplicity. In addition, the lamp delivery system can also include a targeting laser beam to enable accurate delivery of the light. Standard surgery tools, for example cannulas and trochars, may also be used.

[0035] As shown in Figure 2C, in accordance with alternate preferred embodiments, an *ex vivo* light probe 42 for use with the light source and user interface component of Figure 2A is provided to form an *ex vivo* UV radiation system. In this *ex vivo* embodiment, the light probe 42 is designed for non-surgical use, such as the irradiation of a patient's skin or irradiating tissue which has been removed from a patient for the purpose of later being returned into the patient. The *ex vivo* configured light probe 42 has a handle 44, preferably a form fitting handle configured to allow the effective manual manipulation of the probe 42. The light probe 42 configured for external applications also has a shaft housing 46 surrounding a light guide 30 and a light guide terminator 34. An optical connector 28 channels the light from the light delivery cable 24 and preferably allows the light probe 42 to be selectively detached from the light delivery cable 24 when desired.

[0036] Alternate embodiments employ as a light source, a lamp, such as a high intensity argon lamp. In these alternate embodiments, the UV radiation delivery system further includes a wavelength selecting device, such as a dichroic mirror and/or optical filter, set to transmit long wavelength UV and reject unwanted light wavelengths. In these embodiment, the wavelength selecting device and the dichroic mirror are preferably contained in the same housing as the light source.

[0037] As shown in Figure 3, an injecting device 36 having a housing 38 and a plunger mechanism 40 is preferably employed in conjunction with the UV radiation delivery system of Figures 2 and 2B. Preferably, the injecting device 36 is configured for delivering a UV activated viral vector, such as r-AAV, to the target site using minimally invasive surgical techniques. In alternate preferred embodiments, the injecting device can be configured to inject an implant or solid platform to a target site in a patient (Figures 6 and 8).

[0038] Surgery tools, other than the injecting device 36 shown in Figure 3, which can be involved in certain preferred embodiments include a cannula, a trochar and a power percutaneous disc resector, (all not shown) which increases space within a disc space. It should be noted that the size and design of these tools would vary to adapt to both the treatment goal and the target site. Alternate spinal embodiments of these tools would be designed to access cervical, thoracic, and lumbar disk spaces, as well as the facet joints. Other tools which the skilled artisan would recognize as being advantageous can also be used in conjunction with the embodiments provided herein.

[0039] Referring to Figure 4, a method is provided for the treatment of damaged cartilage tear. A UV probe is inserted 200 proximate to a cartilage target site. Preferably, if desirable, torn cartilage is removed via standard arthroscopy. Long wavelength ultraviolet light (*i.e.*, greater than or equal to 255 nm) is transmitted 210 to the target cells via the fiber optic cable of the UV probe and the target cells are irradiated 220 with the long wavelength ultraviolet light in order to effectuate the resurfacing of the target cartilage site. A UV activated viral vector, such as r-AAV, is delivered 230 proximate to the target site, preferably by injection. It should be noted that the method of Figure 4 may be performed in other preferred embodiments in a different order than the textually outlined above.

[0040] It should be noted that the method of Figure 4 may be performed in other preferred embodiments in a different order than the textually outlined above. For example, in another preferred embodiment the vector is delivered prior to locally administering the ultraviolet light.

[0041] Referring to Figures 5A-5E, alternate preferred embodiments provide an implant system and methods for use thereof including the use of implants which serve as solid platforms at the target site (*e.g.*, to create temporary mechanical rigidity between vertebra) while the target cells respond to the introduction of the desired gene into the patient's tissue. Preferably, these carefully engineered implants can be expandable in order to allow insertion through a minimal incision. In addition, these implants can be formed in a number of shapes, including (but not limited to) an unfolding geodosic dome 42 or tetrahedron (not shown), umbrella/dome (not shown), an expanding cylinder 44, and springs which uncoil to increase diameter. Expanding cylinder 44 is shown in a compacted shape in Figure 5A and an expanded state in Figure 5B (and also Figure 5E), while unfolding geodosic dome 42 is shown in a compacted shape in Figure 5C and an expanded state in Figure 5D. Preferably, these implants are produced with implant integrated UV activated viral vector. For example, r-AAV can be integrated with the implant through bonding or coating the r-AAV to the implant, absorbing the r-AAV into the implant, and/or baking the r-AAV to the implant surface. In alternate preferred embodiments the implant is delivered to a target site separate from the UV activated viral vector.

[0042] Figure 5E shows a solid platform 44, to which a UV activated viral vector is preferably integrated, placed between two vertebra 50 in order to facilitate the rebuilding or repair of the intervertebral disc 48. These solid platforms are preferably designed as surgical implants. Non-limiting examples of solid platforms with which UV activated viral vectors could be integrated include spinal spacers, as shown in Figure 5E, and also total joint replacements such as hip implants, coronary stints and other surgical implants. These examples are provided only for illustrative purposes and should not be considered in any way to limit the present invention. Certain preferred embodiments of the present invention include a UV activated viral vector integrated with a solid platform designed to facilitate the infection of cells proximate to the target site at which the solid platform is inserted. In an alternative embodiment, the vector is delivered to the target site in a step separate from the insertion of the implant.

[0043] It should be understood that structural support implants incorporating such conventional structures as, for example, but not limited to, plates, rods, wire, cables, hooks, screws, are also advantageously useful with kits and preferred embodiments provided herein. The support structure may be formed from material such as, but not limited to, metal, carbon-fiber, plastic, and/or reabsorbable material.

[0044] Figure 6 provides a method of treating a patient using UV activated viral vector in conjunction with a solid platform. A UV activated viral vector containing a desired gene is integrated 300 with a solid platform. Preferably, the vector is integrated with the solid platform by bonded, baked, coated, and/or absorbing. The solid platform is then inserted 310 into a patient proximate to target cells in a patient's tissue. A light probe is located 320 proximate to the target cells and long wavelength ultraviolet light, having a wavelength from 225 nm to 400 nm, is transmitted through a light delivery cable, such as a fiber optic cable or bundle, to the light probe 330. The transduction of the viral vector is activated 340 by irradiating the target cells using the light probe.

[0045] Figure 7 shows a method of treating a patient's spinal tissue. A light probe is located 400 proximate to target cells in a patient's spinal tissue. The transduction of an ultraviolet activated viral vector is activated 410 by locally administering ultraviolet light to the target cells using the light probe. The ultraviolet (UV) activated viral vector, containing a desired gene, is delivered 420 proximate to target cells.

[0046] In another preferred embodiment, shown in Figure 8, a implant is inserted 500 at a spinal target site, preferably using a minimally invasive route such as a stab incision. Target cells are infected 510 with a UV activated viral vector, such as r-AAV, containing a desired gene, preferably by attaching the vector to the implant prior to insertion. For example, r-AAV can be integrated with the implant through coating or bonding the r-AAV to the implant, absorbing the r-AAV into the implant, and/or baking the r-AAV to the implant surface. A light probe is placed or located 520 proximate to the target cells. The light probe activates 530 the infected target cell's UV activated viral vector transduction. In an alternate preferred embodiment, a structural support implant is attached to bone inorder to aid the create space and preserve the geometry of the spinal target site. In an alternative embodiment, the vector is delivered to the target site in a step separate from the insertion of the implant.

[0047] In certain embodiments employing spinal implants, the spacer implants can be used to reconstitute disk height and preserve FSU geometry while the surrounding bone fusion progresses. In these embodiments, the UV activated viral vector includes bone forming genes. The light probe would then directly activate target cells to transduct the viral vector.

[0048] In other embodiments employing spinal implants, the spacer implants can be used to reconstitute disk height and preserve FSU geometry while the invertebral disc regenerates to form a repaired or rejuvenated invertebral disc. In another preferred embodiment, structural support implants can be used to reconstitute disk height and preserve FSU geometry while the invertebral disc regenerates to form a repaired or rejuvenated invertebral disc. In these embodiments, the UV activated viral vector includes disc regenerating genes. The light probe would then directly activate target cells to transduct the viral vector.

[0049] Embodiments of the present invention include both *in vivo* and *ex vivo* applications. In the *ex vivo* application the long wavelength UV light dose is applied to cells or biological material external to the patient and then delivered, preferably through injection, to the desired site of treatment. In the *in vivo* application the LAGT probe and the UV activated viral vector are preferably introduced to the treatment site using minimally invasive surgical techniques, such as stab incisions. Alternate *in vivo* embodiments employ direct visualization surgical techniques.

[0050] A UV activated viral vector is any virus, or recombinant thereof, whose replication is regulated by ultraviolet light. Preferred embodiments of UV activated viral vectors are viruses with single stranded DNA, the virus being capable of allowing a therapeutically significant increase in virus transduction when a virus infected target cell is exposed to a therapeutic does of ultraviolet radiation. More preferred embodiments include UV activated viral vectors capable of infecting non-dividing cells, effectuating sustained target gene expression, eliciting a low immune response to the vector, and possessing an ability to transduce a large variety of tissues.

[0051] Proof of principle experiments, both *ex vivo* and *in vivo* based, are currently under way and can determine the optimal wavelengths for activating the gene therapy. The determination of more preferred wavelengths is based on among other factors, the ability to effectively penetrate a target cell, ease and efficiency of fiber optic transmission, the ability to trigger r-AAV transduction, and the length of time a patient must be exposed to receive a therapeutic dose of ultraviolet radiation. Preferably, the LAGT system delivers long_wavelength ultraviolet radiation in the range of 315 nm to 400 nm. Current experiments support the use of ultraviolet radiation having a wavelength from 315 nm to 355 nm, more particularly about 325 nm, but it is believed that these experiments will ultimately support ultraviolet radiation having a wavelength from 315 nm to 400 nm. In addition, alternate embodiments employ a laser which produces ultraviolet radiation having a wavelength of about 290 nm. Once specific wavelengths are determined, the disclosed components can be optimized for these specific wavelengths.

[0052] The wavelength of the ultraviolet light generated in order to activate UV activated viral vector transduction, including r-AAV transduction, in target cells is preferably 255, 256, 258, 265, 275, 285, 290, 295, 305, 314, 325, 335, 345, 355, 365, 375, 385, 395, or 400 nanometers. More preferably, the wavelength of the ultraviolet light is 290, 295, 300, 305, 310, 315, 316, 317, 322, 325, 327, 332, 337, 342, 347, 352, 357, 362, 367, 372, 377, 382, 387, 392, 393, 394, 395, 396, 397, 398, or 399 nanometers. Most preferably, the wavelength of the ultraviolet light is 325 nanometers.

[0053] Tables 1-3 are charts of example growth factors, signaling molecules and/or transcription factors which desired genes, selected based on the desired use (*e.g.*, implant integrated vs. in solution) and outcome (*e.g.*, osteo-integration, spine fusion, perioprosthetic osteolysis, and/or cartilage repair/regeneration) inserted into a UV activated viral vector could encode for. The lists contained in Tables 1-3 are provided for illustrative purposes and should not be taken as limiting the embodiments of the invention in any way.

TABLE 1

osteo-integration and/or spine fusion:

(a) GROWTH FACTORS
Transforming Growth Factor beta (TGFb)1,2 and 3
bone morphogenetic protein (BMP) 1,2,4,6 and 7
parathyroid hormone (PTH) parathyroid hormone related peptide (PTHrP)
fibroblast growth factor (FGF)1,2
insulin-like growth factor (IGF)

(b) SIGNALING MOLECULES AND TRANSCRIPTION FACTORS
LMP-1
Smad 1,5,8 dominant-negative Smad 2,3
Smurf2
Sox-9
CBFA-1
ATF2

TABLE 2

perioprosthetic osteolysis:

soluble tumor necrosis factor receptors TNFR, TNFR:Fc
osteoprotegerin (OPG)
interleukin-1 receptor antagonist (IL-1RA), IL-1RII:Fc
interleukin-4,10 and viral IL-10

TABLE 3

LAGT for cartilage:

(a) GROWTH FACTORS
Transforming Growth Factor beta (TGFb)1,2 and 3
bone morphogenetic protein (BMP) 1,2,4,6 and 7
parathyroid hormone (PTH) parathyroid hormone related peptide (PTHrP)
fibroblast growth factor (FGF)1,2
insulin-like growth factor (IGF)
osteoprotegerin (OPG)

(b) SIGNALING MOLECULES AND TRANSCRIPTION FACTORS
Sox9
Smad 2,3, dominant-negative Smad 1,5,8
Smurf 1,2
ATF2
CREB

[0054] The results of a completed proof of principle experiment are shown in Example 1.

Example 1

I. Methods

A. Isolation of Human Mesenchymal Stem Cells

[0055] Human Mesenchymal Stem Cells (hMSC) were isolated from patient blood samples harvested from the iliac crest. The blood samples were diluted in an equal volume of sterile Phosphate Buffered Saline (PBS). The diluted sample was then gently layered over 10 ml of Lymphoprep (Media Prep) in a 50 ml conical tube (Corning). The samples were then centrifuged at 1800 rpm for 30 minutes. This isolation protocol is a standard laboratory technique, and the resulting gradient that formed enabled the isolation of the hMSCs from the layer immediately above the Lymphoprep. The isolated fraction was placed into a new 50 ml conical tube, along with an additional 20 ml of sterile PBS. The sample was centrifuged at 1400 rpm for 8 minutes. The supernatant was removed the cell pellet was resuspended in 20 ml for fresh PBS, and centrifuged again for 8 minutes at 1400 rpm. Afterwards the supernatant was removed, the cell pellet was resuspended in 10 ml of Dulbecco's Modified Eagle Medium (DMEM) with 10% Fetal Bovine Serum (FBS) and 1% Penicillin/ Streptomycin (P/S) (Invitrogen). The hMSCs were grown and passed as necessary in a 37°/5% CO_2, water-jacketed incubator (Forma Scientific).

B. 325 nm UV treatment of Human Mesenchymal Stem Cells

[0056] Prior to irradiation, hMSCs were plated at a density of 5 x 10^4 cells/well in 12-well plates. The cells were allowed to sit down overnight. The next morning the media was removed immediately prior to irradiation. The cells were irradiated at various doses (500 J/m^2, 1000 J/m^2, 3000 J/m^2, 6000 J/m^2, or 10,000 J/m^2) of 325 nm UV light using a helium-cadmium laser system (Melles Griot). After irradiation, fresh media, either with or without recombinant adeno-associated virus was added to the wells.

C. Infection of Human Mesenchymal Stem Cells with Recombinant Adeno-Associated Virus

[0057] Infections were carried out in 12-well dishes. The cells were infected at various multiplicities of infection (MOIs = 10, 100, and 1000), using a recombinant adeno-associated virus carrying the bacterial β-galactosidase reporter gene (rAAV-LacZ via UNC-Chapel Hill Gene Therapy Vector Core Facility). After being irradiated, the cells were infected with the predetermined amount of virus in a total volume of 500 µl of DMEM/10% FBS/1% P/S. Two hours after the initial infection, and additional 1 ml of media was added to the cultures. The cultures were then allowed to incubate (37°/5% CO_2) for forty-eight hours before harvest for analysis.

D. Quantifying Recombinant Gene Expression

[0058] Forty-eight hours after infection, the cells were harvested; cell lysates were made and analyzed using a commercially available Luminescent β-gal Reporter System. (BD Biosciences), Briefly, experimental cell samples were removed from the 12-well dish using 0.25% Trypsin-EDTA. The cell suspension was transferred to a 1.5 ml conical tube and the cells were pelleted via a 15 second centrifugation at 13,000 rpm. The cell pellet was washed using two successive rounds of resuspension in ice cold PBS and pelleting for 15 seconds at 13,000 rpm. The final pellet was resuspended in 75 µl of Lysis Buffer (100 mM K_2HPO_4, 100 mM KH_2PO_4, 1 M DTT) and subjected to three rounds of freeze/thaw in an isopropanol dry ice bath and a 37° water bath. The lysates were centrifuged for a final time for 5 minutes at 13,000 rpm. Aliquots (15 µl) of the resulting supernatant were incubated with the provided substrate/buffer solution for one hour and then analyzed using a standard tube luminometer. The read out of this analysis is expressed in Relative Light Units (RLU) in the Results section.

II. Results

A. Exposure to 325 nm UV Increased the Level of Reporter Gene Expression

[0059] Exposure to 325 nm UV prior to infection with rAAV-LacZ had a dose dependent increase in LacZ reporter gene expression at each of the MOI's used. The controls for each experiment were as follows: Mock (cells alone, no treatment) and cells treated with each of the various UV dosages (500 J/m^2, 1000 J/m^2, 3000 J/m^2, 6000 J/m^2, which had RLU levels consistent with the Mock cultures (data not shown). Statistical significance was calculated using the Student T-Test. The results are shown below in Figures 9-11.

[0060] Although this invention has been disclosed in the context of certain preferred embodiments and an Example, it will be understood by those skilled in the art that the present invention extends beyond the specifically disclosed embodiments to other alternative embodiments and/or uses of the invention and obvious modifications thereof. It will be appreciated, however, that no matter how detailed the foregoing may appear in text, the invention may be practiced in many ways. Thus, it is intended that the scope of the present invention herein disclosed should not be limited by the particular disclosed embodiments described above, but should be determined only by a fair reading of the claims that follow and any equivalents thereof.

WE CLAIM:

1. A kit for introducing a desired gene into a patient's tissue, the kit comprising:

an ultraviolet light activated viral vector, the vector being capable of delivering the gene to the tissue;

a light source capable of producing an ultraviolet light beam of light having a wavelength from about 255 nm to about 400 nm; and

a light probe operatively connected to the light source, the light probe being configured to deliver the light to the tissue.

2. The kit according to Claim 1, wherein the ultraviolet light has a wavelength from about 4 nm to about 400 nm.

3. The kit according to Claim 1, wherein the ultraviolet light has a wavelength from about 280 nm to about 330 nm.

4. The kit according to Claim 1, wherein the ultraviolet light has a wavelength of about 290 nm.

5. The kit according to Claim 1, wherein the ultraviolet light has a wavelength of about 325 nm.

6. The kit according to Claim 5, wherein the light source is a helium cadmium laser.

7. The kit according to Claim 1, wherein the ultraviolet light has a wavelength from about 315 nm to about 355 nm.

8. The kit according to Claim 1, wherein the ultraviolet light has a wavelength from about 315 nm to about 400 nm.

9. The kit according to Claim 1, wherein the viral vector is recombinant adeno-associated virus (r-AAV).

10. The kit according to Claim 1, wherein the ultraviolet light is UVA light.

11. The kit according to Claim 1, wherein the ultraviolet light is UVB light.

12. The kit according to Claim 1, wherein the light probe is designed for arthroscopic surgery.

13. The kit according to Claim 12, further comprising a sheath for minimally invasive surgery.

14. The kit according to Claim 1, further comprising:

a spacer configured to be surgically inserted in a patient for therapeutic purposes.

15. The kit according to Claim 14, wherein the spacer is adapted to preserve space within a joint.

16. The kit according to Claim 14, wherein the viral vector is integrated onto the spacer.

17. The kit according to Claim 14, wherein the ultraviolet activated viral vector is recombinant adeno-associated virus (rAAV) and the spacer is adapted for insertion into a functional spinal unit (FSU).

18. The kit according to Claim 1, wherein the light source is a laser.

19. The kit according to Claim 1, wherein the desired gene is selected to effectuate tissue regeneration.

20. The kit according to Claim 1, wherein the desired gene is selected to effectuate tissue repair.

21. The kit according to Claim 1, wherein the desired gene is selected to effectuate tissue fusion.

22. A kit according to Claim 1, further comprising:

a light delivery cable configured to transmit the ultraviolet light from the light source to the light probe; and

light channeling optics configured to channel the ultraviolet light beam into the light delivery cable.

23. The kit according to Claim 1, wherein the light source is a lamp.

24. The kit according to Claim 23, further comprising:

a wavelength selecting device set to transmit a therapeutically appropriate wavelength of ultraviolet light; and

focusing optics.

25. The kit according to Claim 22, wherein the light probe is configured to access a spinal treatment site.

26. The kit according to Claim 22, wherein the light probe is configured to access a cartilage treatment site.

27. The kit according to Claim 1, wherein the treatment site for which the light probe is configured to access is a treatment site external to a patient being treated.

28. The kit according to Claim 22, further comprising:

a solid platform which includes the ultraviolet light activated viral vector, and

a solid platform delivery device configured to place the solid implant at the treatment site.

29. The kit of Claim 22, further comprising:

a power source powering the light source;

a timed shutter configured to selectively block the light beam;

a shutter control interface; and

an optical coupler for channeling the light beam into the light delivery cable.

30. An implant kit for introducing a desired gene into a patient's tissue comprising:

an implant configured to be inserted into a patient's tissue in a minimally-intrusive surgical procedure;

an ultraviolet light activated viral vector integrated with the implant; and

a light probe configured to access the implant when inserted in a patient's tissue and locally administer ultraviolet light to the vector.

31. The kit of Claim 30, wherein the ultraviolet light is 255 nm to 400 nm.

32. The kit of Claim 30, wherein the r-AAV is bonded to the implant.

33. The kit of Claim 30, wherein the r-AAV is baked to the implant.

34. The kit of Claim 30, wherein the implant is expandable.

35. The kit of Claim 30, wherein the implant is configured as a spacer designed to be inserted between two vertebra using minimally invasive surgical techniques.

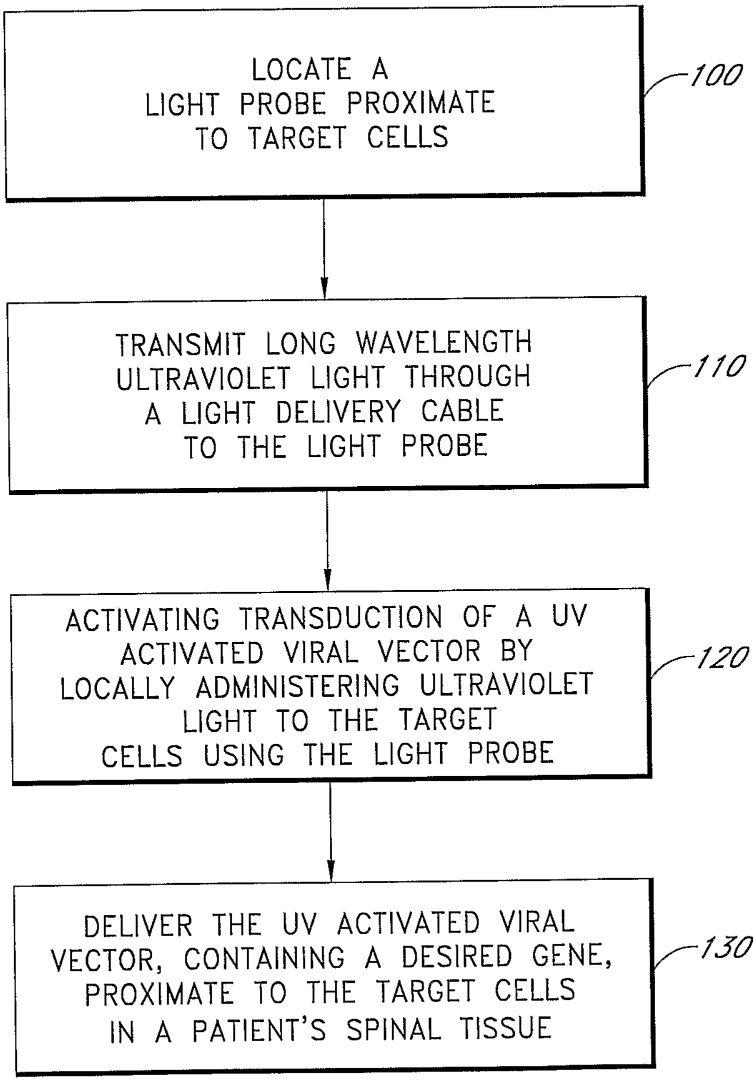

LOCATE A LIGHT PROBE PROXIMATE TO TARGET CELLS
100
TRANSMIT LONG WAVELENGTH ULTRAVIOLET LIGHT THROUGH A LIGHT DELIVERY CABLE TO THE LIGHT PROBE
110
ACTIVATING TRANSDUCTION OF A UV ACTIVATED VIRAL VECTOR BY LOCALLY ADMINISTERING ULTRAVIOLET LIGHT TO THE TARGET CELLS USING THE LIGHT PROBE
120
DELIVER THE UV ACTIVATED VIRAL VECTOR, CONTAINING A DESIRED GENE, PROXIMATE TO THE TARGET CELLS IN A PATIENT'S SPINAL TISSUE
130

FIG. 1

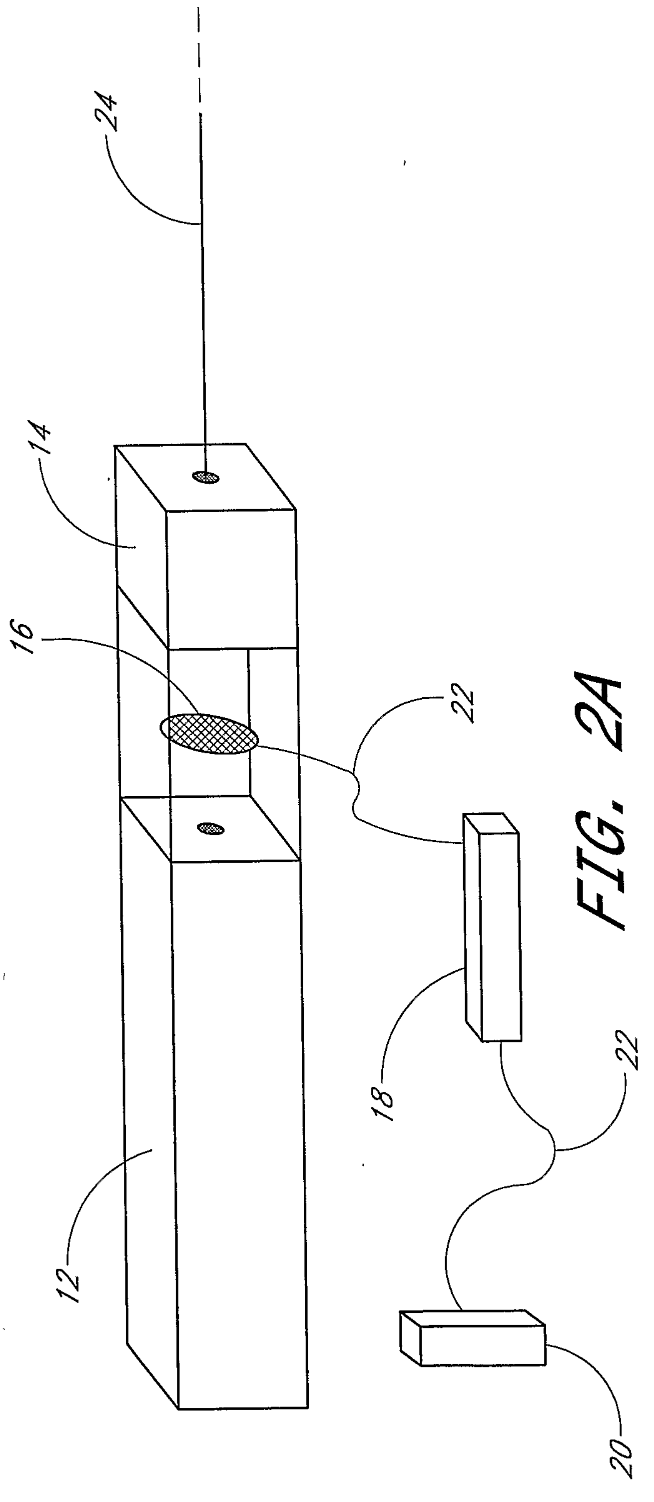


FIG. 2A

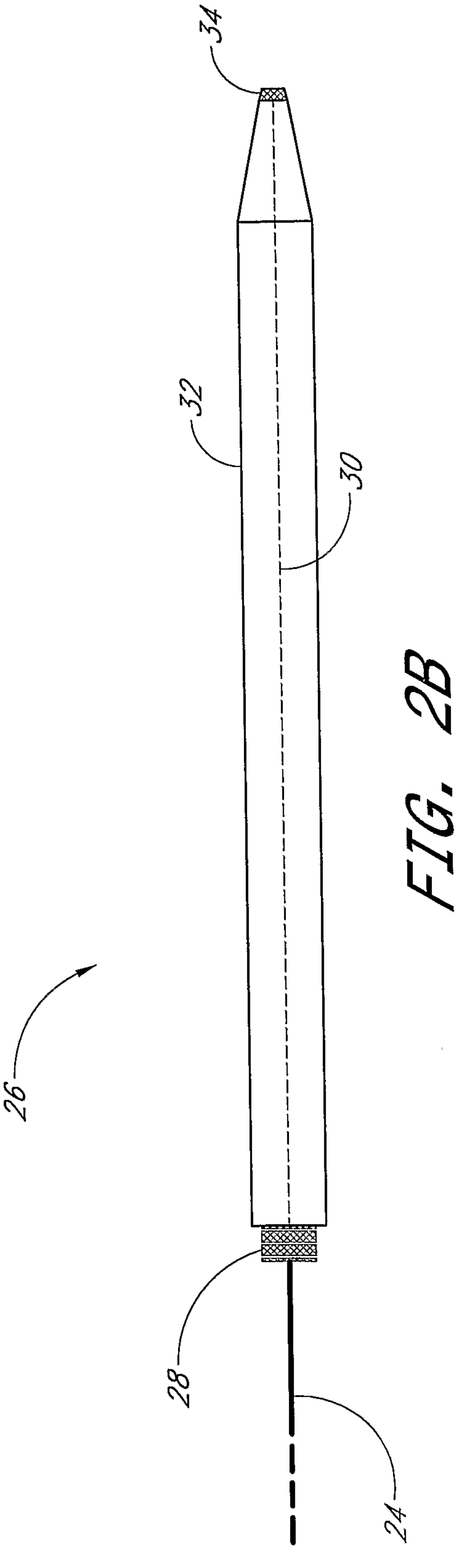


FIG. 2B

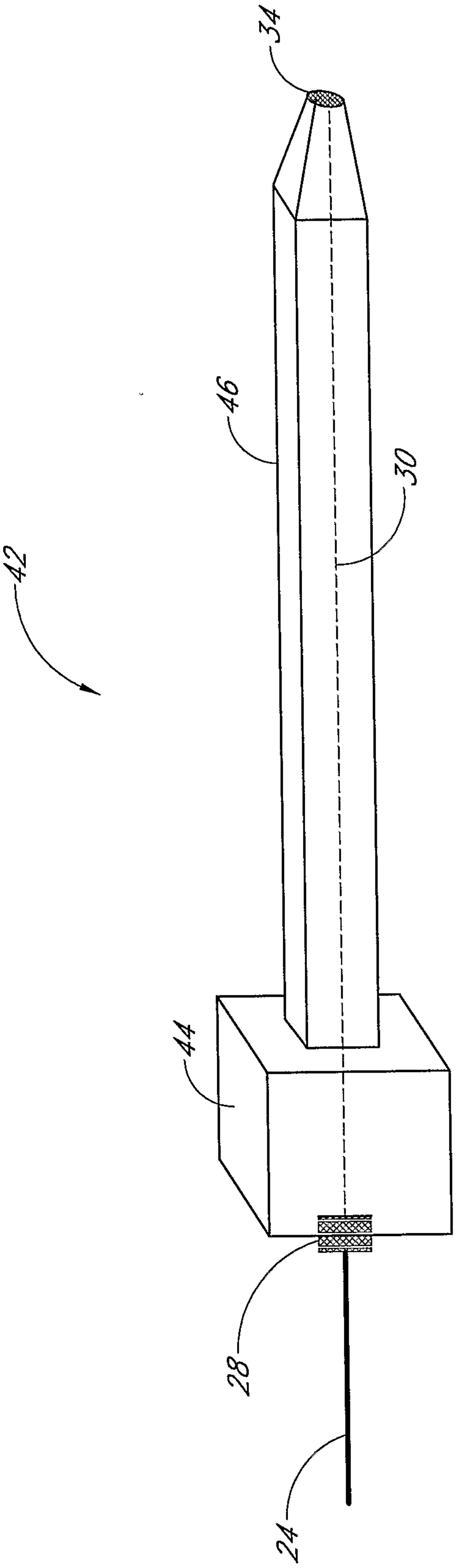


FIG. 2C

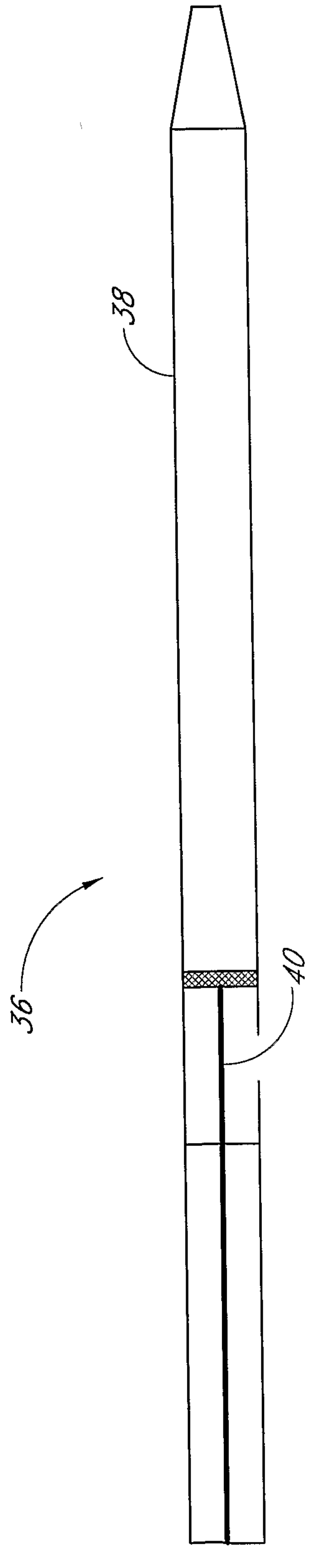


FIG. 3

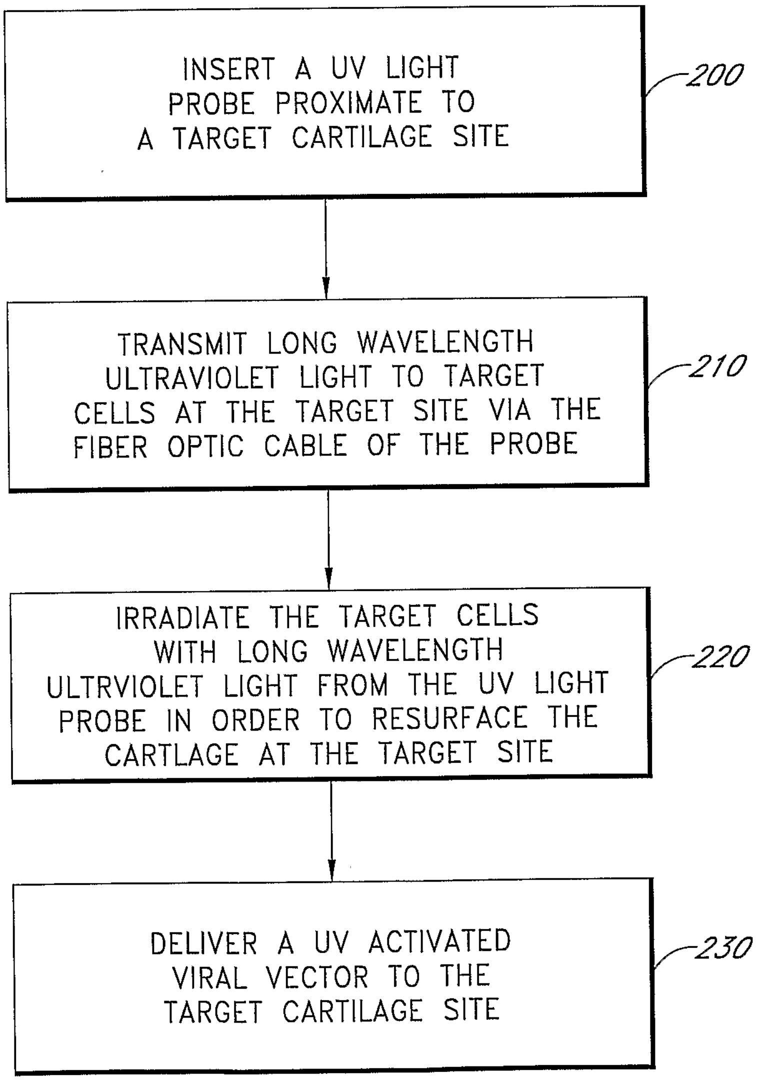

INSERT A UV LIGHT PROBE PROXIMATE TO A TARGET CARTILAGE SITE
200
TRANSMIT LONG WAVELENGTH ULTRAVIOLET LIGHT TO TARGET CELLS AT THE TARGET SITE VIA THE FIBER OPTIC CABLE OF THE PROBE
210
IRRADIATE THE TARGET CELLS WITH LONG WAVELENGTH ULTRVIOLET LIGHT FROM THE UV LIGHT PROBE IN ORDER TO RESURFACE THE CARTLAGE AT THE TARGET SITE
220
DELIVER A UV ACTIVATED VIRAL VECTOR TO THE TARGET CARTILAGE SITE
230

FIG. 4

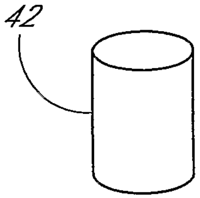


FIG. 5A

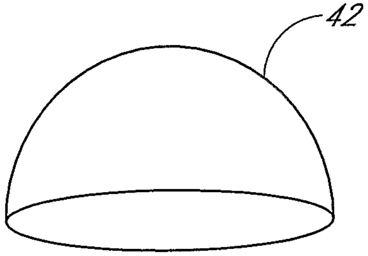


FIG. 5B

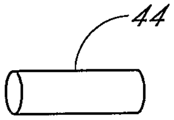


FIG. 5C

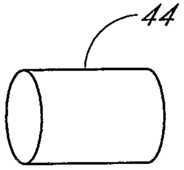


FIG. 5D

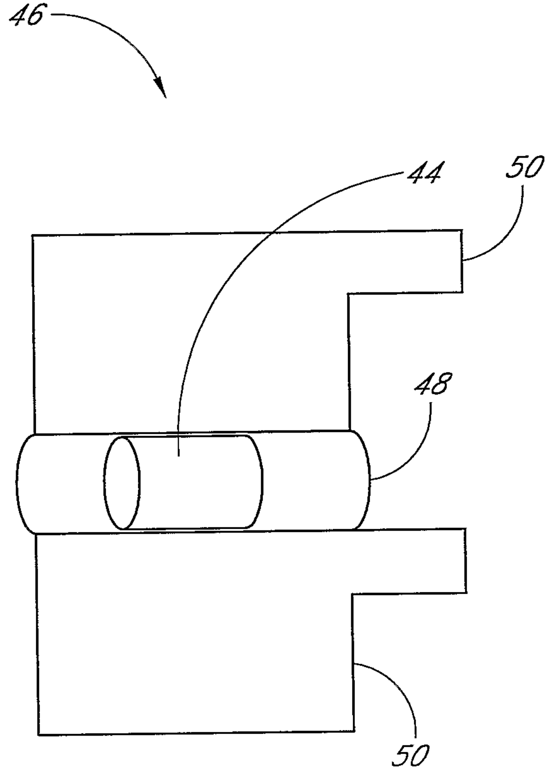


FIG. 5E

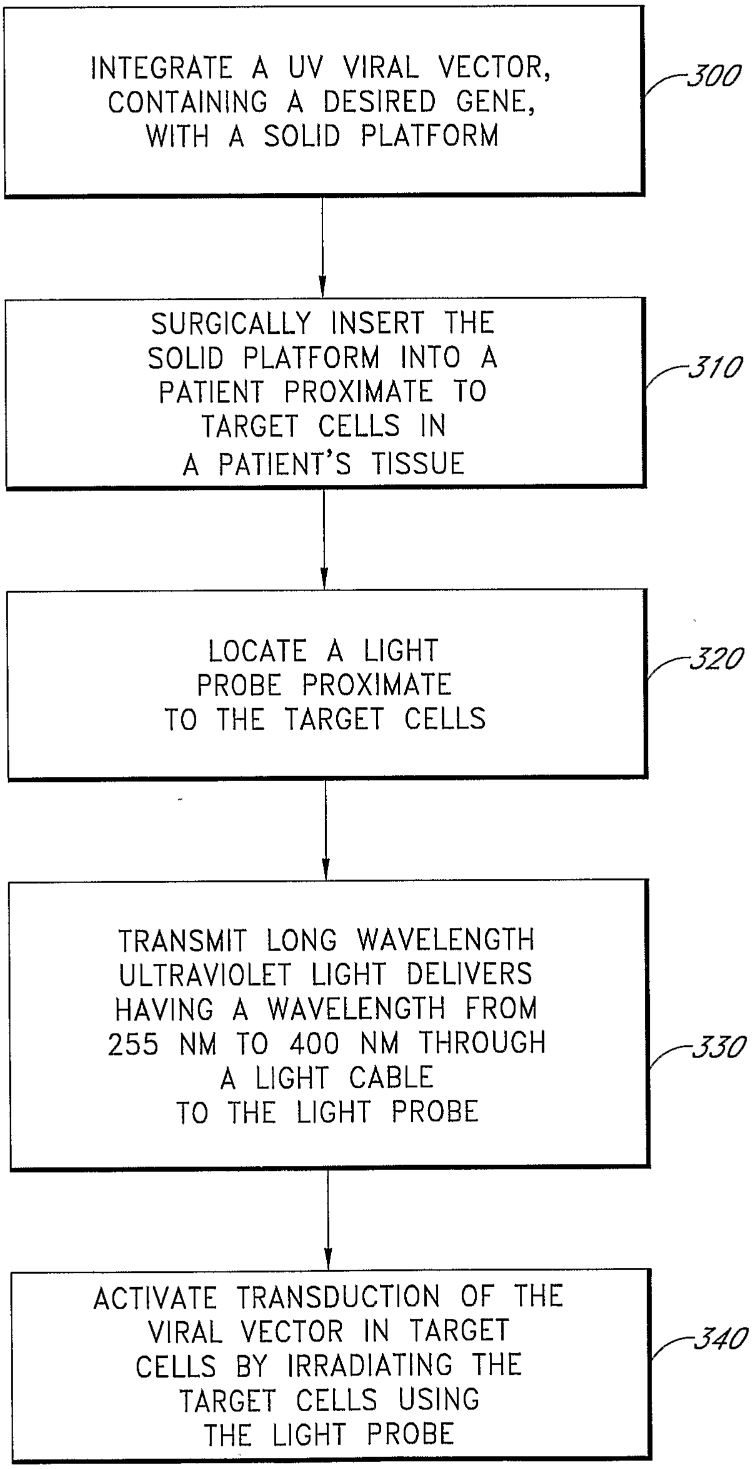
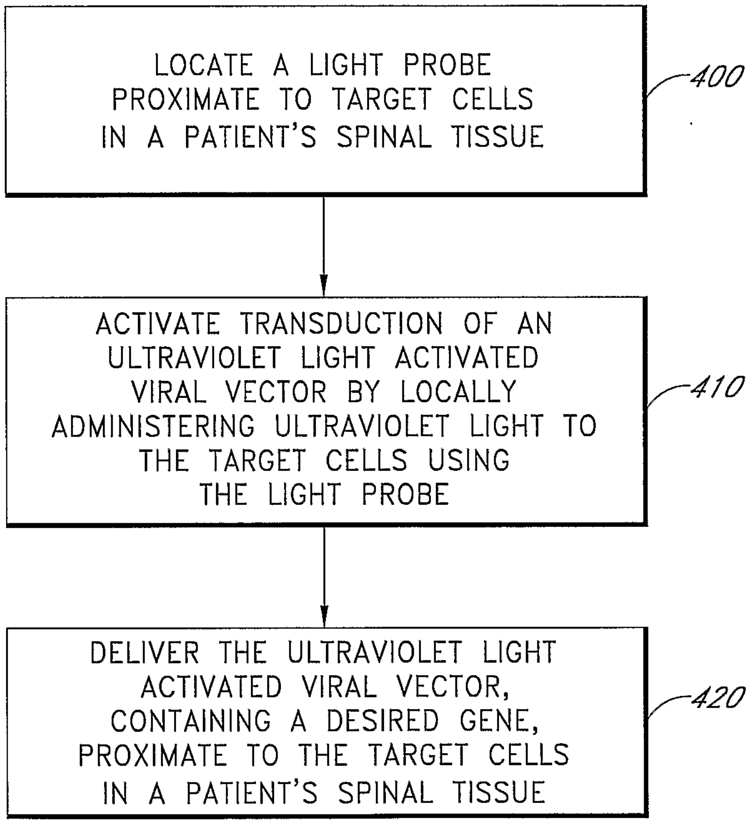

INTEGRATE A UV VIRAL VECTOR, CONTAINING A DESIRED GENE, WITH A SOLID PLATFORM
300
SURGICALLY INSERT THE SOLID PLATFORM INTO A PATIENT PROXIMATE TO TARGET CELLS IN A PATIENT'S TISSUE
310
LOCATE A LIGHT PROBE PROXIMATE TO THE TARGET CELLS
320
TRANSMIT LONG WAVELENGTH ULTRAVIOLET LIGHT DELIVERS HAVING A WAVELENGTH FROM 255 NM TO 400 NM THROUGH A LIGHT CABLE TO THE LIGHT PROBE
330
ACTIVATE TRANSDUCTION OF THE VIRAL VECTOR IN TARGET CELLS BY IRRADIATING THE TARGET CELLS USING THE LIGHT PROBE
340

FIG. 6



LOCATE A LIGHT PROBE PROXIMATE TO TARGET CELLS IN A PATIENT'S SPINAL TISSUE

ACTIVATE TRANSDUCTION OF AN ULTRAVIOLET LIGHT ACTIVATED VIRAL VECTOR BY LOCALLY ADMINISTERING ULTRAVIOLET LIGHT TO THE TARGET CELLS USING THE LIGHT PROBE

DELIVER THE ULTRAVIOLET LIGHT ACTIVATED VIRAL VECTOR, CONTAINING A DESIRED GENE, PROXIMATE TO THE TARGET CELLS IN A PATIENT'S SPINAL TISSUE

FIG. 7

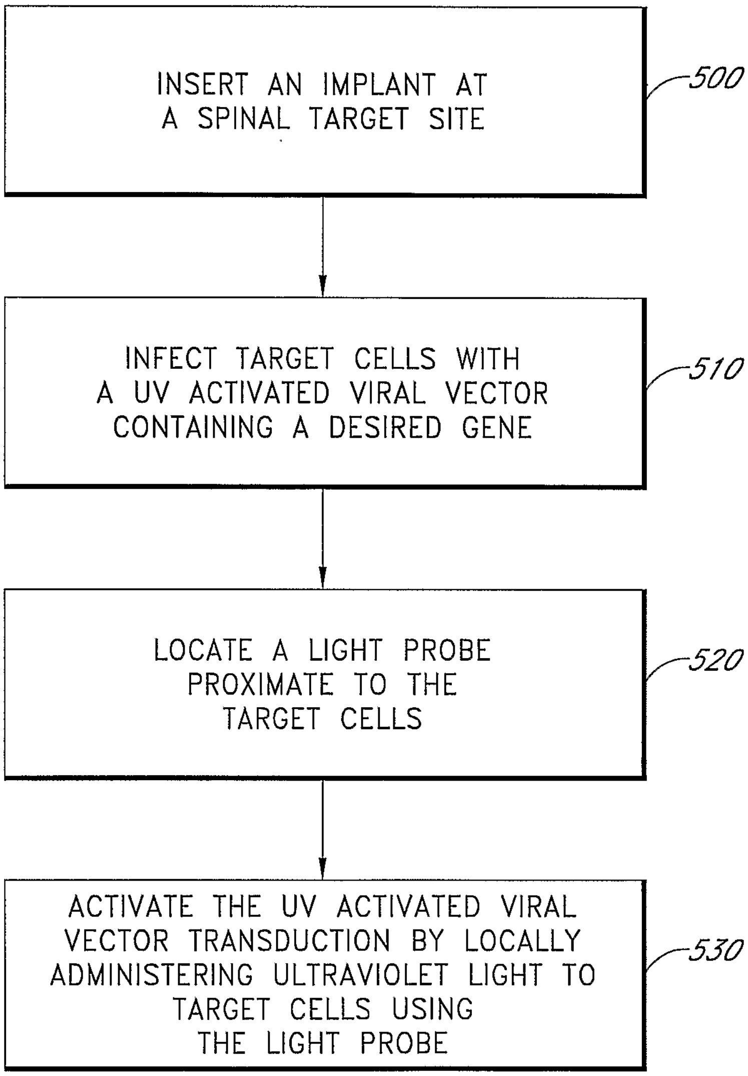
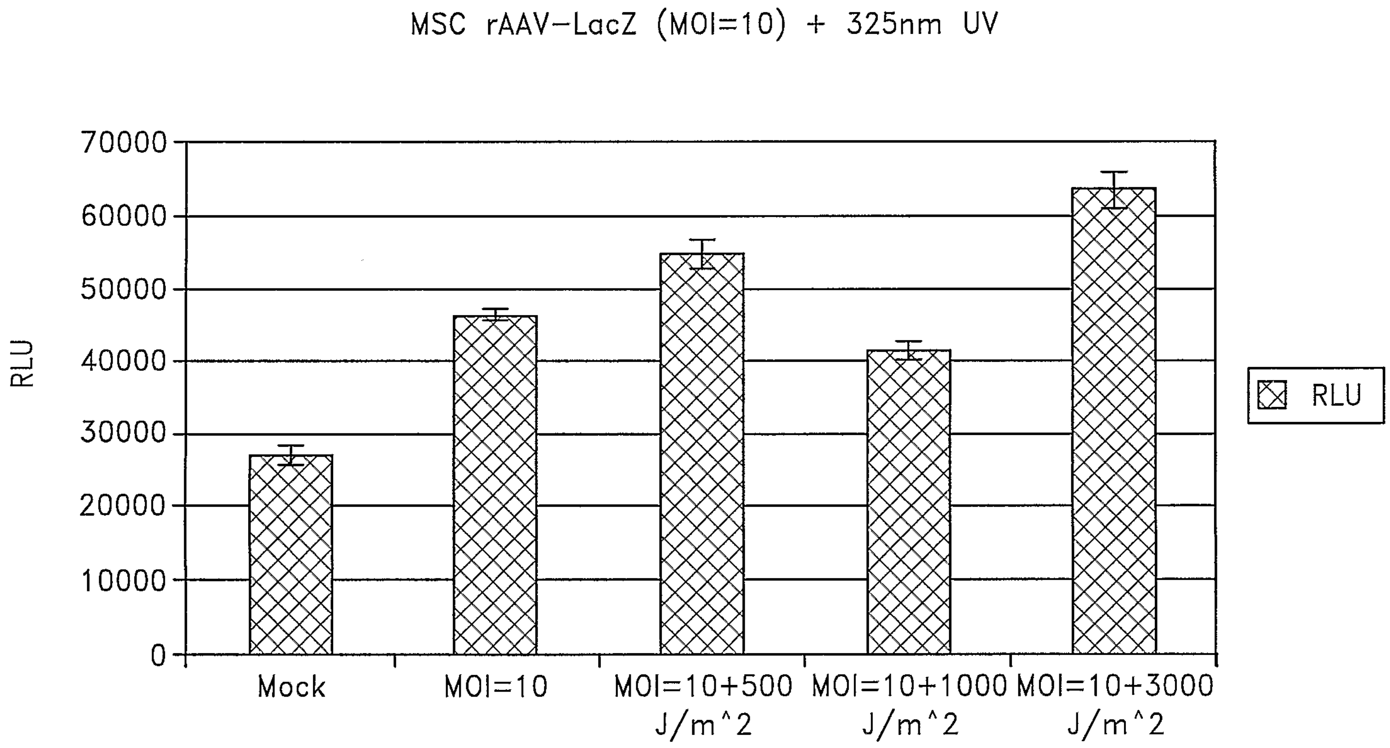
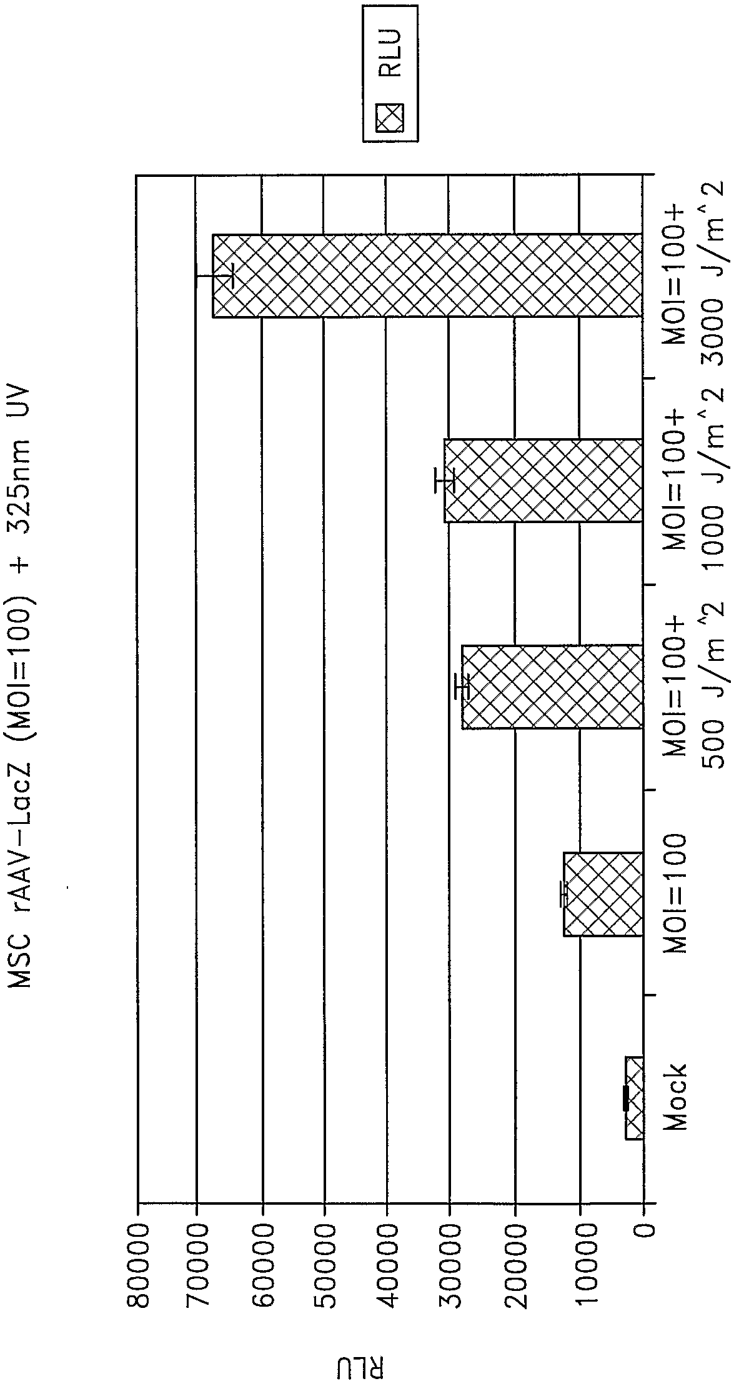

INSERT AN IMPLANT AT A SPINAL TARGET SITE
500
INFECT TARGET CELLS WITH A UV ACTIVATED VIRAL VECTOR CONTAINING A DESIRED GENE
510
LOCATE A LIGHT PROBE PROXIMATE TO THE TARGET CELLS
520
ACTIVATE THE UV ACTIVATED VIRAL VECTOR TRANSDUCTION BY LOCALLY ADMINISTERING ULTRAVIOLET LIGHT TO TARGET CELLS USING THE LIGHT PROBE
530

FIG. 8



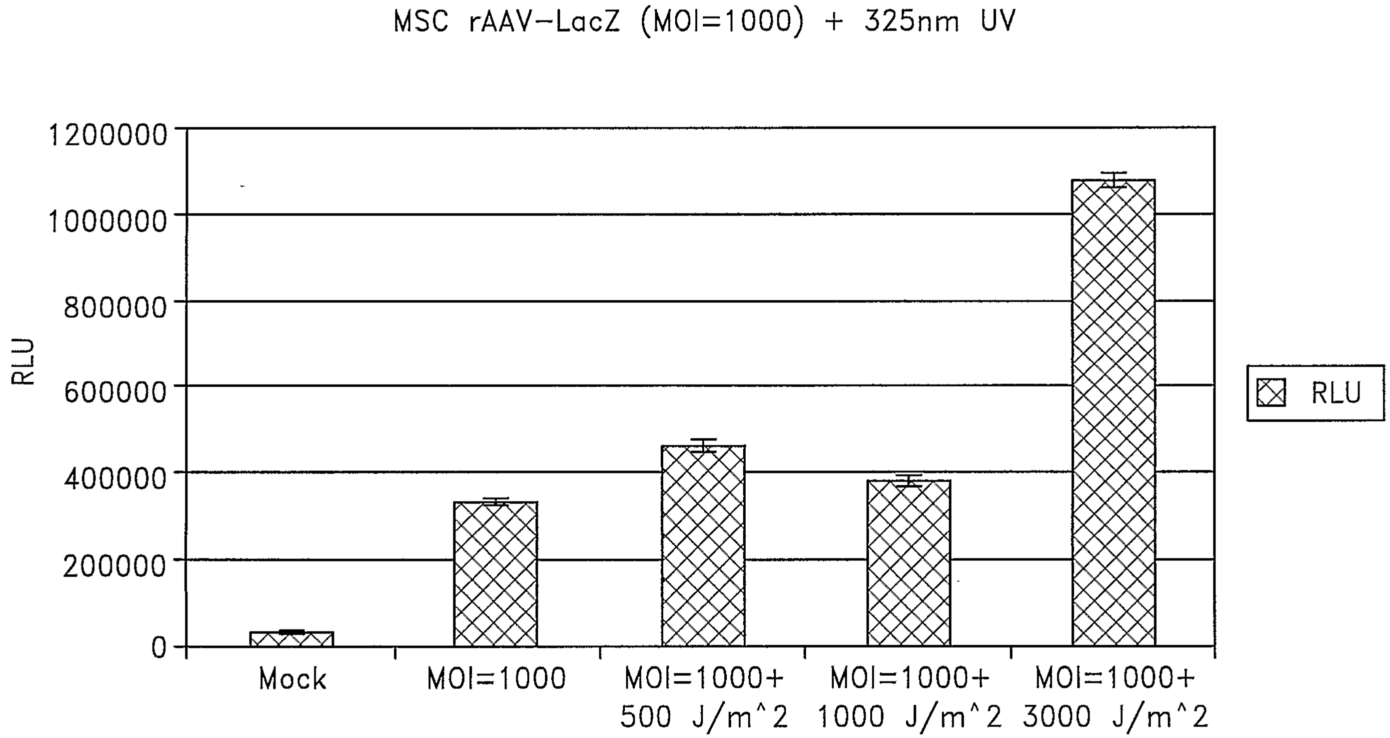
* For samples treated with 500 J/m^2 and 3000 J/m^2 compared to MOI=100, $p<0.05$

FIG. 9



* For all samples compared to MOI=100, $p<0.05$

FIG. 10



* For all samples compared to MOI=1000, $p<0.05$

FIG. 11