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(54) Title: METHODS OF MANUFACTURING BIOACTIVE GELS FROM EXTRACELLULAR MATRIX MATERIAL

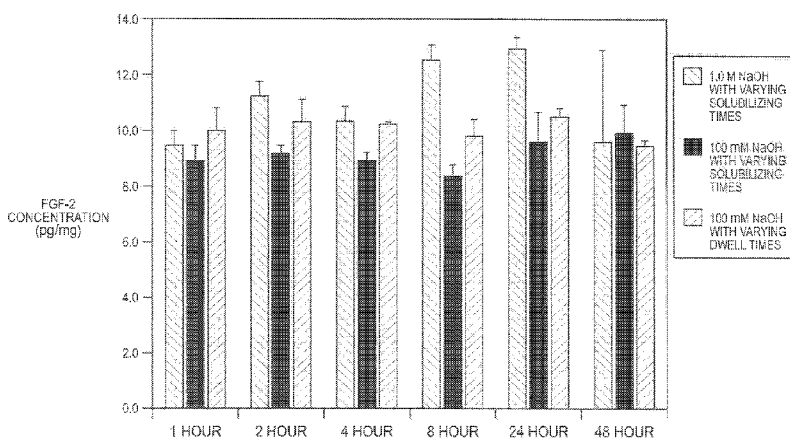


FIG. 1

(57) Abstract: The present invention is directed to methods of manufacturing bioactive gels from ECM material, i.e., gels which retain bioactivity, and can serve as scaffolds for preclinical and clinical tissue engineering and regenerative medicine approaches to tissue reconstruction. The manufacturing methods take advantage of a new recognition that bioactive gels from ECM material can be created by digesting particularized ECM material in an alkaline environment and neutralizing to provide bioactive gels.



METHODS OF MANUFACTURING BIOACTIVE GELS FROM EXTRACELLULAR MATRIX MATERIAL

5 TECHNICAL FIELD OF THE INVENTION

The present invention is related to methods of manufacturing bioactive gels from extracellular matrix material and their uses for restoration of tissues in a patient.

BACKGROUND

10 Biologic scaffolds composed of extracellular matrix material (ECM) have been used for the repair of variety of tissues including the lower urinary tract, esophagus, myocardium and musculotendinous tissues, often leading to tissue-specific constructive remodeling with minimal or no scar tissue formation.

Although uses of ECM as scaffolds for preclinical and clinical tissue engineering and regenerative medicine approaches to tissue reconstruction are very promising, challenges remain in the process to manufacture bioactive gels from ECM, which retain their bioactivity.

The methods of manufacturing bioactive gels from ECM described in the prior art require the use of enzymes and are time consuming because they require aggressive purification steps, which may lead to depletion in the bioactivity of the gels and may present additional regulatory
20 barriers to marketing.

Thus, a need exists to manufacture bioactive gels from ECM which avoids cumbersome preparation and purification steps yet result in gels that retain the bioactivity of the original material.

25 SUMMARY OF THE INVENTION

The present invention generally pertains to improved methods of manufacturing bioactive gels from ECM which retain sufficient bioactivity to positively assist in tissue repair. The present invention utilizes reagents that do not introduce additional regulatory burdens for market approval or clearance of the gel invention. Thus, the invention describes methods of
30 manufacturing bioactive gels from an ECM comprising (a) providing the ECM from one or more of the group consisting of but not limited to small intestine submucosa (SIS), urinary

bladder submucosa (UBS), urinary bladder matrix (UBM) (includes epithelial basement membrane), porcine dermis (PD), and liver basement membrane (LBM), (b) particularizing the ECM to a particle size in the range of about 1 μ m to about 1000 μ m, (c) solubilizing concentrations in the range of about 0.5 to 11% weight/volume (w/v) of particularized powder in sodium hydroxide (NaOH) in the range of 0.1 to 1.0 M for periods of time ranging from about 1
5 hour to about 48 hours at 4°C, (d) neutralizing the solubilized ECM prepared in step (c) with hydrochloric acid (HCl), optionally equimolar relative to NaOH, ranging from 0.1 to 1M to form the gel, and (e) optionally, freezing the neutralized solubilized ECM prepared in step (d), optionally (f) lyophilizing the frozen ECM prepared in step (e), and optionally (f) reconstituting
10 the lyophilized gel in water or saline.

The advantages provided by the methods of manufacturing bioactive gels in the above manner are that aggressive purification steps, which are deleterious to bioactivity, tedious to perform or are time consuming, and which increase the regulatory burden (e.g. FDA approval), are avoided.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the FGF-2 content (pg/mg) of gels following various solubilization conditions in NaOH according to embodiments of the invention. All gels not marked with a % w/v were done at 7.0% w/v UBM to NaOH. All gels in Figure 1 were done at 7.0% w/v UBM to
20 NaOH.

Figure 2 shows the VEGF content (pg/mg) of gels following various solubilization conditions in NaOH according to embodiments of the invention. All gels not marked with a % w/v were done at 7.0% w/v UBM to NaOH. All gels in Figure 1 were done at 7.0% w/v UBM to
25 NaOH.

25

DETAIL DESCRIPTION

The present invention is directed to methods of manufacturing bioactive gels from ECM, i.e., gels which retain sufficient bioactivity to positively assist tissue repair by decreasing the time needed for repair, decreasing scar tissue formation, and improving restoration of the injured
30 tissue to its pre-damaged native structure and function as compared to injured tissues not treated with the bioactive gel according to the invention. The gel invention and methods of making

described herein serves as scaffolds for preclinical and clinical tissue engineering and regenerative medicine approaches to tissue reconstruction. Bioactivity in the ECM gel according to the invention is in the range of about 0 to 100%, 25-75%, 10-25%, less than 10%, less than 5% or less than 1% of the bioactivity of one or more bioactive molecules in the native ECM from which the gel was derived. As will be described in detail below, these manufacturing methods take advantage of a new recognition that bioactive gels from ECM can be created by solubilizing a particularized ECM in a basic (greater than pH 7) environment, which when neutralized with acid provides bioactive gels.

In accordance with the inventive methods, the ECM may be derived from layers of native mammalian tissues including but not limited to submucosa, dermis, epithelial basement membrane, or from tissues such as aponeurosis, fascia, tendon, ligament, smooth and skeletal muscle and treatment site-specific ECM. The native mammalian tissue source may be porcine, bovine, ovine, allogenic, or autogenic, for example. For example, the ECM may be SIS (small intestinal submucosa), UBS (urinary bladder submucosa) or UBM (urinary bladder matrix) or liver basement membrane (LBM) described in U.S. Pat. No. 6,576,265, U.S. Patent No. 6,579,538, U.S. Patent No. 5,573,784, U.S. Patent No. 5,554,389, U.S. Patent No. 4,956,178, and U.S. Patent No. 4,902,508, each of which are incorporated by reference herein. In one embodiment of the invention, the ECM is derived from a mammalian tissue and comprises bioactive components of the extracellular matrix material that are arranged and in quantities similar to those in the tissue in its native form.

In accordance with the inventive method, the ECM derived from any one of the above sources is particularized, i.e., the size of the ECM particles are in a range of about 1 μ m to about 1000 μ m. In one embodiment, particularization of the ECM prior to subjecting the ECM to a basic environment provides homogeneity to the ECM, i.e., provides a more uniform composition in comparison to ECM from individual animals, decreasing the impact of inter-donor variability. In another embodiment, the particularization of the ECM facilitates in solubilizing the matrix in a basic environment by increasing surface area to volume ratio.

The particulate ECM product, e.g., particularized ECM, is manufactured by grinding/milling or otherwise performing a size reduction process to ECM typically but not exclusively originally provided in sheet form. The resulting particulate can be any desired range of density for example in the range of about 0.1 g/cm³ – 10 g/cm³, about 0.10.1 g/cm³ – 1 g/cm³

or about 1 g/cm³, and particle size for example in the range of about 1 micron - 1000 microns, about 200-700 microns, about 300-600 microns, or about 400 microns.

A basic environment is provided by solutions of alkaline compounds. Alkaline compounds which could be used in accordance with the invention are metal hydroxides which include, but are not limited to, LiOH, NaOH, KOH, RbOH, and CsOH. Alkaline compounds which could be used in accordance with the invention also include weak bases, such as but not limited to, ammonia (NH₃), pyridine (C₅H₅N), hydroxylamine (H₂NOH), methylamine (NH₂CH₃) and the like. Alkaline compounds are generally used at a concentration ranging from 0.1 Molar to 1.0 Molar, although concentrations lower than 0.1 Molar or higher than 1.0 Molar are also contemplated in an embodiment of the invention.

Concentrations of particularized ECM to NaOH (w/v) are in the range of 0.1% to about 20%, in particular 0.5% to 11%, and more particular, 7%.

The solubilization step at 4°C (i.e., digestion) of the particularized ECM can extend over a period of time ranging from a few minutes to several hours (e.g., 30 minutes to 48 hours) or days (e.g., 3-7 days), 30 minutes to 12 hours, 12-24 hours, 24 to 36 hours, 36 to 48 hours, or two to seven days. In an embodiment of the invention, it is contemplated that the time period required for the digestion step is determined by the size of the particularized extracellular matrix material and/or the concentration of the metal hydroxide used for solubilization. For example, if the concentration of an alkaline compound, such as NaOH, is low, longer incubation, i.e., longer time period for solubilization may be required. After the solubilization step in a basic solution, the solubilized ECM (i.e., the gel form) is neutralized to a neutral pH using molar concentrations, e.g., equimolar concentrations of an acid in a volume sufficient for the solubilized ECM to reach pH 6.8 to 7.4. Acids, which aid in neutralization of the ECM gel, can be selected from weak or strong acids. Selectivity of acids for the neutralization step depends on the salts which are produced when an acids reacts with the basic environment during neutralization. The resulting salt should be biocompatible. For example, in an embodiment of the invention, hydrochloric acid (HCl) is used to neutralize the basic environment created by the base NaOH because the resulting salt (i.e., NaCl) is clinically acceptable.

Following neutralization, optionally, gels can be subjected to various dwell periods, 1-48 hours, 12-36 hours, or 36 to 48 hours to promote refolding of denatured bioactive components. Dwell periods are generally performed with or without shaking or stirring the gel in a cold room

(i.e., at temperature of about 4°C), alternatively at room temperature. Dwell periods could extend beyond 48 hours to a few days, for example, 3-7 days to promote restructuring of the gel.

According to the method of the invention, once the gel is neutralized it may optionally be subjected to one or more steps of freeze drying cycles to facilitate the conversion of the
5 neutralized gel to a powder (having a neutral pH). The powder can be reconstituted into a gel without altering its bioactivity by mixing the powder with a liquid, such as water, or a buffer solution which maintains the neutral pH of the gel. In addition, preservation of bioactivity of ECMs may be achieved through lyophilization.

In one embodiment according to the invention, the freeze dried, solubilized ECM is
10 reconstituted using water and two 3 mL syringes. One syringe contains the lyophilized gel, the other water, and they are mixed together via a connector between the two syringes. The mixture is injected back and forth several times to achieve mixing. Various concentrations of ECM in NaOH can be tested for handling properties (i.e. injectability, tackiness, viscosity) to determine their ability to be applied using the two syringe system. The final consistency of all gels is foam-
15 like, and each one adheres to the surface to which it is applied while also maintaining consistency, which may be desirable in zero gravity conditions, for example, in space. Accordingly, the gel invention may be used for tissue repair during space exploration.

In one embodiment, to the solubilized and neutralized ECM gel, particularized ECM is added to increase the viscosity or the bioactivity of the gel. For example, UBM powder in the
20 size range of about 1 micron – 1000 microns, about 200-700 microns, about 300-600 microns, about 100 to 400 microns, about 200 microns or about 400 microns is added to a UBM gel prepared by the above methods to enhance the viscosity or the bioactivity of the gel, that is, the gel has better handling or the gel is made capable of producing a higher concentration of bioactive molecules, for example, growth factors, such as FGF, e.g., FGF-2, CTGF, or VEGF.
25 ECM powder can be added, prior to, during, or after the gels are neutralized.

In a particular embodiment, 7.0% UBM to 100 mM NaOH solubilized at 4°C is used to manufacture the bioactive gel. A dwell period may or may not be used. UBM powder may be added to the gel to increase viscosity and/or bioactivity.

30

EXEMPLIFICATIONS

For the following exemplifications, any number of ECM products such as but not limited to one or more of isolated urinary bladder submucosa, small intestinal submucosa, dermis, for example, could be used. In the following exemplifications, UBM, an ECM isolated from the urinary bladder and having epithelial basement membrane is used as an exemplary ECM. However the invention disclosed herein is not limited to UBM and is applicable to any isolated ECM.

In an exemplification, gels were created using various concentrations of particularized UBM (0.5-11% w/v) solubilized in various concentrations of NaOH (0.1-1.0M). UBM was solubilized for various time periods (1-48 hours) in its respective concentration of UBM and NaOH at 4°C. In order to test whether the UBM could restructure after solubilization, gels were also made using various dwell periods (1-48 hours) following neutralization.

UBM gels created in the above manner were tested in vitro for bioactive molecular content. In this study, growth factor (e.g., FGF-2, CTGF, VEGF) content was analyzed. Data for FGF-2 and VEGF content following solubilization for each gel structure is shown in Figures 1 and 2. Lower concentration gels (1-6%) are not shown but produced similar results. As shown in Figures 1 and 2, FGF-2 and VEGF, particularly VEGF levels increased in these studies.

In one study it was found that using 7.0% w/v UBM to various range of NaOH with 24 hours of solubilizing at 4°C and no dwell period had significantly influenced the FGF-2 and VEGF contents in the gel. FGF-2 and VEGF contents were measure by standard ELISA procedures.

What is claimed is:

CLAIMS

1. A method of manufacturing a bioactive gel from an extracellular matrix material comprising:
 - a) providing an extracellular matrix material derived from a mammalian tissue and
5 comprising bioactive components of the extracellular matrix material arranged and in quantities found in the tissue in its native form;
 - b) particularizing the extracellular matrix material of a);
 - c) solubilizing the particularized extracellular matrix material of b) in an alkaline solution;
 - 10 d) neutralizing the solution of step c) by the addition of equimolar concentrations of an acid.
2. The method of claim 1 further comprising,
 - e) freezing the neutralized solubilized extracellular matrix material prepared in step d);
15 and
 - f) lyophilizing the frozen material prepared in step e).
3. The method of claim 2 further comprising reconstituting the lyophilized gel in an aqueous solution.
20
4. The method of claim 1 further comprising a dwell period following step d) at 4° C up to 48 hours.
5. The method of claim 1 wherein the period of time for step c) is selected from the group
25 consisting of 30 minutes to 48 hours, and 3 to 7 days.
6. The method of claim 1 wherein the extracellular matrix material is derived from the group consisting of small intestine submucosa, urinary bladder submucosa, urinary bladder matrix comprising epithelial basement membrane, and liver basement membrane.
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7. The method of claim 1 wherein said particularized extracellular matrix material is in the particle range size of about 1 μ m to about 1000 μ m.
8. The method of claim 1 wherein said extracellular matrix material is solubilized in concentrations of about 0.5% to about 11% w/v of particularized extracellular matrix material in NaOH in the molar range of about 0.1M to about 1.0M.
9. The method of claim 1 wherein said solubilized extracellular matrix material is neutralized in hydrochloric acid.
10. The method of claim 9 wherein said hydrochloric acid comprises concentrations of 0.1M to 1.0M.
11. The method of claim 1 wherein said bioactive components are selected from the group consisting of FGF-2, CTGF and VEGF.
12. The method of claim 11 wherein concentration of said FGF-2 in said solubilized extracellular matrix material is greater when said extracellular matrix material is solubilized in 1.0M NaOH as compared to 100mM NaOH when said extracellular matrix is solubilized for more than 2 hours.
13. The method of claim 11 wherein concentration of said VEGF in said solubilized extracellular matrix material is greater when said extracellular matrix material is solubilized in 1.0M NaOH as compared to 100mM NaOH when said extracellular matrix material is solubilized for more than 2 hours.
14. The method of claim 1 wherein said particularized extracellular matrix material comprises UBM wherein said UBM is solubilized in concentrations of 7% of particularized UBM in 100mM NaOH at 4°C for 24 hours.

AMENDED CLAIMS

received by the International Bureau on 04 July 2014 (04.07.2014)

1. A method of manufacturing a bioactive gel from an extracellular matrix material comprising:
 - a) providing an extracellular matrix material derived from a mammalian tissue and comprising bioactive components of the extracellular matrix material arranged and in quantities found in the tissue in its native form;
 - b) particularizing the extracellular matrix material of a);
 - c) solubilizing the particularized extracellular matrix material of b) in an alkaline solution;
 - d) neutralizing the solution of step c) by the addition of of an acid.
2. (Previously presented) The method of claim 1 further comprising,
 - e) freezing the neutralized solubilized extracellular matrix material prepared in step d); and
 - f) lyophilizing the frozen material prepared in step e).
3. The method of claim 2 further comprising reconstituting the lyophilized gel in an aqueous solution.
4. The method of claim 1 further comprising a dwell period following step d) at 4° C up to 48 hours.
5. The method of claim 1 wherein the period of time for step c) is selected from the group consisting of 30 minutes to 48 hours, and 3 to 7 days.
6. The method of claim 1 wherein the extracellular matrix material is derived from the group consisting of small intestine submucosa, urinary bladder submucosa, urinary bladder matrix comprising epithelial basement membrane, and liver basement membrane.
7. (Currently amended) The method of claim 1 wherein said particularized extracellular matrix material is in the particle range size of 1 μ m to about 1000 μ m.
8. The method of claim 1 wherein said extracellular matrix material is solubilized in concentrations of about 0.5% to 11% w/v of particularized extracellular matrix material in NaOH in the molar range of about 0.1M to about 1.0M.
9. The method of claim 1 wherein said solubilized extracellular matrix material is neutralized in hydrochloric acid.
10. The method of claim 9 wherein said hydrochloric acid comprises concentrations of 0.1M to 1.0M.

11. The method of claim 1 wherein said bioactive components are selected from the group consisting of FGF-2, CTGF and VEGF.
12. The method of claim 11 wherein concentration of said FGF-2 in said solubilized extracellular matrix material is greater when said extracellular matrix material is solubilized in 1.0M NaOH as compared to 100mM NaOH when said extracellular matrix is solubilized for more than 2 hours.
13. The method of claim 11 wherein concentration of said VEGF in said solubilized extracellular matrix material is greater when said extracellular matrix material is solubilized in 1.0M NaOH as compared to 100mM NaOH when said extracellular matrix material is solubilized for more than 2 hours.
14. The method of claim 1 wherein said particularized extracellular matrix material comprises UBM wherein said UBM is solubilized in concentrations of 7% of particularized UBM in 100mM NaOH at 4°C for 24 hours.
15. The method of claim 1 wherein said particularized material of step (b) is in the range of 200-700 microns.

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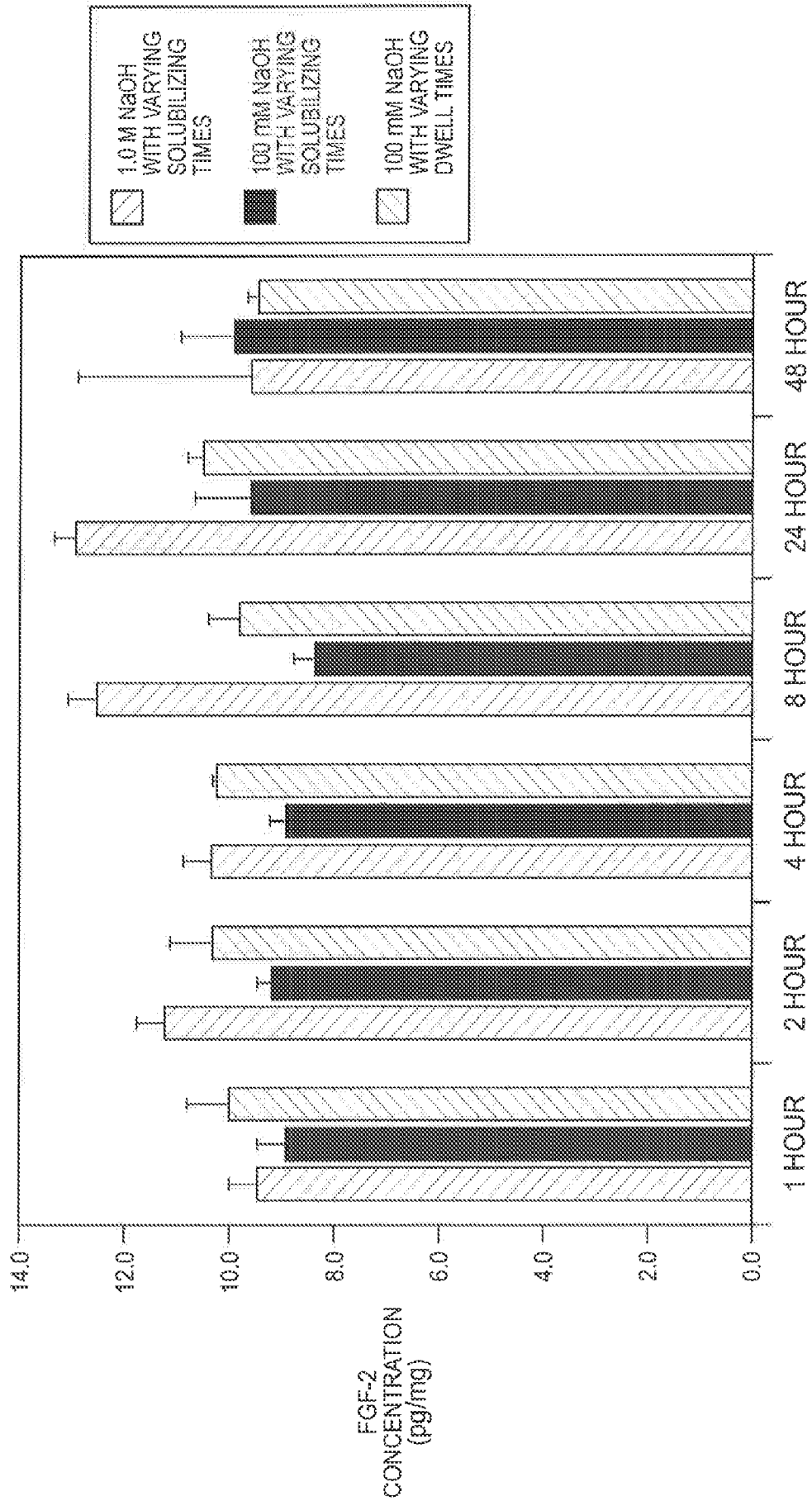


FIG. 1

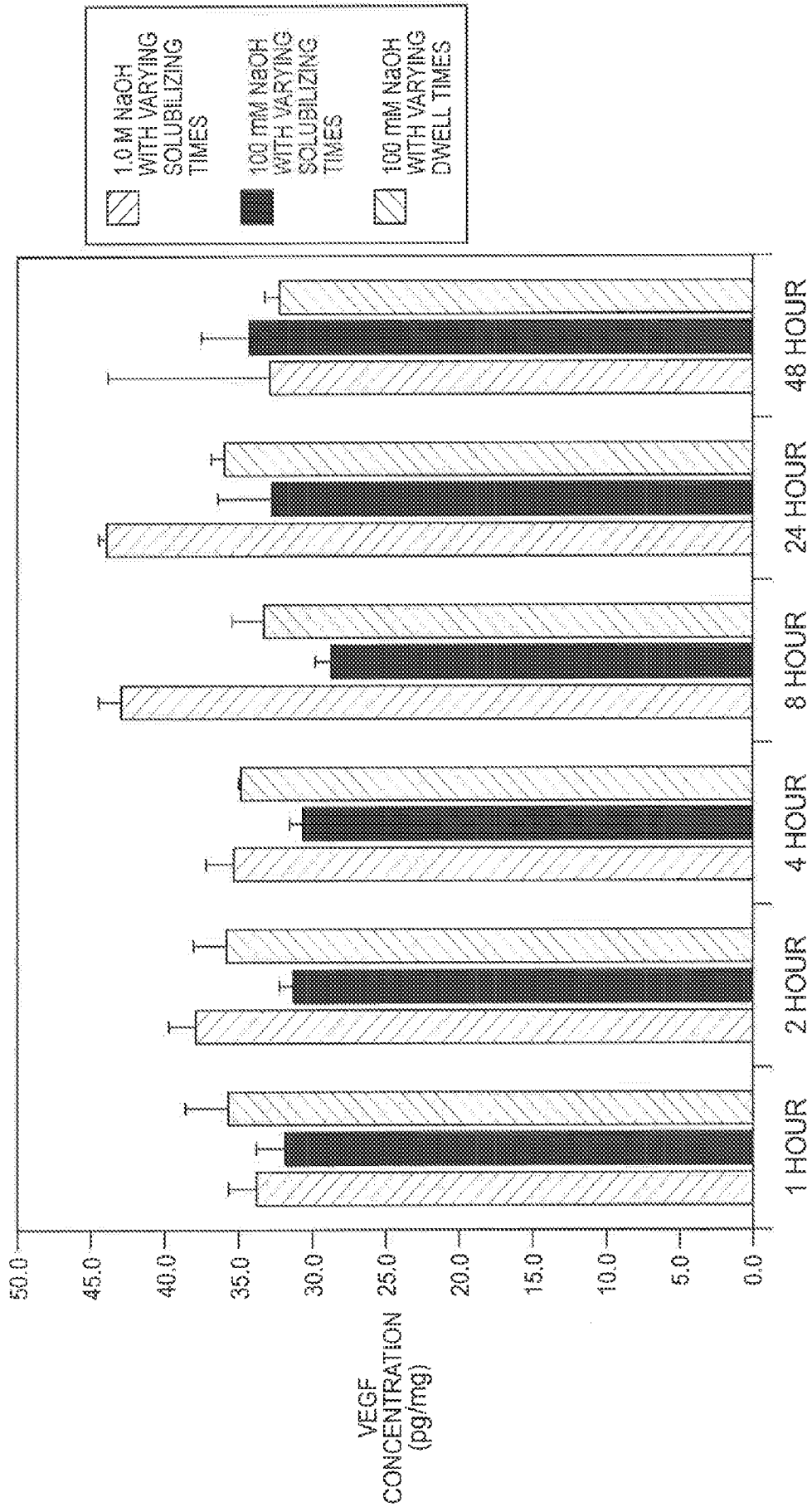


FIG. 2

INTERNATIONAL SEARCH REPORT

International application No PCT/US2014/015214

A. CLASSIFICATION OF SUBJECT MATTER INV. A61L27/36 A61L27/52 A61L27/54 ADD.				
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) A61L				
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched				
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data				
C. DOCUMENTS CONSIDERED TO BE RELEVANT				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.		
A	WO 2009/086499 A2 (COOK BIOTECH INC [US]; HOODE JASON P [US]; PATEL UMESH H [US]) 9 July 2009 (2009-07-09) pages 10-11 pages 15-17 page 21	1-14		
X	----- WO 2008/060377 A2 (ANTHROGENESIS CORP [US]; LIU QING [US]; RAY CYNTHIA [US]) 22 May 2008 (2008-05-22) paragraphs [0039] - [0041] paragraphs [0051], [0063] - [0069] paragraphs [0073] - [0081], [0103] ----- -/--	1-14		
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.				
* Special categories of cited documents : <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border: none; vertical-align: top;"> "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 </td> <td style="width: 50%; border: none; vertical-align: top;"> "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 </td> </tr> </table>			"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
"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			
29 April 2014	08/05/2014			
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Messemanne, Jasmine			

INTERNATIONAL SEARCH REPORT

International application No PCT/US2014/015214

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>FREYTES ET AL: "Preparation and rheological characterization of a gel form of the porcine urinary bladder matrix", BIOMATERIALS, ELSEVIER SCIENCE PUBLISHERS BV., BARKING, GB, vol. 29, no. 11, 16 January 2008 (2008-01-16), pages 1630-1637, XP022458611, ISSN: 0142-9612, DOI: 10.1016/J.BIOMATERIALS.2007.12.014 Materials and Method -----</p>	1-14

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2014/015214

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2009086499 A2	09-07-2009	US 2010266654 A1 WO 2009086499 A2	21-10-2010 09-07-2009
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