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TISSUE DECELLULARIZATION METHODS

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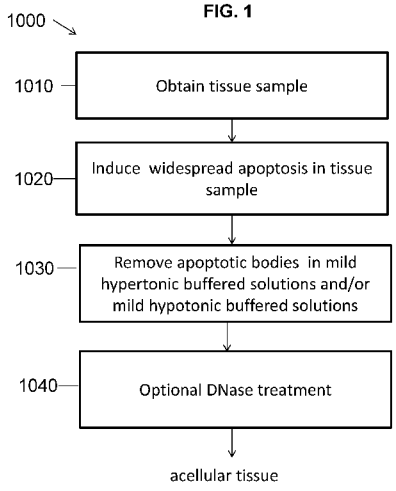
FIG. 1



(57) Abstract: Provided herein are methods of producing an acellular tissue product wherein the method can include the step of inducing apoptosis and washing the tissue after induction of apoptosis with a tonic solution. Also provided herein are acellular tissue products produced by the methods provided herein and methods of administering the acellular tissue products to a subject in need thereof.

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TISSUE DECELLULARIZATION METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of and priority to co-pending U.S. Provisional Patent Application No. 62/192,823, filed on July 15, 2015, entitled "TISSUE DECELLULARIZATION METHODS," the contents of which is incorporated by reference herein in its entirety.

BACKGROUND

Decellularization technology offers the potential to attain tissue-specific scaffolds that guide tissue regeneration following injury and/or disease. As such there exists a need for improved decllularization methods for scaffold generation for tissue regeneration for treatment of injury and/or disease.

SUMMARY

Provided herein are tissue decellularization methods, where the methods can include the steps of obtaining a tissue sample from a subject to generate an *ex vivo* tissue sample; exposing the *ex vivo* tissue sample to an apoptotic agent or apoptotic process; and washing the *ex vivo* tissue sample in a hypertonic solution, a hypotonic solution, or a hypertonic solution and a hypotonic solution. The tissue sample can be a peripheral nerve, a nucleus pulposus, and/or a combination thereof. The tissue sample can be a lung tissue. The apoptotic agent is camptothecin, staurosporine, doxorubicin, or an analog thereof. The apoptotic process can contain one or more freeze-thaw cycles. The concentration of the apoptotic agent can range from about 5μM to about 10 μM. The concentration of the apoptotic agent can be about 10 μM. The concentration of the apoptotic agent can be about 5 μM. The *ex vivo* tissue sample can be exposed to the apoptotic agent for about 2 days. The tissue can be washed with a hypertonic solution. The hypertonic solution can be greater than 1X buffered solution. The hypertonic solution is 4X saline. The tissue can be washed with a hypotonic solution. The hypotonic solution can less than 1X buffered solution. The hypotonic solution can be a 0.5X saline solution. The concentration the concentration of the apoptotic agent can be about 5 μM. The apoptotic agent can be camptothecin, staurosporine, doxorubicin, or an analog thereof. The method can further include the step of treating the tissue with DNAse for a period of time ranging from 30 minutes to 24 hours. The step of washing can produce an acellular tissue product. The method can further include step of adding an active agent to the acellular tissue product. The active agent can selected from the group consisting of: a stem cell, nucleic acid, amino acid, peptide, polypeptide,

antibody, aptamer, ribozyme, guide sequence for a ribozyme that inhibit translation or transcription of essential tumor proteins and genes, hormone, immunomodulator, antipyretic, anxiolytic, antipsychotic, analgesic, antispasmodic, anti-inflammatory, anti-histamine, anti-infective, a chemotherapeutic, or combinations thereof.

Also provided herein are acellular tissue products, where the acellular tissue product can be formed by a method as described herein. The method can further include the step of treating the tissue with DNAse for a period of time ranging from about 30 minutes to about 24 hours. The acellular tissue product can contain an active agent. The active agent can be selected from the group consisting of: a stem cell, nucleic acid, amino acid, peptide, polypeptide, antibody, aptamer, ribozyme, guide sequence for a ribozyme that inhibit translation or transcription of essential tumor proteins and genes, hormone, immunomodulator, antipyretic, anxiolytic, antipsychotic, analgesic, antispasmodic, anti-inflammatory, anti-histamine, anti-infective, a chemotherapeutic, or combinations thereof. The acellular tissue product can be formulated for injection.

Also provided herein are methods including the step of administering an acellular tissue product as provided herein to a subject in need thereof. The subject in need thereof can have a spinal injury or disease, intervertebral disc degeneration, disease or trauma of the lungs or liver, or volumetric muscle loss, peripheral nerve injury, amputation or spinal degradation, osteoarthritis of the hip or knee, volumetric muscle loss, cirrhosis of the liver, or otherwise requires partial or total organ replacement.

BRIEF DESCRIPTION OF THE DRAWINGS

Further aspects of the present disclosure will be readily appreciated upon review of the detailed description of its various embodiments, described below, when taken in conjunction with the accompanying drawings.

Fig. 1 shows one embodiment of a method for decellularization of a tissue sample.

Figs. 2A-2F show fluorescence micrographs of peripheral nerve with and without apoptosis induction followed by washing with various regimens.

Fig. 3 shows a graph demonstrating DNA content of peripheral nerve under various treatment regimens.

Fig. 4 shows a table demonstrating the quantification of DNA content shown in Fig. 3.

Figs. 5A-5C demonstrate fluorescence micrographs of nerve tissue labeled for cell or basal lamina markers. For Figs. 5A and 5B, the images are fresh nerve (top half) and apoptosis decellularized nerve (bottom half). Fig. 5A was labeled for neurons (neurofilament, green), Schwann cells (S100, red), and nuclei (DAPI, blue). Fig. 5B shows cross-sections of

the basal lamina stained for laminin (red). Fig. 5C shows a representative basal lamina staining in nerve tissue decellularized according to a conventional detergent-based method.

Figs. 6A-6D demonstrate fluorescence micrographs of nucleus pulposus stained with a nuclear stain (blue) and a chondroitin sulfate proteoglycan (CSPG) antibody (red).

Figs. 7A-7B demonstrate images of a carefully dissected motion segment of the spine and an extracted nucleus pulposus.

Fig. 8 shows a graph demonstrating tibialis anterior muscle weight changes over time in rats receiving detergent decellularized nerve graft, apoptosis decellularized nerve graft, or an isograft of fresh nerve. This figure demonstrates that the apoptosis decellularization method was not statistically different from isograft after 8 weeks, suggesting that the apoptosis decellularization method has the potential to perform similarly to the clinical gold standard and outperform traditional decellularization methods.

Figs. 9A-9C show fluorescence images demonstrating that the more gentle apoptosis decellularization (Fig. 9C) process can result in less tissue disruption than the harsher traditional decellularization methods which uses a water treatment to initiate decellularization (Fig. 9B), and more comparable to fresh nerve (Fig. 9A).

DETAILED DESCRIPTION

Before the present disclosure is described in greater detail, it is to be understood that this disclosure is not limited to particular embodiments described, and as such may, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

Where a range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range, is encompassed within the disclosure. The upper and lower limits of these smaller ranges may independently be included in the smaller ranges and are also encompassed within the disclosure, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included in the disclosure.

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. Although any methods and materials similar or equivalent to those described herein can also be used in the practice or testing of the present disclosure, the preferred methods and materials are now described.

All publications and patents cited in this specification are herein incorporated by reference as if each individual publication or patent were specifically and individually indicated to be incorporated by reference and are incorporated herein by reference to disclose and describe the methods and/or materials in connection with which the publications are cited. The citation of any publication is for its disclosure prior to the filing date and should not be construed as an admission that the present disclosure is not entitled to antedate such publication by virtue of prior disclosure. Further, the dates of publication provided could be different from the actual publication dates that may need to be independently confirmed.

As will be apparent to those of skill in the art upon reading this disclosure, each of the individual embodiments described and illustrated herein has discrete components and features which may be readily separated from or combined with the features of any of the other several embodiments without departing from the scope or spirit of the present disclosure. Any recited method can be carried out in the order of events recited or in any other order that is logically possible.

Embodiments of the present disclosure will employ, unless otherwise indicated, techniques of molecular biology, microbiology, nanotechnology, organic chemistry, biochemistry, botany and the like, which are within the skill of the art. Such techniques are explained fully in the literature.

Definitions

As used herein, "about," "approximately," and the like, when used in connection with a numerical variable, generally refers to the value of the variable and to all values of the variable that are within the experimental error (e.g., within the 95% confidence interval for the mean) or within ±10% of the indicated value, whichever is greater.

As used herein, “administering” refers to an administration that is oral, topical, intravenous, subcutaneous, transcutaneous, transdermal, intramuscular, intra-joint, parenteral, intra-arteriole, intradermal, intraventricular, intracranial, intraperitoneal, intralesional, intranasal, rectal, vaginal, by inhalation or via an implanted reservoir. The term “parenteral” includes but is not limited to, subcutaneous, intravenous, intramuscular, intra-articular, intra-synovial, intrasternal, intrathecal, intrahepatic, intralesional, and intracranial injections or infusion techniques.

As used interchangeably herein, "subject," "individual," or "patient," refers to a vertebrate, preferably a mammal, more preferably a human. Mammals include, but are not limited to, murines, simians, humans, farm animals, sport animals, and pets. The term “pet” includes a dog, cat, guinea pig, mouse, rat, rabbit, ferret, and the like. The term farm animal includes a horse, sheep, goat, chicken, pig, cow, donkey, llama, alpaca, turkey, and the like.

As used herein, "control" is an alternative subject or sample used in an experiment for comparison purposes and included to minimize or distinguish the effect of variables other than an independent variable.

As used herein, "positive control" refers to a "control" that is designed to produce the desired result, provided that all reagents are functioning properly and that the experiment is properly conducted.

As used herein, "negative control" refers to a "control" that is designed to produce no effect or result, provided that all reagents are functioning properly and that the experiment is properly conducted. Other terms that are interchangeable with "negative control" include "sham," "placebo," and "mock."

As used herein, "autologous" refers to being derived from the same subject that is the recipient.

As used herein, "allograft" refers to a graft that is derived from one member of a species and grafted in a genetically dissimilar member of the same species.

As used herein "xenograft" or "xenogeneic" refers to a substance or graft that is derived from one member of a species and grafted or used in a member of a different species.

As used herein, "autograft" refers to a graft that is derived from a subject and grafted into the same subject from which the graft was derived.

As used herein, "allogeneic" refers to involving, derived from, or being individuals of the same species that are sufficiently genetically different so as to interact with one another antigenically.

As used herein, "donor" refers to a subject from which cells or tissues are derived.

As used herein, "hypertonic solution" refers to a solution that has a greater concentration of solutes than the concentration of solutes inside of a cell.

As used herein, "hypotonic solution" refers to a solution that has a concentration of solutes that is less than the concentration of solutes within a cell.

As used herein, "analog" refers to another compound, composition, or other substance of matter that is considered comparable to the reference compound, composition, or substance of matter and includes structural analogs and functional analogs.

Discussion

Decellularization technology offers the potential to attain tissue-specific scaffolds that guide tissue regeneration following injury and/or disease. Most decellularization protocols used in research and industry contain an initial cell lysis step in a hypotonic buffer, such as water, followed by chemical solutions to remove cellular remnants. These harsh conditions result in an undesirable broad dispersal of intracellular components, disruption of tissue morphology, and removal of desired tissue elements.

With that said, described herein are decellularization methods that do not require cell lysis buffers or harsh chemicals. The decellularization methods described herein can include inducing apoptosis in *ex vivo* tissue. The decellularization methods described herein can effectively remove cellular components without having to rely on harsh conditions. In some embodiments, the methods can effectively remove cellular components from peripheral nerve and/or nucleus pulposus. In addition to reducing time, labor, and expense of decellularization, some embodiments described herein can only need one step for inducing apoptosis and one step for washing the cells.

Other compositions, compounds, methods, features, and advantages of the present disclosure will be or become apparent to one having ordinary skill in the art upon examination of the following drawings, detailed description, and examples. It is intended that all such additional compositions, compounds, methods, features, and advantages be included within this description, and be within the scope of the present disclosure.

Methods

Described herein are methods of decellularization that include inducing apoptosis in an *ex vivo* tissue sample, where tissue wide apoptosis can be induced by exposing the tissue to an apoptosis-inducing agent or apoptosis inducing process for a time period. Induction of apoptosis in the *ex vivo* tissue sample can cause cell detachment from the tissue extracellular matrix, degradation of intracellular DNA, RNA and proteins, and allocation into apoptotic bodies, which can be removed using mild hypotonic and/or mild hypertonic buffered solutions.

As shown in Fig. 1, the method 1000 can begin with obtaining a tissue sample from a subject or other donor source 1010. The tissue can be autologous, xenogeneic, allogeneic, or syngeneic. In some embodiments, the tissue can be obtained from anywhere in a subject. In some embodiments, the tissue sample can be obtained from the periphery or spinal column of a subject. In some embodiments, the tissue can be a peripheral nerve and/or nucleus pulposus. In other embodiments, the tissue can be brain, spinal cord, heart, lung, liver, muscle, cartilage, tendons, ligaments, menisci, stomach, intestine, pancreas, and/or kidney. In further embodiments, the tissue is blood vessels, bone, and/or cornea.

After the tissue sample has been obtained, apoptosis can be induced 1020 in the *ex vivo* tissue sample by exposing the *ex vivo* tissue sample to an apoptotic agent (*i.e.* a compound and/or composition that induces apoptosis in a cell) for a time period. In some embodiments, apoptosis can be induced by an apoptotic process (*i.e.* a process that can include one or more steps that induces apoptosis). In some embodiments, the apoptotic agent can be camptothecin, staurosporine, doxorubicin, and/or analogs thereof, or any other agent or process that induces apoptosis. In other embodiments, the apoptotic agent could be nitric oxide, hypoxia, pH, or hydrogen peroxide. In some embodiments where an apoptotic

agent is used to induce apoptosis, the *ex vivo* tissue sample can be exposed to the apoptotic agent for any length of time, including but not limited to, greater than about 1 hour, about 1 hour to about 10 days, about 1 hour to about 7 days, about 1 hour to about 4 days, about 1 hour to about 2 days, or about 1 hour to about 1 day. In some embodiments, the ex vivo tissue sample can be exposed to camptothecin or analog thereof for 2 days. In some embodiments, the tissue ex vivo tissue sample can be exposed to the apoptotic agent, such as camptothecin, for about 1 day.

The *ex vivo* tissue sample can be exposed to a solution containing a concentration of the apoptotic agent and/or to an apoptotic process. In some embodiments, the apoptotic process does not use an apoptotic agent. In embodiments that employ an apoptotic agent, the concentration of the apoptotic agent can range from about 1 nM to about 1 mM or greater. In some embodiments, the concentration of the apoptotic agent can range from about 1 μM to about 100μM. In some embodiments, the concentration of the apoptotic agent can be about 10μM. In some embodiments, the *ex vivo* tissue sample can be exposed to 10 μM of camptothecin or an analog thereof. In some embodiments, the *ex vivo* tissue sample can be exposed to 10 μM of camptothecin or an analog thereof for about 2 days. In some embodiments, the concentration of the apoptotic agent can range from about 5 μM to about 10 μM. In some embodiments, the concentration of the apoptotic agent is about 5 μM. In some embodiments, the *ex vivo* tissue sample can be exposed to 5 μM camptothecin or an analog thereof. In some embodiments, the *ex vivo* tissue sample can be exposed to 5 μM of camptothecin or an analog thereof for about 1 day.

In some embodiments, the apoptotic process includes exposure of the *ex vivo* tissue to one or more freeze-thaw cycles to induce apoptosis.

After the *ex vivo* tissue sample can be exposed to an apoptotic agent or process for a desired amount of time, the tissue sample can be washed 1030 with one or more washes with one or more buffered solutions to facilitate cell removal. The *ex vivo* tissue sample can be washed with one or more washes of a hypertonic buffered solution (*i.e.* greater than 1X buffered solution). In some embodiments the number of washes ranges from one to six. In some embodiments, the hypertonic solution can be a 1.01X-10X buffered solution. In some embodiments, the concentration can be 4X with an intermediate 2X wash. The tissue sample can be washed with one or more washes of a hypotonic buffered solution (*i.e.* less than 1X buffered solution). In some embodiments, the hypotonic solution can be a 0.01X up to a 0.99X buffered solution. In embodiments, the buffered solution is a saline solution at the given concentrations to result in a hypotonic or hypertonic solution. The starting saline solution can be isotonic. The starting saline solution can have a formulation of 10X which is diluted with water to attain various hypertonic washes. While not being bound to theory, it is believed that DNA removal occurs under the hypotonic wash conditions, while protein

removal occurs under the hypertonic wash conditions. Some embodiments employ only hypertonic washes. Other embodiments employ only hypotonic washes. Yet further embodiments employ both hypertonic and hypotonic washes.

In some embodiments, the method 1000 can also include an optional step of DNAse treatment 1040. The DNAse treatment can occur after the wash(es) previously performed 1030. In some embodiments, the optional DNAse treatment 1040 is performed after hypotonic washes 1030 were performed. In some embodiments where the optional DNAse 1040 treatment is performed, only hypertonic washes have been performed. In embodiments, the concentration of DNAse can range from 25 U/mL to 250 U/ mL. The preferred concentration is 75 U/mL. The DNase can be any suitable DNase. The DNase treatment can be performed at a temperature ranging from about 4 to about 37°C. The preferred temperature is 25°C. It will be appreciated by those of ordinary skill in the art that the temperature can be dependent on the temperature that the DNase has optimal activity. The time period for the DNase treatment can range from about 30 minutes or less to 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 24, or 36 hours or more. The treatment time can vary based on tissue type, but in some embodiments the treatment time is 18-24 hours.

The method 1000 can produce an acellular tissue. The resulting acellular tissue can be used as a scaffold substrate for three dimensional (3D) cell culture and tissue engineering techniques. Further, the resulting acellular tissue can be delivered to a subject in need thereof to facilitate the *in vivo* generation and/or regeneration of cells and tissues within the subject. The resulting acellular tissue product can be formulated to be delivered to a subject in need thereof by any suitable method of deliver, including but not limited to, implantation or injection. The acellular tissue products can be enhanced by the addition of one or more other agents or compounds to the acellular tissue product, including without limitation other cells (*e.g.* stem cells or other progenitor cells), nucleic acids, amino acids, peptides, polypeptides, antibodies, aptamers, ribozymes, guide sequences for ribozymes that inhibit translation or transcription of essential tumor proteins and genes, hormones, immunomodulators, antipyretics, anxiolytics, antipsychotics, analgesics, antispasmodics, anti-inflammatories, anti-histamines, anti-infectives, and chemotherapeutics. In some embodiments, the acellular tissue products can be co-administered with one or more other agents or compounds, including without limitation other cells (*e.g.* stem cells or other progenitor cells), nucleic acids, amino acids, peptides, polypeptides, antibodies, aptamers, ribozymes, guide sequences for ribozymes that inhibit translation or transcription of essential tumor proteins and genes, hormones, immunomodulators, antipyretics, anxiolytics, antipsychotics, analgesics, antispasmodics, anti-inflammatories, anti-histamines, anti-infectives, and chemotherapeutics.

In some embodiments, any of the acellular tissue scaffolds described herein can be administered to a subject in need thereof in the original form, as an injectable formulation, or as other derivatives of the acellular tissue. In some embodiments, the subject in need thereof has a peripheral nerve injury, spinal cord injury, spinal cord disease, amputation or otherwise suffers from degradation of a component of the spine (*e.g.* intervertebral disc degeneration). In other embodiments, the subject could have osteoarthritis of the hip or knee, trauma to the lungs, volumetric muscle loss, cirrhosis of the liver, or otherwise requires partial or total organ replacement.

EXAMPLES

Now having described the embodiments of the present disclosure, in general, the following Examples describe some additional embodiments of the present disclosure. While embodiments of the present disclosure are described in connection with the following examples and the corresponding text and figures, there is no intent to limit embodiments of the present disclosure to this description. On the contrary, the intent is to cover all alternatives, modifications, and equivalents included within the spirit and scope of embodiments of the present disclosure.

Example 1:

Peripheral nerves were harvested from Sprague Dawley rats and decellularized according to an apoptosis-assisted protocol using 5 μM camptothecin in non-supplemented media at 37°C for 1 day. Tissue in media without camptothecin, an apoptotic agent, was used as a control. Apoptotic agent treatment was succeeded by washes in saline buffered solutions to optimize cell removal. Furthermore, the tissue was treated with 75 u/mL DNAse for 24 hours to ensure DNA removal. The degree of apoptosis, cellular removal, and matrix preservation was assessed using immunochemistry on nerve tissue sections and fluorescence imaging (Fig 2). Antibodies used to identify apoptosis, cell removal, and tissue preservation include those against active caspase 3 (Abcam); neurofilament (RT-97, DSHB) and S100 (Dako); and laminin (Sigma), respectively. Fig. 2A shows immunochemical staining of a fresh peripheral nerve used as a no treatment control. Figs. 2B and 2C show nerves treated with 5 μM for 1 day, washed with a hypertonic, and either washed with a hypertonic solution or treated for 24 hours with DNAse, respectively. Fig. 2D shows staining of a fresh nerve that was subjected to the same hypertonic and hypotonic washes and represents the results of not inducing apoptosis prior to washing the tissue. Figs. 2E and 2F show treatment with higher camptothecin (10 μM), again for 1 day, and washed similarly to tissue in Figs. 2B and 2C. These images depict 1) apoptosis induction is necessary prior to

washing to effectively remove cellular components and 2) combing apoptosis induction with washes in non-isotonic solutions achieves cellular removal of peripheral nerve tissue.

Total DNA content was quantified using a Picogreen DNA assay (Life Technologies) according to manufacturer's instructions. DNA quantification data are shown in Figs. 3 and 4. Washing the tissue without first inducing apoptosis resulted in only a 29.8% reduction of DNA content compared to fresh nerve. Conversely, inducing apoptosis using 5 or 10 μM camptothecin yielded a 71.9 and 57.3% reduction in DNA, respectively. Replacing the hypotonic wash with DNAse treatment further reduced the DNA content, with 5 and 10 μM camptothecin treatment for 1 day resulting in a 95.1 and 95.8% reduction.

Example 2:

Peripheral nerves were harvested from Sprague Dawley rats and decellularized according to an apoptosis-assisted protocol using 10 μM camptothecin in non-supplemented media at 37°C for 2 days. Tissue in media without camptothecin was used as a control. Apoptotic agent treatment was succeeded by washes in saline buffered solutions to optimize cell removal. The degree of apoptosis, cellular removal, and matrix preservation was assessed using immunochemistry on nerve tissue sections and fluorescence imaging. Antibodies used to identify apoptosis, cell removal, and tissue preservation include those against active caspase 3 (Abcam); neurofilament (RT-97, DSHB) and S100 (Dako); and laminin (Sigma), respectively. Apoptosis-mediated DNA fragmentation was assessed using a terminal deoxynucleotidyl transferase dUTP nick end labeling (TUNEL) assay. Total DNA content was quantified using a Picogreen DNA assay (Life Technologies) according to manufacturer's instructions.

Figs. 5A-5C demonstrate fluorescence micrographs of nerve tissue labeled for cell or basal lamina markers. For Figs. 5A and 5B, the images are fresh nerve (top half) and apoptosis decellularized nerve (bottom half). Fig. 5A was labeled for neurons (neurofilament, green), Schwann cells (S100, red), and nuclei (DAPI, blue). Fig. 5B shows cross-sections of the basal lamina stained for laminin (red). Fig. 5C shows a representative basal lamina staining in nerve tissue decellularized according to a conventional detergent-based method. Induction of apoptosis was confirmed in treated nerve tissue by an increase in active caspase 3, an early mediator of apoptosis. Moreover, TUNEL staining revealed pervasive DNA fragmentation in treated nerves, indicating late stage apoptosis, as well. Media controls exhibited neither hallmark of apoptosis. Following induction of apoptosis, cellular proteins were easily removed using only washes in hypertonic 4X saline buffer while removal of DNA required brief washes in mildly hypotonic 0.5X saline buffer. Using this regimen, a substantial reduction in cellular and nuclear staining was achieved compared to fresh nerve.

Notably, the basal lamina microstructure was nearly identical to fresh nerve and was significantly improved over alternatively processed tissue.

Treatment with camptothecin was observed to be sufficient to elicit aspects of apoptosis ex vivo, including caspase 3 activation and DNA fragmentation. Moreover, induction of apoptosis was observed to enable extensive removal of cellular and nuclear components from peripheral nerve tissue using only non-isotonic buffers. Two analogs of camptothecin are considered safe by the FDA, which bolsters the clinical potential of this apoptosis-assisted decellularization method. Ultimately, the approach demonstrated here and described herein can eliminate the need for harsh lysis and chemical steps in conventional protocols and pushes decellularization technology toward achieving 3D, cell-free replicas of native tissue.

Example 3:

Cervical and lumbar segments were removed Yorkshire-Landrace porcine. Each motion segment was carefully dissected to extract the nucleus pulposus as shown in Figure 7. Nucleus pulposi were decellularized according to an apoptosis-assisted protocol using 10 μm camptothecin in standard non-supplemented culture media for 24 hours. Control samples were also processed in parallel without camptothecin. After induction of apoptosis, samples were washed in a series of hypertonic and hypotonic buffers to remove apoptotic cell bodies (Table 1).

Table 1

Wash Type	**Method**
Hypertonic	2X PBS 30min, 4X PBS 18hrs, 2X PBS 30min, 1X PBS 30min
Hypotonic	0.5X PBS 18hrs, 1X PBS 30min
Hyper-Hypo	2X PBS 30min, 4X PBS 18hrs, 2X PBS 30min, 1X PBS 30min, 0.5X PBS 6hr, 1X PBS 30min
Hypo-Hyper	0.5X PBS 18hrs, 1X PBS 30min, 2X PBS 30min, 4X PBS 6hrs, 2X PBS 30min, 1X PBS 30min
Hyper-DNase	2X PBS 30min, 4X PBS 18hrs, 2X PBS 30min, 1X PBS 30min, 24hrs DNase, 1X PBS 45 mins
No Wash	Fix Immediately after 24hrs in media.

After washes, samples were processed for fixed and stained using DAPI (ThermoFisher, D1306) to detect removal of cell nuclei, and a chondroitin sulfate proteoglycan (CSPG) antibody (Sigma, C8035) to examine maintenance of key proteins. Confocal imaging was

used to assess removal of cell nuclei and maintenance of CSPGs. Results demonstrated in Figs. 6A-6D suggest the hypertonic wash and the hypertonic-hypotonic wash substantially remove cell nuclei while maintaining desired CSPGs.

Example 4:

Rat sciatic nerve was isolated from Sprague Dawley rats and decellularized using either standard detergent-based methods or apoptosis induction and tonic wash methods as detailed in Example 1 above. A rat transection model of nerve injury was performed in Lewis rats to determine efficacy of apoptosis decellularized samples compared to detergent decellularized samples, fresh harvested Lewis isograft sciatic nerves, and a sham control group. Briefly, sciatic nerve was transected and 8 mm of sciatic nerve was then removed to create a 10 mm nerve gap. After transection, one of three samples was implanted via direct suture to the nerve stumps (detergent, apoptosis, or isograft). Implants and sham controls were harvested at 4 weeks (n=3) and 8 weeks (n=6) for histological analysis. Tibialis anterior muscles were also harvested and weighed at 4 and 8 weeks to determine degree or re-innervation of a distal target, an indirect assessment of regeneration.

Results are shown in Fig. 8 and indicate that apoptosis decellularized samples enhance muscle recovery compared to detergent decellularized samples at both weeks 4 and 8, and are approaching levels of the isograft gold standard treatment.. Throughout the time course of the study (2, 4, 6, and 8 weeks), animals were also recorded while walking on a track to analyze alterations in gait (data not shown). Histology was used to assess the degree of regeneration between groups at both 4 weeks and 8 weeks. (data not shown).

We claim:

1. A tissue decellularization method comprising:

obtaining a tissue sample from a subject to generate an *ex vivo* tissue sample;

exposing the *ex vivo* tissue sample to an apoptotic agent or apoptotic process; and

washing the *ex vivo* tissue sample in a hypertonic solution, a hypotonic solution, or a hypertonic solution and a hypotonic solution.

2. The method of claim 1, wherein the tissue sample is a peripheral nerve, a nucleus pulposus, or a combination thereof.

3. The method of claim 1, wherein the tissue sample is lung tissue.

4. The method of claim 1, wherein the apoptotic agent is camptothecin, staurosporine, doxorubicin, or an analog thereof.

5. The method of claim 1, wherein the apoptotic process comprises one or more freeze-thaw cycles.

6. The method of claim 1, wherein the concentration of the apoptotic agent ranges from about 5μM to about 10 μM.

7. The method of claim 1, wherein the concentration of the apoptotic agent is about 10 μM.

8. The method of claim 1, wherein the concentration of the apoptotic agent is about 5 μM.

9. The method of claim 1, wherein the *ex vivo* tissue sample is exposed to the apoptotic agent for about 2 days.

10. The method of claim 1, wherein the tissue is washed with a hypertonic solution.

11. The method of claim 10, wherein the hypertonic solution is greater than 1X buffered solution.

12. The method of claim 10, wherein the hypertonic solution is 4X saline.

13. The method of claim 1, wherein the tissue is washed with a hypotonic solution.

14. The method of claim 13, wherein the hypotonic solution is less than 1X buffered solution.

15. The method of claim 13, wherein the hypotonic solution is a 0.5X saline solution.

16. The method of claim 13, wherein the concentration the concentration of the apoptotic agent is about 5 μM.

17. The method of claim 16, wherein the apoptotic agent is camptothecin, staurosporine, doxorubicin, an analog thereof.

18. The method of any one of claims 1, 8, or 13-17, further comprising the step of treating the tissue with DNAse for a period of time ranging from 30 minutes to 24 hours.

19. The method of claim 1, wherein the step of washing produces an acellular tissue product.

20. The method of claim 19, further comprising the step of adding an active agent to the acellular tissue product.

21. The method of claim 20, wherein the active agent is selected from the group consisting of: a stem cell, nucleic acid, amino acid, peptide, polypeptide, antibody, aptamer, ribozyme, guide sequence for a ribozyme that inhibit translation or transcription of essential tumor proteins and genes, hormone, immunomodulator, antipyretic, anxiolytic, antipsychotic, analgesic, antispasmodic, anti-inflammatory, anti-histamine, anti-infective, a chemotherapeutic, or combinations thereof.

22. An acellular tissue product, where the acellular tissue product is formed by a method according to any one of claims 1-17.

23. The acellular tissue product of claim 22, wherein the method further includes the step of treating the tissue with DNAse for a period of time ranging from 30 minutes to 24 hours.

24. The acellular tissue product of claim 22, further comprising an active agent.

25. The acellular tissue product of claim 23, wherein the active agent is selected from the group consisting of: a stem cell, nucleic acid, amino acid, peptide, polypeptide, antibody, aptamer, ribozyme, guide sequence for a ribozyme that inhibit translation or transcription of essential tumor proteins and genes, hormone, immunomodulator, antipyretic, anxiolytic, antipsychotic, analgesic, antispasmodic, anti-inflammatory, anti-histamine, anti-infective, a chemotherapeutic, or a combinations thereof.

26. The acellular tissue product of any one of claims 22-25, wherein the acellular tissue product is formulated for injection.

27. A method comprising:

administering an acellular tissue product as in any one of claims 19-21 or 22-26 to a subject in need thereof.

28. The method of claim 27, where the subject in need thereof has a spinal injury or disease, intervertebral disc degeneration, disease or trauma of the lungs or liver, or volumetric muscle loss, peripheral nerve injury, amputation or spinal degradation, osteoarthritis of the hip or knee, volumetric muscle loss, cirrhosis of the liver, or otherwise requires partial or total organ replacement.

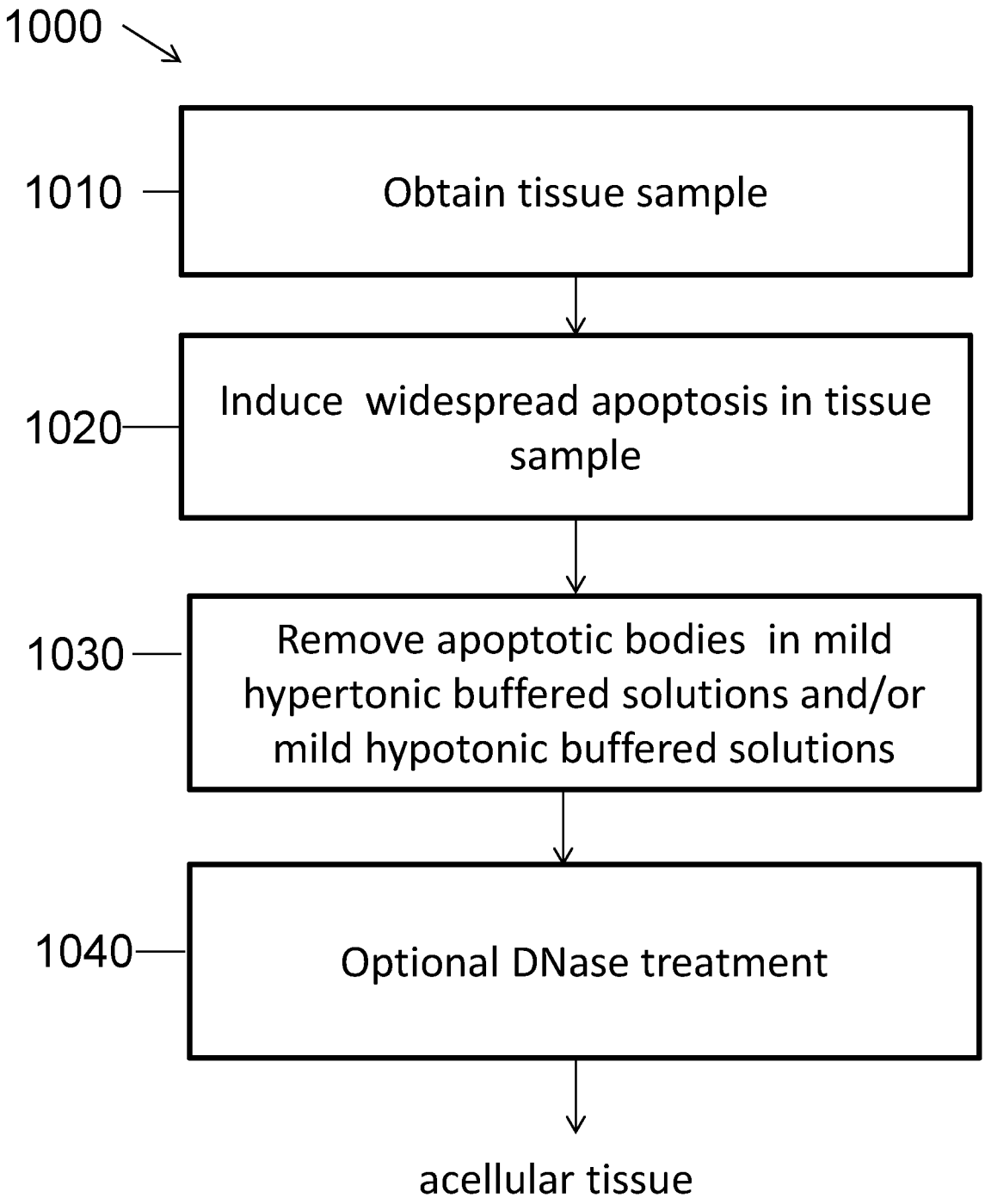
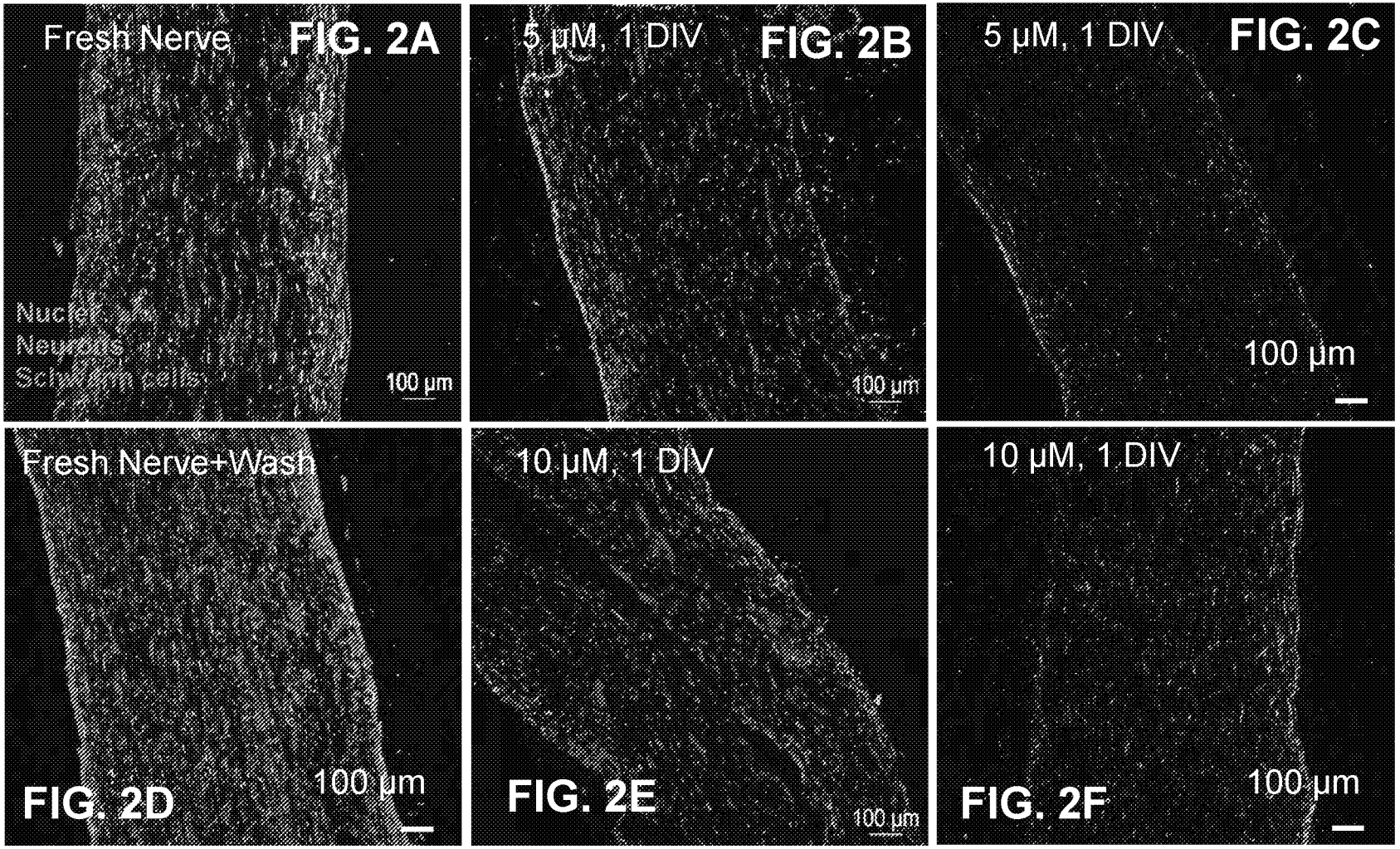

1000
1010
Obtain tissue sample
1020
Induce widespread apoptosis in tissue sample
1030
Remove apoptotic bodies in mild hypertonic buffered solutions and/or mild hypotonic buffered solutions
1040
Optional DNase treatment
acellular tissue

FIG. 1


Controls
Hypertonic + Hypotonic
Hypertonic + DNase
Fresh Nerve
FIG. 2A
Nuclei
Neurons
Schwann cells
100 µm
5 µM, 1 DIV
FIG. 2B
100 µm
5 µM, 1 DIV
FIG. 2C
100 µm
Fresh Nerve+Wash
FIG. 2D
100 µm
10 µM, 1 DIV
FIG. 2E
100 µm
10 µM, 1 DIV
FIG. 2F
100 µm

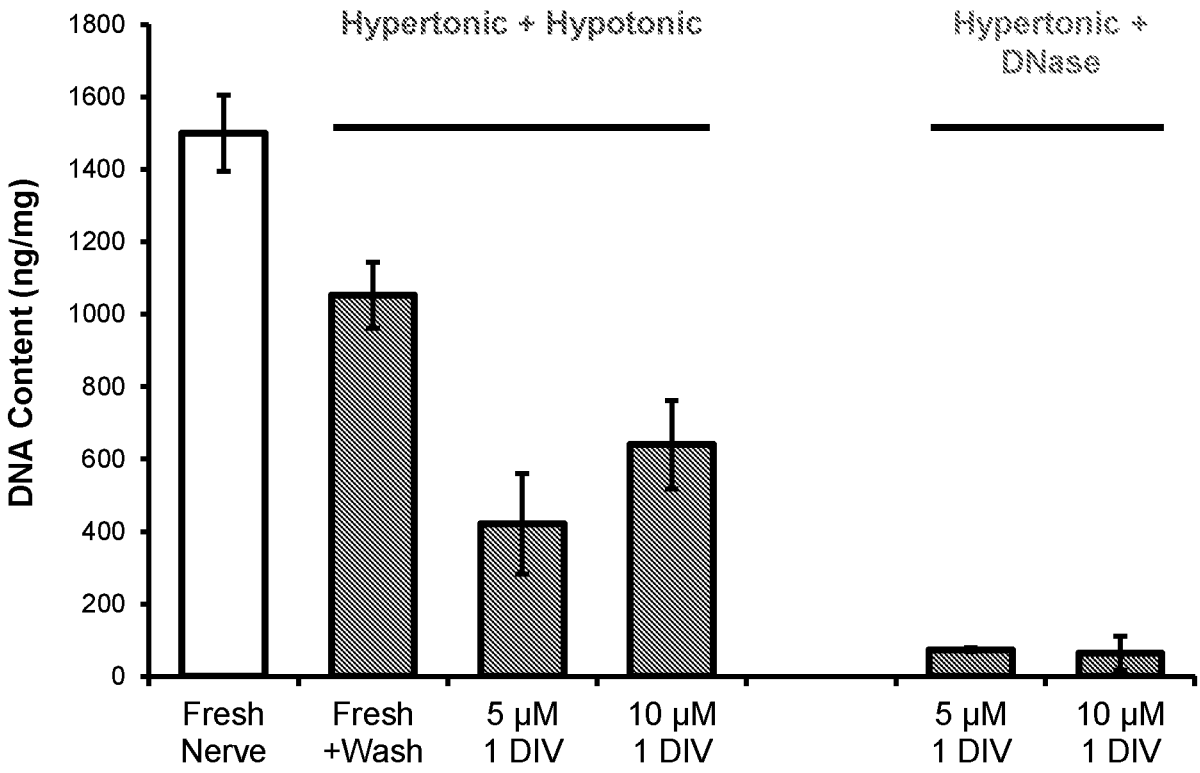


FIG. 3

ng/mg	1500.0	1052.7	420.9	640.0		73.4	63.2
% Removal	--	29.8	71.9	57.3		95.1	95.8

FIG. 4

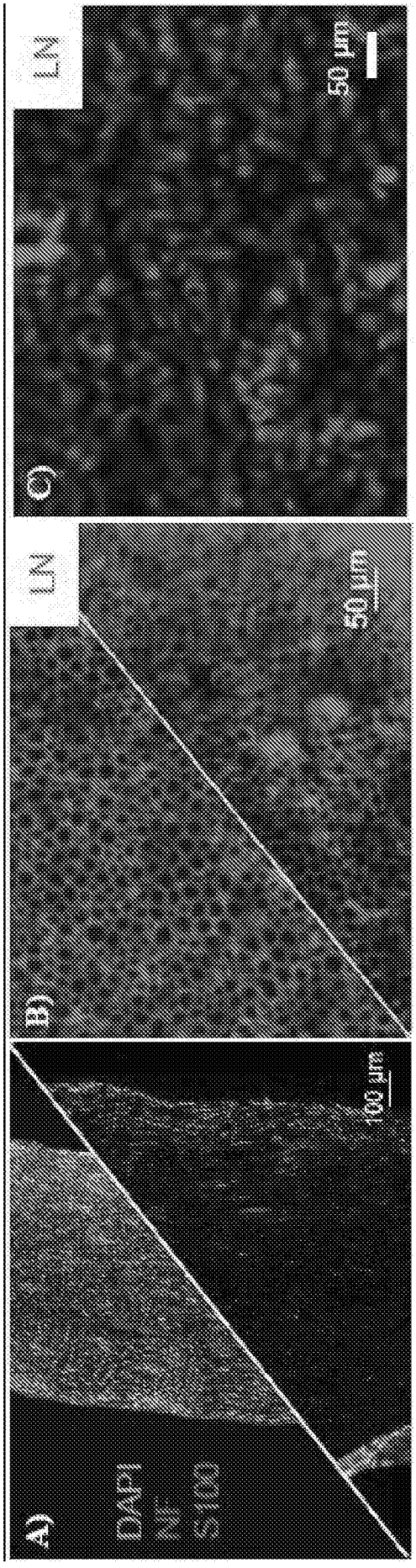
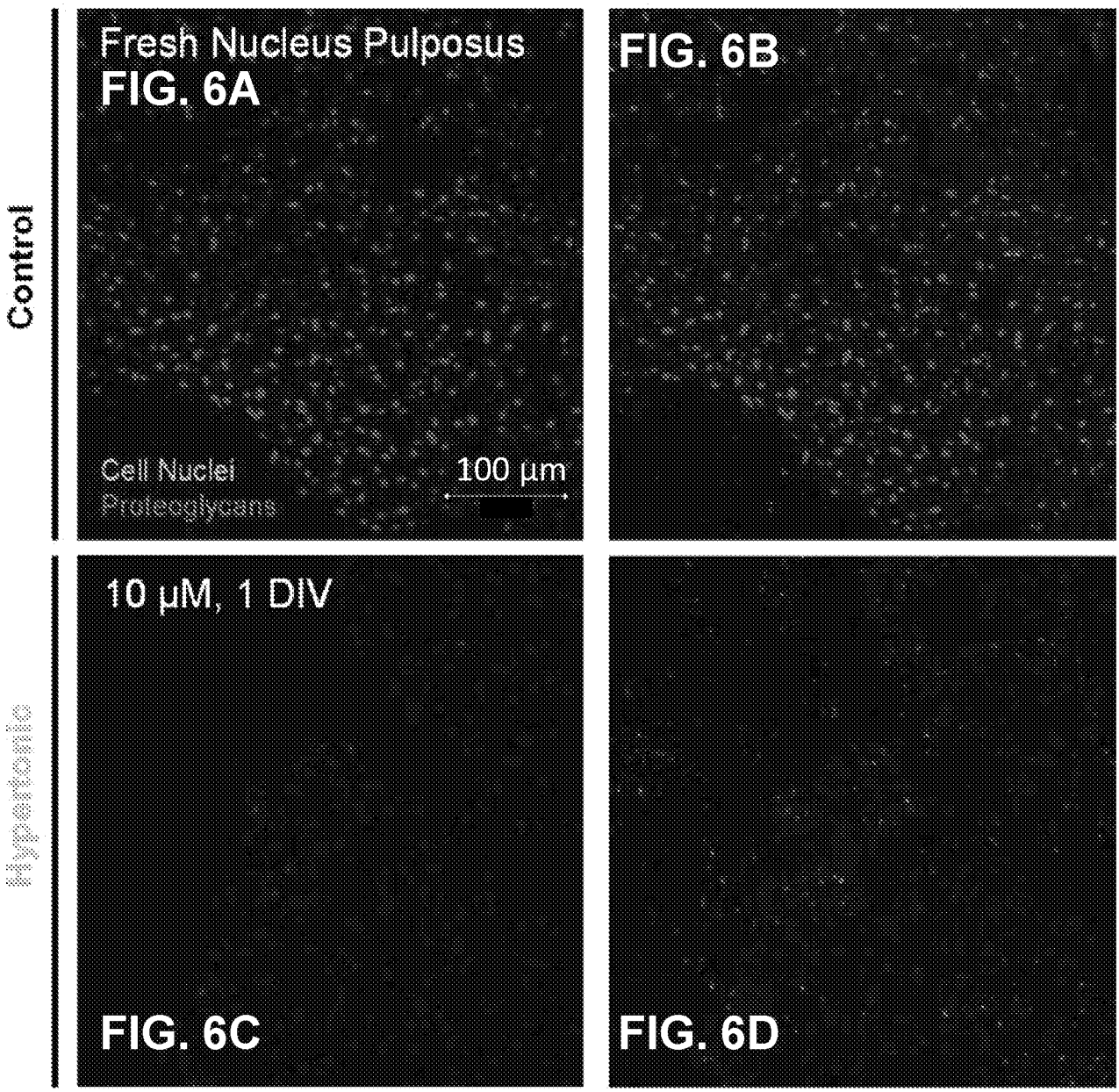


FIG. 5A

FIG. 5B

FIG. 5C


Control
Hypertonic
Fresh Nucleus Pulposus
FIG. 6A
Cell Nuclei
Proteoglycans
100 µm
FIG. 6B
10 µM, 1 DIV
FIG. 6C
FIG. 6D

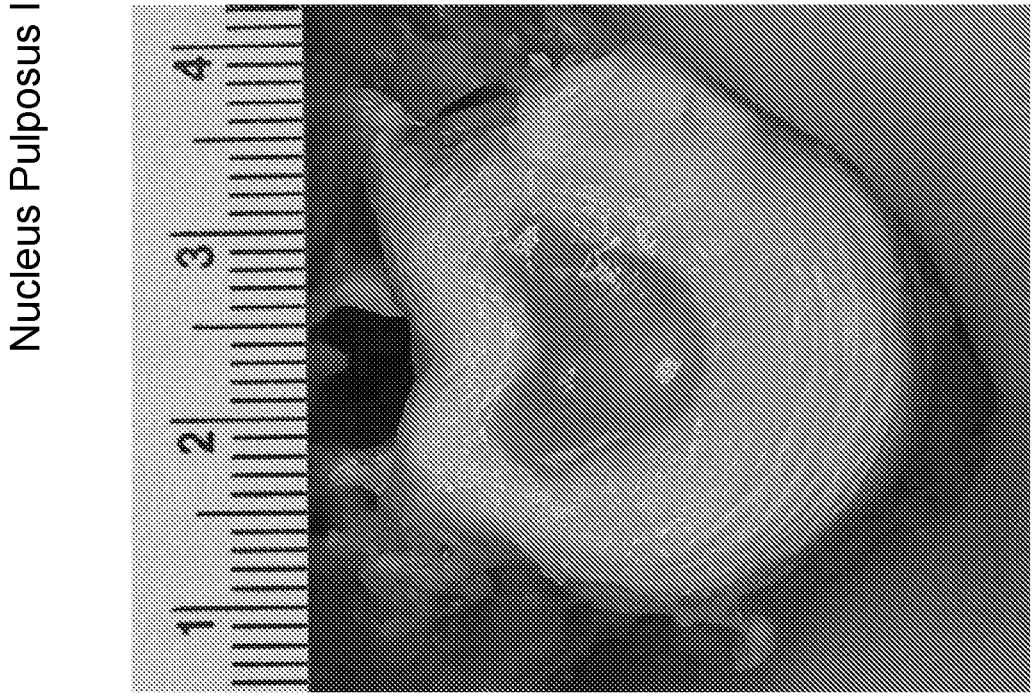


FIG. 7A

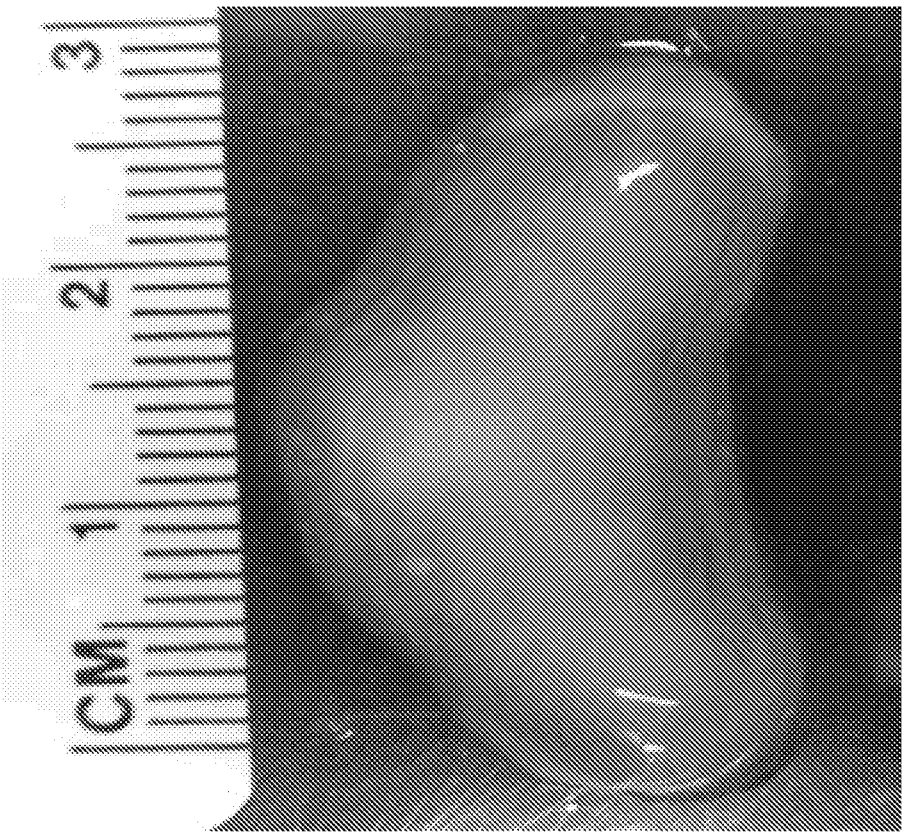


FIG. 7B

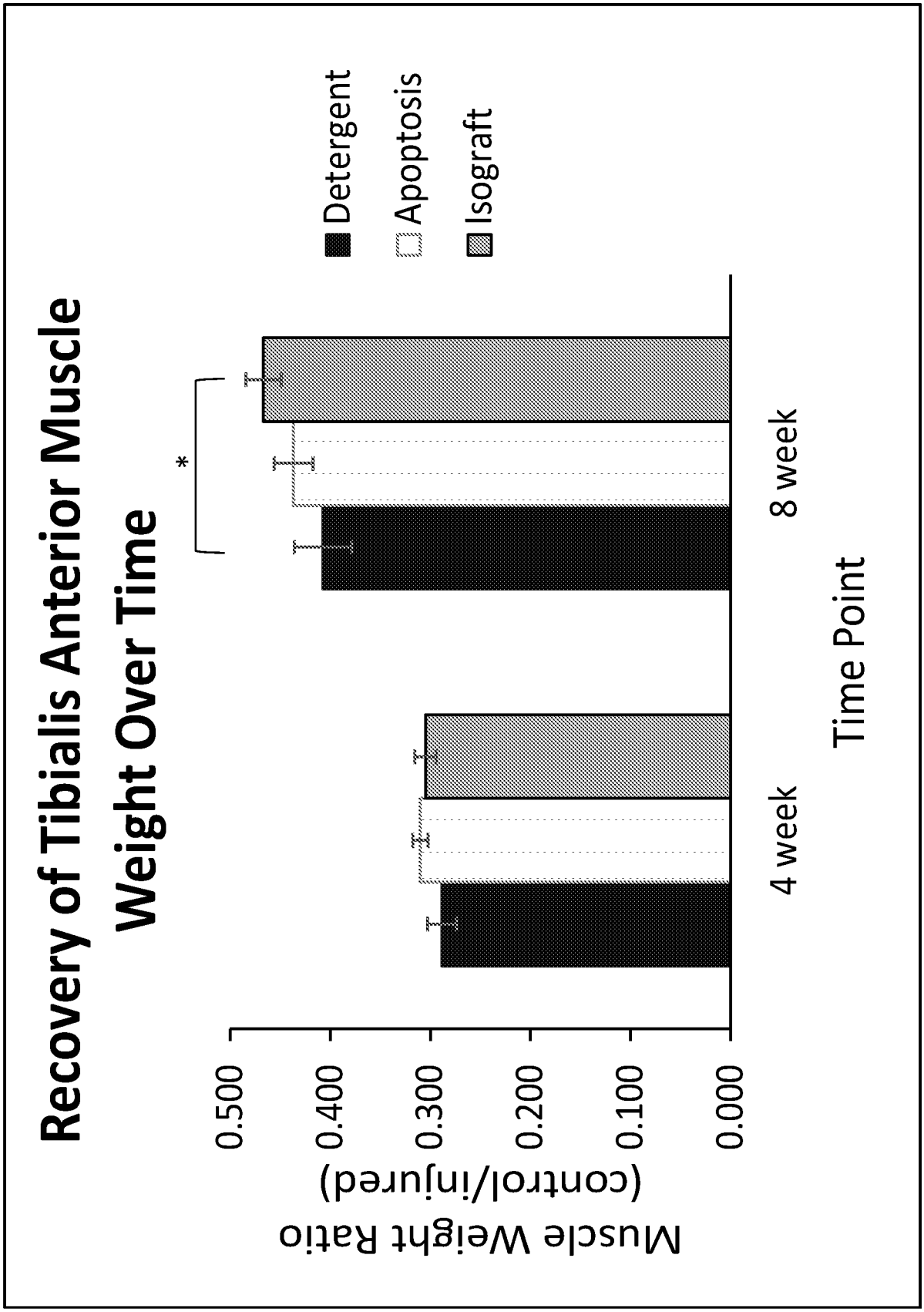
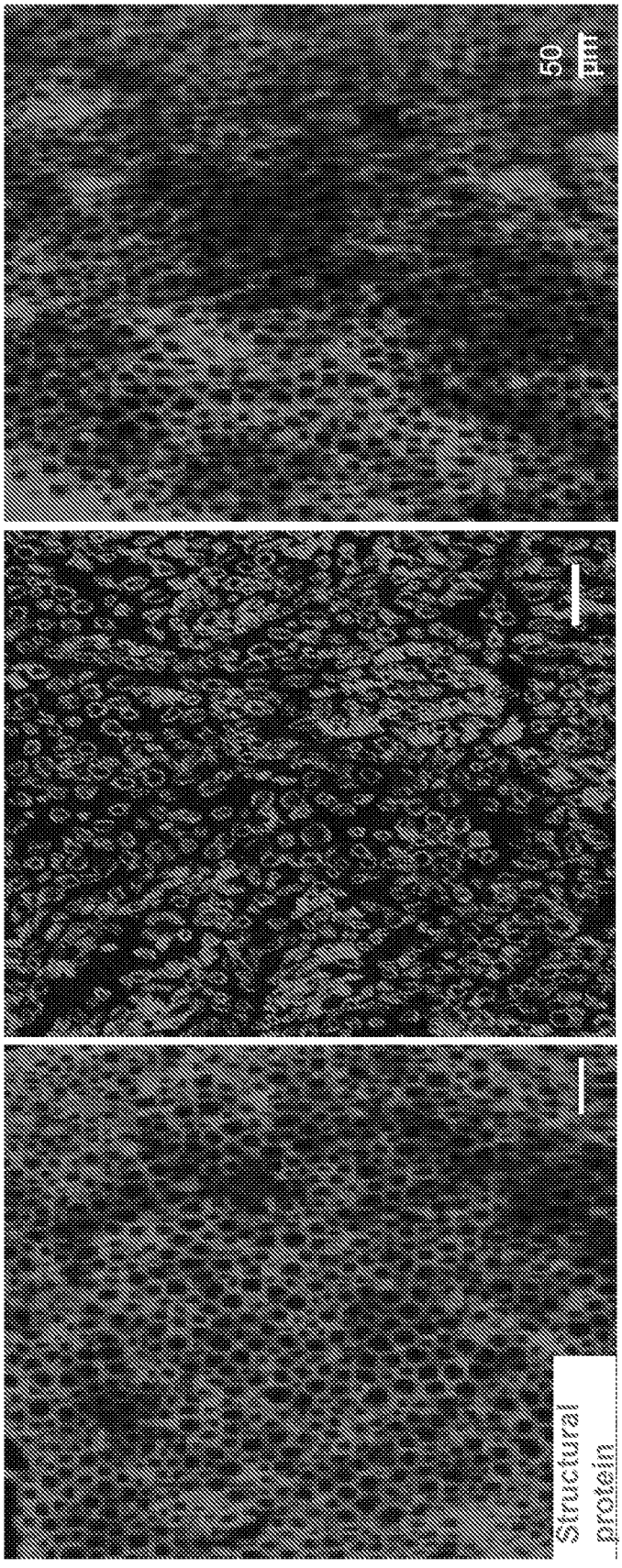

Recovery of Tibialis Anterior Muscle
Weight Over Time
Detergent
Apoptosis
Isograft
*
Muscle Weight Ratio
(control/injured)
0.500
0.400
0.300
0.200
0.100
0.000
4 week
8 week
Time Point

FIG. 8



Fresh Nerve

FIG. 9A

Treatment with Water

FIG. 9B

Apoptosis
Decellularization

FIG. 9C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 16/42273

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - A61K 35/32, A61K 35/36, A61K 35/34 (2016.01)
CPC - A61L 27/3641, A61L 2430/40, A61L 27/3683, A61L 27/60
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (8) - A61K 35/32, A61K 35/36, A61K 35/34 (2016.01)
CPC - A61L 27/3641, A61L 2430/40, A61L 27/3683, A61L 27/60

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 424/548, 424/574, 424/569

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase, Google Patent, Google Scholar
Terms used: decellularization tissue acellular washing hypotonic hypertonic apoptotic agent apoptosis camptothecin staurosporin doxorubicin saline dnase deoxyribonuclease endonuclease freeze thaw cryo lung peripheral nerve nucleus pulposus

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2003/0219417 A1 (Wolfinbarger, JR) 27 November 2003 (27.11.2003) para [0012]; [0039]-[0041]	1-25
Y	US 2011/0045045 A1 (Cortiella et al.) 24 February 2011 (24.02.2011) para [0032]; [0036]	1-3, 5, 10-15, 18-25
Y	Bourgine et al., 'Tissue decellularization by activation of programmed cell death', Biomaterials 34 (2013) 6099-6108, whole document, especially pg 6106, para 2	1, 4, 6-9, 13, 16-17
Y	US 2015/0037436 A1 (Huang et al.) 05 February 2015 (05.02.2015) para [0011]-[0012]	2
Y	US 5,968,824 A (Spruce et al.) 19 October 1999 (19.10.1999) col 14, ln 26-27; col 22, ln 52-53, 57;	4, 6-9, 13, 16-17
A	US 2008/0306610 A1 (Wang et al.) 11 December 2008 (11.12.2008) whole document, especially para [0006]; [0022]; [0034]	1, 10-15
A	US 2012/0259415 A1 (Van Dyke et al.) 11 October 2012 (11.10.2012) whole document, especially para [0011]; [0014]; [0041]	1, 10-15
A	WO 1998/031787 A1 (EISAI CO LTD) 23 July 1998 (23.07.1998) whole document	4, 6-9, 16-17
A	WO 1998/045429 A2 (NOVARTIS AG) 15 October 1998 (15.10.1998) whole document	4, 6-9, 16-17

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 August 2016	30 SEP 2016
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 16/42273

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 26-28
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.