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**(54) Title:** HYBRID MATRIX IMPLANTS AND EXPLANTS**(57) Abstract**

An implantable device having a body of matrix material made up of insoluble collagen fibrils, and disposed therewithin: (a) a plurality of vertebrate cells; and (b) a plurality of microspheres each of which consists primarily of one or more of the following materials: collagen, polystyrene, dextran, polyacrylamide, cellulose, calcium alginate, latex, polysulfone, or glass.

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HYBRID MATRIX IMPLANTS AND EXPLANTS

The field of the invention is medical devices used in vivo or in vitro for production and delivery of 5 medically useful substances.

Background of the Invention

The means used to deliver medically useful substances can significantly affect their efficacy. The standard route of administration for many such substances 10 is either oral, intravenous, or subcutaneous. Each has inherent limitations which can affect the therapeutic utility of the substances being delivered. For example, many protein-based drugs have short half-lives and low bioavailabilities, factors that must be considered in 15 their formulation and delivery. Although various devices have been developed to deliver medically useful substances, including portable pumps and catheters, there is still a significant need for improved delivery devices.

20 Many medically useful substances, including proteins, glycoproteins, and some peptide and nonpeptide hormones, are more efficiently produced by cultured cells than via artificial synthetic routes. Appropriate cells are typically cultured in bioreactors, and the desired 25 product purified therefrom for administration to the patient by standard means, e.g. orally or by intravenous or subcutaneous injection. Alternatively, the cells may be implanted directly into the patient, where they produce and deliver the desired product. While this 30 method has a number of theoretical advantages over injection of the product itself, including the possibility that normal cellular feedback mechanisms may be harnessed to allow the delivery of physiologically

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appropriate levels of the product, it introduces additional complexities. One of these concerns the appropriate environment for the cells at the time of implantation. It would be desirable to organize the 5 cells of the implant in a form that is compatible with the natural *in vivo* environment of the cell type comprising the implant (fibroblasts, for example, exist naturally in a rich network of extracellular matrix composed primarily of collagen). There is also a need in 10 some cases to ensure that the implanted cells remain localized to a defined site in the patient's body, so that they can be monitored and perhaps removed when no longer needed.

One technique that has been tested for this 15 purpose utilizes an implantation device consisting of a solid, unitary piece of collagen gel (a "collagen matrix") in which the cells are embedded (e.g., Bell, U.S. Patent No. 4,485,096). Other substances, such as polytetrafluoro-ethylene (PTFE) fibers (Moullier et al., 20 *Nature Genetics*, 4:154, 1993; WO 94/24298), may be included in the collagen implant to impart strength or other desirable characteristics to the collagen gel.

#### Summary of the Invention

It has been found that the function of collagen 25 matrices can be substantially improved by the addition of microspheres to the collagen matrix, thereby forming what is herein termed a "hybrid matrix". This may be accomplished by mixing microspheres with the cells and soluble collagen prior to gelling of the collagen to form 30 the matrix. If desired, the microspheres and cells can be cultured together for a period which permits the cells to adhere to the microspheres before addition of the non-gelled collagen solution; alternatively, the three constituents can be mixed essentially simultaneously or

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in any desired order, followed by gelation of the soluble collagen within the mixture, to form a gelled mixture consisting of insoluble collagen fibrils, cells and microspheres. This gelled mixture gradually becomes 5 smaller through the exclusion of liquid to form a solid, relatively resilient, implantable unit that contains both the microspheres and the cells embedded in the insoluble collagen fibril network. When the microspheres are also composed largely of collagen, the resulting matrix is 10 herein termed a "hybrid collagen matrix".

The invention thus includes an article or device having a body made of matrix material that includes insoluble collagen fibrils, and disposed within the body:

(a) a plurality of vertebrate cells (particularly 15 mammalian cells such as cells derived from a human, chimpanzee, mouse, rat, hamster, guinea pig, rabbit, cow, horse, pig, goat, sheep, dog, or cat); and

(b) a plurality of microspheres (or beads), each of which consists primarily of (i.e., greater than 50% of 20 its dry weight is) one or more substances selected from a list including collagen (preferably type I collagen), polystyrene, dextran, polyacrylamide, cellulose, calcium alginate, latex, polysulfone, and glass (e.g., glass coated with a gel such as collagen, to improve adherence 25 of cells). Generally at least 70%, and preferably at least 80% (most preferably between approximately 90% and approximately 100%, e.g., at least 95%) of each microsphere's dry weight is one or more of the listed substances. Commercial examples of microspheres which 30 are described as consisting essentially of purified collagen include ICN Collagen™ Beads and Cellex Biosciences macroporous microspheres. The microspheres are preferably of a porous consistency, but may be smooth, and typically have an approximately spherical 35 shape with a diameter of approximately 0.1 to 2 mm (e.g.,

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between approximately 0.3 and 1 mm). Of course, the shape and size of microspheres from any particular lot or preparation will vary within manufacturing tolerances. The article may be configured to be implanted into an 5 animal, e.g., a mammal such as a human patient, or may be designed for producing cellular products *in vitro*; e.g., in an extracorporeal bioreactor apparatus having a means for shunting blood from an animal to the article and then back into a blood vessel of the animal, or in a 10 bioreactor or other vessel from which medium containing the desired cellular product can be recovered for purification and the preparation of a pharmaceutical agent. The cells may be derived from one or more cells removed from the patient, and preferably are transfected 15 cells containing exogenous DNA encoding one or more medically useful polypeptides such as an enzyme, hormone, cytokine, colony stimulating factor, angiogenesis factor, vaccine antigen, antibody, clotting factor, regulatory protein, transcription factor, receptor, or structural 20 protein. Examples of such polypeptides include human growth hormone (hGH), Factor VIII, Factor IX, erythropoietin (EPO), albumin, hemoglobin, alpha-1 antitrypsin, calcitonin, glucocerebrosidase, low density lipoprotein (LDL) receptor, IL-2 receptor, globins, 25 immunoglobulins, catalytic antibodies, the interleukins, insulin, insulin-like growth factor 1 (IGF-1), parathyroid hormone (PTH), leptin, the interferons, nerve growth factors, basic fibroblast growth factor (bFGF), acidic FGF (aFGF), epidermal growth factor (EGF), 30 endothelial cell growth factor, platelet derived growth factor (PDGF), transforming growth factors, endothelial cell stimulating angiogenesis factor (ESAF), angiogenin, tissue plasminogen activator (t-PA), granulocyte colony stimulating factor (G-CSF), and granulocyte-macrophage 35 colony stimulating factor (GM-CSF). Alternatively, the

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exogenous DNA can be a regulatory sequence that will activate expression of an endogenous gene (for example, using homologous recombination as described in WO94/12650-PCT/US93/11704, which is incorporated by 5 referenced herein).

Generally any type of cell which is capable of attaching to collagen and/or the microspheres, and which exhibits a desirable property such as expression of a medically useful cellular product or performance of an 10 essential structural or metabolic function, can be utilized in the matrices of the invention. Examples include adipocytes, astrocytes, cardiac muscle cells, chondrocytes, endothelial cells, epithelial cells, fibroblasts, gangliocytes, glandular cells, glial cells, 15 hematopoietic cells, hepatocytes, keratinocytes, myoblasts, neural cells, osteoblasts, pancreatic beta cells, renal cells, smooth muscle cells and striated muscle cells, as well as precursors of any of the above. If desired, more than one type of cell can be included in 20 a given matrix. The cells may be present as clonal or heterogenous populations.

The collagen in the matrix material is preferably type I, but may be any other type of collagen. The matrix material may optionally include two or more types 25 of collagen (e.g., selected from types I, II, III, IV, V, VI, VII, VIII, IX, X, and XI), as well as any additional components that impart desirable characteristics to the resulting matrix: e.g., agarose, alginate, fibronectin, laminin, hyaluronic acid, heparan sulfate, dermatan 30 sulfate, chondroitin sulfate, sulfated proteoglycans, fibrin, elastin, or tenascin. Any of the above mentioned collagenous and non-collagenous components may be derived from human sources or from another animal source. One could also include collagen or non-collagen fibers 35 disposed within the device. Such fibers can, for

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example, be made of a material that includes nylon, dacron, polytetrafluoro-ethylene, polyglycolic acid, polylactic/polyglycolic acid polymer mixtures, polystyrene, polyvinylchloride co-polymer, cat gut, 5 cotton, linen, polyester, or silk.

Large numbers of cells can be contained within the hybrid matrices. For example, hybrid matrices can be prepared which contain at least approximately two (and preferably approximately three) times as many cells as 10 matrices prepared with soluble collagen alone, assuming the number of cells inoculated and the initial production volume are equivalent. The total amount of polypeptide expressed by the cells embedded in a given hybrid matrix in a given time period is typically significantly higher 15 (e.g., at least 50% higher, preferably at least 100% higher, and more preferably at least 200% higher) than achieved with a standard collagen matrix of equivalent volume.

The hybrid matrix of the invention is generally 20 prepared by a process that includes the following steps:

forming a mixture that includes (a) a plurality of vertebrate cells; (b) a plurality of microspheres, each of which consists primarily of one or more substances selected from the list consisting of collagen, 25 polystyrene, dextran, polyacrylamide, cellulose, calcium alginate, latex, polysulfone, and glass; and (c) a solution comprising soluble collagen;

causing the soluble collagen in the mixture to form a gel of insoluble collagen fibrils in which the 30 cells and the microspheres are embedded; and

exposing the gel to culture conditions which cause the gel to become smaller by the exclusion of liquid, thereby forming the body of the article. Gelation is typically triggered by raising the pH of the relatively 35 acidic collagen solution to above 5, e.g., by addition of

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concentrated, buffered culture medium, whereupon the collagen forms insoluble fibrils. When this step is carried out in a mold, the gel will take the shape of the interior of the mold. Generally the contraction of the 5 gel is effected by the cells in the mixture, which attach to the fibrils and cause it to contract to a smaller version of the molded shape (e.g., a disk, as in the case where the mold is a petri dish which is cylindrical in shape). The matrix may be utilized immediately after 10 manufacture, may be cultured to increase the number of cells present in the matrix or to improve their functioning, or may be cryopreserved indefinitely at a temperature below 0°C.

A medically useful polypeptide, such as one listed 15 above, may be delivered to a patient by a treatment method that involves providing a hybrid matrix containing cells which secrete the polypeptide of interest, and implanting the article in the patient in a selected site, such as a subcutaneous, intraperitoneal, sub-renal 20 capsular, inguinal, intramuscular or intrathecal site. Where the polypeptide is one which promotes wound healing (e.g., PDGF or IGF-I), the matrix may be implanted at the site of a preexisting wound. As discussed above, the 25 cells may be derived from one or more cells removed from the patient, and are preferably transfected *in vitro* with exogenous DNA encoding the polypeptide. Alternatively, they may be cells which naturally secrete the polypeptide or perform the desired metabolic function (e.g., hepatocytes or pancreatic beta cells).

30 In another embodiment, the medically useful polypeptide may be administered to the patient by shunting a portion of the patient's blood through the apparatus described above, so that the polypeptide secreted by the cells in the hybrid matrix mixes with the 35 blood. Generally, any such apparatus known to those in

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that field can be adapted to accommodate the matrix of the invention. For example, blood shunted into a device which contains a perm-selective membrane surrounding a matrix of the present invention will result in the 5 delivery of a therapeutic product of the matrix to the blood. A device similar to an artificial pancreas (Sullivan et al., Science 252:718-721, 1991) may be used for this purpose.

Yet another use for the hybrid matrices of the 10 invention is as a means for producing a polypeptide *in vitro*. This method includes the steps of placing the hybrid matrix under conditions whereby the cells in the matrix express and secrete the polypeptide; contacting the matrix with a liquid such that the cells secrete the 15 polypeptide into the liquid; and obtaining the polypeptide from the liquid, e.g., by standard purification techniques appropriate for the given polypeptide. In one embodiment, the matrix is anchored to a surface and is bathed by the liquid; alternatively, 20 the matrix floats freely in the liquid. Cells embedded in the hybrid matrix function at a high level in a small space. Furthermore, the first step in purification of the expressed polypeptide (removal of the cells from the medium) is considerably more efficient with the matrices 25 than with most standard methods of cell culture.

Other features and advantages of the invention are apparent from the claims, and from the detailed description provided below.

Brief Description of the Drawings

30 Fig. 1 is a map of hGH expression plasmid pXGH302. Fig. 2 is a plan view in partial section of one embodiment of the invention.

Fig. 3 is a graph showing the *in vivo* hGH levels in nude mice implanted with either a collagen matrix or a

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hybrid collagen matrix containing HF165-24 cells, human skin fibroblasts stably transfected with pXGH302 and expressing hGH.

Detailed Description

5 The examples set forth below illustrate several embodiments of the invention. These examples are for illustrative purposes only, and are not meant to be limiting.

EXAMPLE I

10 This example describes the procedures utilized to prepare a clonal cell strain of human fibroblasts stably transfected with the plasmid pXGH302 secreting recombinant human growth hormone (hGH), and to combine them with porous collagen microspheres in a hybrid matrix 15 of the invention. Such matrices are referred to as hybrid collagen matrices (HCM).

A. Generation of Primary Human Fibroblasts Expressing Human Growth Hormone

20 Fibroblasts were isolated from freshly excised human foreskins by an enzymatic dissociation technique. Upon confluence, primary cultures were dislodged from the plastic surface by mild trypsinization, diluted and replated to produce the secondary cell culture for transfection.

25 Plasmid pXGH302 was constructed as described in Example II, and transfection was carried out by electroporation, a process in which cells are suspended in a solution of plasmid DNA, placed between a pair of oppositely charged electrodes, and subjected to a brief 30 electric pulse.

Treated cells were selected in G418-containing medium for 10-14 days. Cells that integrated the plasmid

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into their genomes stably expressed the product of the neo gene and formed colonies resistant to killing by the neomycin analog G418. Each colony, consisting of a clonal population of cells, was individually removed from 5 its position on the tissue culture dish by trypsinization. Those clones scoring positive for hGH expression were expanded for quantitative assays, and clone HF165-24 was chosen for further use.

Further detailed procedures for preparing and 10 transfecting cells suitable for use in the matrices of this invention are provided in WO93/09222 (PCT/US92/09627), which is incorporated herein by reference.

#### B. Preparation of Hybrid Collagen Matrices

15        1. *Microsphere Preparation*  
Collagen microspheres (Cellex Biosciences cat. #YB00-0015UW) were transferred from each original bottle provided by the manufacturer (~10ml per bottle) into 50 ml conical tubes (1 tube per bottle). The microspheres 20 were allowed to settle in the tube, and the storage buffer solution was aspirated off. Microsphere wash medium (DMEM with 1% calf serum and 1% penicillin/streptomycin) was added to the 50 ml mark on the graduated tube, the microspheres allowed to settle, 25 and the medium aspirated off. This series of washing steps was repeated for a total of 4 washes. The microspheres were transferred to a 250 ml Erlenmeyer flask using a 25 ml plastic pipette, limiting the volume of microspheres to 100 ml per 250 ml flask. Microsphere 30 wash medium was added to the 250 ml mark, and the flask was capped and placed in a tissue culture incubator at 37°C for 2-3 hours. The flask was removed from the incubator, the microspheres allowed to settle, and the wash medium aspirated off. This series of incubation and

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washing steps was repeated for a total of 3 washes.

## 2. *Hybrid Collagen Matrix Preparation*

The cells and microspheres were mixed just prior to adding the collagen solution. Washed microspheres 5 were added to 15 ml graduated conical tube(s) to the desired volume (volume = no. of matrices multiplied by 1 ml; see Table 1). Microspheres were allowed to settle for at least 10 minutes before measuring volume. Excess wash medium was removed by aspiration.

10 Cells to be embedded in the matrix were harvested by trypsinization and the cell number was determined. The required number of cells (cell no. per matrix multiplied by total no. of matrices to be produced) was centrifuged at 1500 rpm (500xg) for 7 min at room 15 temperature. In an appropriately sized conical-bottom polypropylene tube, a mixture of equal volumes of modified 2x DMEM (2x DMEM with 9 g/L glucose, 4 mM L-glutamine, and 22.5 mM HEPES) and calf serum was prepared according to Table 1. (Note: for volumes greater than 20 250 ml, the total pooled volume should be divided into appropriately sized tubes.) The cell pellet was resuspended in the 2x DMEM-calf serum mixture. The collagen microspheres were mixed with the cell suspension by adding 1 - 2 ml of the cell suspension to the packed 25 microspheres and then transferring the concentrated microspheres by 10 ml pipette into the remaining cell suspension, followed by gentle mixing with the pipette. The mixture was placed on ice and the appropriate volume of collagen solution was added (rat tail Type I collagen; 30 UBI cat #08-115, diluted to concentration of 4.0 mg/ml in 0.02 M acetic acid), as indicated in Table 1. The contents of the tube were mixed carefully (avoiding creating bubbles or frothing) using a 10 ml glass pipette, until the matrix solution appeared homogenous.

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To produce the matrix, an appropriate volume of the collagen/cell/microsphere/medium mix was added to a sterile petri dish with a pipette (10 or 25 ml capacity), according to the total volume per dish listed in Table 1.

5 (The mix was agitated by pipetting occasionally during the filling of dishes to prevent settling of cells or microspheres.) The filled dishes were placed in a 37°C, 5% CO<sub>2</sub>, 98% relative humidity tissue culture incubator and left undisturbed for approximately 24 h, during which

10 time the contents gelled and the size of the gel decreased in all dimensions to form the hybrid matrices of the invention, which were approximately 50% of the diameter and 10% of the volume of the non-gelled mixture.

One embodiment of the hybrid matrix of the

15 invention is illustrated in Fig. 2. The matrix 10 consists of a contracted collagen gel body 12 in which are embedded vertebrate cells 14 and microspheres 16. For clarity in this figure, the cells are shown as dots separate from the microspheres. In fact, most of the

20 cells would be expected to be attached to the microspheres, and would be substantially smaller than represented in the figure.

**TABLE 1** Medium, Microsphere, and Collagen Volumes Required for HCM Production

25	Dish Size	Number of Matrices	Modified 2x DMEM	Serum	Microspheres	Collagen Solution	Total Vol.
30	60 mm	1	1 ml	1 ml	1 ml	1 ml	4 ml
	60 mm	12	12 ml	12 ml	12 ml	12 ml	48 ml
	100 mm	1	2.5 ml	2.5 ml	2.5 ml	2.5 ml	10 ml
	100 mm	12	30 ml	30 ml	30 ml	30 ml	120 ml
	150 mm	1	7.5 ml	7.5 ml	7.5 ml	7.5 ml	30 ml
	150 mm	12	90 ml	90 ml	90 ml	90 ml	360 ml

**EXAMPLE II**

pXGH302 was constructed by subcloning the 6.9 kb *Hind*III fragment extending from positions 11,960-18,869

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in the human HPRT sequence (Edwards et al., *Genomics*, 6:593-608, 1990; Genbank entry HUMHPRTB) and including exons 2 and 3 of the HPRT gene, into the *Hind*III site of pTZ18R (Pharmacia P-L Biochemicals, Inc.). The resulting 5 clone was cleaved at the unique *Xba*I site in exon 3 of the HPRT gene fragment, and the 1.1 kb *Sal*I-*Xba*I fragment containing the *neo* gene from pMC1Neo (Stratagene) was inserted, disrupting the coding sequence of exon 3. One orientation, with the direction of *neo* transcription 10 opposite that of HPRT, was chosen and designated pE3neo.

To combine the hGH gene, HPRT sequences, and *neo* gene in the same plasmid, pXGH5 (Selden et al., *Mol. Cell. Biol.* 6:3173-3179, 1986) was digested with *Eco*RI, and the 4.0 kb fragment containing the hGH gene and 15 linked mouse metallothionein-I (mMT-I) promoter was isolated. The *Exo*RI overhangs were filled in with the Klenow fragment from *E. coli* DNA polymerase. pE3Neo was digested with *Xba*I, which cuts at the junction of the *neo* fragment and HPRT exon 3 (the 3' junction of the 20 insertion into exon 3). The *Xba*I overhanging ends of the linearized plasmid were filled in with the Klenow fragment from *E. coli* DNA polymerase, and the resulting fragment was ligated to the 4.0 kb blunt-ended mMT/hGH fragment. Bacterial colonies derived from the ligation 25 mixture were screened by restriction enzyme analysis for a single copy insertion of the mMT-I/hGH fragment. One subclone, in which the hGH gene is transcribed in the same direction as the *neo* gene, was designated pXGH302. A map of plasmid pXGH302 is shown in Fig. 1. In this 30 figure, the position and orientation of the hGH coding region and the mouse metallothionein-I promoter (mMT-I) controlling hGH expression are noted. The positions of basal promoter elements (TATA), transcription initiation sites (CAP), and translation initiation sites (ATG) are 35 indicated. As illustrated, *neo* gene transcription is

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controlled by the polyoma enhancer/herpes simplex virus (HSV) thymidine kinase (TK) gene promoter. HPRT denotes the positions of sequences from the human hypoxanthine-guanine phosphoribosyl transferase locus. Plasmid 5 pXGH302 utilizes the pTZ18R (Pharmacia P-L Biochemicals, Inc.) backbone, a derivative of plasmid pUC18 (Yanisch-Perron et al., Gene 33: 103-119, 1985) carrying a T7 RNA polymerase promoter and the f1 origin of replication.

**EXAMPLE III**

10 This example illustrates a method of making a hybrid collagen matrix in which transfected cells prepared as described above are precultured with the microspheres prior to formation of the hybrid collagen matrix. Such "precultured" hybrid collagen matrices are 15 referred to as PCHCM.

**A. Preculture of cells and microspheres**

Trypsinized transfected cells are seeded onto washed collagen microspheres at a ratio of  $2 \times 10^6$  cells per ml microspheres (e.g.  $10 \times 10^6$  cells onto 5 ml 20 microspheres) by the following protocol:

1. Add cell suspension in a volume of growth medium that is twice the volume of the microspheres to a 125 ml Erlenmeyer flask. The limit is 10 ml of microspheres per flask.

25 2. Remove 1 - 2 ml of this suspension and add to 5 ml (packed volume) microspheres premeasured in a 15 ml tube.

3. Transfer cell suspension/microspheres back into the 125 ml Erlenmeyer flask.

30 4. Place flask into tissue culture incubator and swirl gently for approximately 5 seconds each hour for 4-5 h. Add growth medium to the 50 ml gradation on the flask, and allow cells and microspheres to incubate undisturbed overnight.

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After 20 - 24h from the time of seeding, determine the number of cells attached to collagen microspheres by the following procedure:

1. Determine the weight of a 5 ml round bottom 5 polystyrene test tube.

2. Remove a small sample of microspheres (0.1 - 0.2 ml) from the Erlenmeyer flask and add to the pre-weighed test tube.

3. Aspirate medium from microsphere sample and 10 determine the weight of the tube plus sample. Calculate sample weight by subtracting weight of tube from weight of tube plus sample.

4. Add 1 ml of matrix digestion enzyme [collagenase IA (Sigma cat #C9891) at 1 - 2 mg/ml in PBS 15 with  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ] to microsphere sample and mix gently by tapping on the side of the tube.

5. Cover the tube with parafilm and place in a 37°C water bath for 1h, promoting disintegration of microspheres by pipetting through a Pasteur pipette at 20 15 minute intervals.

6. After 1h incubation, further dissociate cells by pipetting vigorously with a 5 ml glass pipette.

(Note: If clumps still remain, add to the tube a solution of 10x trypsin-EDTA at a volume 1/10th that of 25 the volume of collagenase solution added, and incubate an additional 10 min.)

7. Perform cell counts using a hemacytometer.

8. Determine density of cells per ml microspheres using the following formula, which assumes 30 that 50% of the wet packed volume of these microspheres is interstitial:

Total number of cells/ml microspheres =  $1000 \text{ mg}/(\text{mg weight of sample}) \times (\text{cell number in sample}) \times 0.5$ .

The cell/microsphere mixture is transferred from 35 the 125 ml Erlenmeyer flask to a 250 ml spinner flask

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(Bellco Microcarrier Spinner Flasks, 250 ml, with model #1965-60001 impeller shafts), growth medium is added to the 150 ml gradation mark, and the spinner flask is placed on a magnetic stirrer plate (set at 50 rpm) in a 5 tissue culture incubator. The culture is fed with fresh medium the next day and 3 times weekly thereafter by allowing the microspheres to settle on the bottom of the flask, aspirating "spent" medium to the 50 ml mark on the flask, and adding fresh growth medium to the 200 ml mark. 10 The density of cells per ml microspheres may be determined at desired time points as described above.

B. Preparation of Precultured Hybrid Collagen Matrices

(PCHCM)

PCHCM are produced by the following protocol:

15 1. When the desired density of cells per ml microspheres is achieved (as determined by cell counts), remove microspheres containing cells from the spinner flask.

20 2. Produce matrices following the procedure outlined above for producing HCM, with the following modifications:

25 i. Cells are not trypsinized.  
ii. Add cultured microspheres containing cells to 15 ml graduated conical tube(s), to the desired packed volume (volume = no. of matrices x 0.5 ml).

iii. Add empty microspheres to 15 ml graduated conical tube(s) to the desired packed volume (volume = no. of matrices x 0.5 ml).

30 3. Prepare modified 2x DMEM and calf serum mixture as described in Example I above. Add both empty microspheres (50% of total microsphere volume) and microspheres containing cells (50% of total microsphere volume) to the modified 2x DMEM/calf serum mixture (see 35 Table 2 below). The microsphere/DMEM/calf serum mixture

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is placed on ice and the appropriate volume of collagen solution is added (rat tail Type I collagen; UBI cat #08-115, diluted to concentration of 4.0 mg/ml in 0.02M acetic acid), as specified in Table 2. The contents of 5 the tube are mixed carefully (avoiding creating bubbles or frothing) using a 10 ml glass pipette, until matrix solution appears homogenous.

**TABLE 2 Medium, Microsphere, and Collagen Volumes Used for PCHCM Production**

10	Dish Size	Number of Matrices	Mod. 2xDMEM	Serum	Microspheres	Collagen Solution	Total Vol.	
15	60 mm	1	1 ml	1 ml	0.5 ml	0.5 ml	1 ml	4 ml
15	60 mm	12	12 ml	12 ml	6 ml	6 ml	12 ml	48 ml
15	100 mm	1	2.5 ml	2.5 ml	1.25 ml	1.25 ml	2.5 ml	10 ml
15	100 mm	12	30 ml	30 ml	15 ml	15 ml	30 ml	120 ml
15	150 mm	1	7.5 ml	7.5 ml	3.75 ml	3.75 ml	7.5 ml	30 ml
20	150 mm	12	90 ml	90 ml	45 ml	45 ml	90 ml	360 ml

**EXAMPLE IV**

A. Hybrid matrices (HCM or PCHCM) are maintained in culture by feeding the matrices on day 1, and then 2 to 3 times weekly using the following protocol:

25 1. Carefully aspirate the culture medium.

2. Add the required volume of appropriate growth medium, taking into consideration the size of the dish used for each matrix (5 - 7 ml per 60 mm dish, 10 - 15 ml per 100 mm dish, 30 - 40 ml per 150 mm dish). The 30 medium may be supplemented with ascorbic acid 2-phosphate and/or TGF- $\beta$  (e.g. 10-50  $\mu$ g/ml ascorbic acid 2-phosphate and/or 1-10 ng/ml TGF- $\beta$ ).

B. The diameter of a hybrid collagen matrix can be determined using the following procedure:

35 1. Place the petri dish containing the matrix to be measured on top of a metric ruler resting on a dark background.

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2. Record diameters (in centimeters) as desired: e.g., daily for the first 2 weeks, every other day after the first 2 weeks, and on days of cell quantitation for the duration of the experiment.

5 C. Cells can be recovered and quantified from a hybrid collagen matrix as follows:

1. Enzymatic Digestion of Hybrid Collagen Matrices
  - a. Prepare a solution of collagenase IA (1.0 mg/ml for HCM and PCHCM, 2.0 mg/ml for HCM or PCHCM supplemented with ascorbic acid 2-phosphate and/or TGF- $\beta$ ) in PBS.
  - b. Dispense the collagenase solution into 15 ml conical centrifuge tubes at a volume of 1 ml for matrices seeded with 1 - 5 $\times$ 10<sup>6</sup> cells and 5 ml for matrices seeded with greater than 5 $\times$ 10<sup>6</sup> cells per matrix. Prepare as many collagenase tubes as there are matrices to be counted.
  - c. Remove each matrix from its dish using flat forceps, and carefully blot the excess fluid from the matrix using an absorbent paper towel (if cells will be discarded after counting) or sterile absorbent pad.
  - d. Place each matrix in an individual collagenase-containing tube, cap tightly, and secure onto an orbital shaker set at 40 rpm in a tissue culture incubator.
  - e. Incubate the matrices for approximately 1 hour or until digestion is complete. To accelerate digestion, break up the matrices by pipetting at 5 min intervals.
2. Cell Counting
  - a. Measure the total volume of each digested cell suspension using the gradations on the side of the centrifuge tube.

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b. For measuring cell viability, remove 0.1 ml of cell suspension and add to 0.1 ml of 0.08% trypan blue in a 1.5 ml microcentrifuge tube. Mix by tapping the tube lightly.

5 c. Count the viable and dead cells using a hemacytometer. If necessary, further dilute the cell suspension in PBS prior to adding the trypan blue. Calculate the total number of cells, taking into consideration the total volume

10 measured in step 2a.

**EXAMPLE V**

This example describes experiments varying the inoculum density of clones of human fibroblasts stably transfected with the plasmid pXGH302 in a hybrid collagen matrix, to determine the cell density that can be supported in HCM. hGH production by each HCM was also monitored.

Hybrid collagen matrices were produced with 3 inoculum densities (ID) of the stably transfected hGH-expressing neonatal foreskin fibroblast clone designated HF165-24. The densities were 5, 10, and  $20 \times 10^6$  cells per HCM. For each ID, 9 HCM were produced in 60 mm dishes. The hybrid matrix production medium for each ID consisted of 9 ml of modified 2x DMEM, 9 ml of calf serum, 9 ml of collagen microspheres, and 9 ml of 4 mg/ml soluble rat tail collagen, in 50 ml conical tubes.

HF165-24 harvested from monolayer cultures were pooled to provide enough of each ID for 9 HCM:  
 $5 \times 10^6$  cells times 9 HCM =  $45 \times 10^6$  cells total;  
30  $10 \times 10^6$  cells times 9 HCM =  $90 \times 10^6$  cells total;  
 $20 \times 10^6$  cells times 9 HCM =  $180 \times 10^6$  cells total.  
Pooled cells for each ID were centrifuged at 1500 rpm for 7 min, supernatant was aspirated, and pellets were resuspended in 9 ml modified 2x DMEM and 9 ml calf serum

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and transferred to 50 ml tubes. Nine ml of collagen microspheres pre-measured in 15 ml graduated tubes were added to the cells/2x DMEM/calf serum mixture and mixed by gentle pipetting with a 10 ml pipette. This mixture 5 was then placed on ice, and 9 ml of ice cold rat tail type I collagen solution (4 mg/ml) was added and mixed with a 10 ml pipette to produce a homogenous solution. Four ml of this mixture was added to each of nine 60 mm petri dishes for each density. The petri dishes were set 10 in a tissue culture incubator and left undisturbed for 24 h. Medium was carefully aspirated from each dish after the 24 h incubation, and HCM were re-fed with Growth Medium (DMEM, 10% calf serum, and 1% Pen/Strep), using 5 ml per dish. To provide a greater volume of Growth 15 Medium per matrix, HCMs were transferred on day 3 from 60 mm petri dishes to 100 mm petri dishes using flat forceps, and 10 ml of Growth Medium was added per dish. On day 6, medium was aspirated from each HCM, matrices were rinsed with 5 ml of Hank's Balanced Salt Solution 20 (HBSS) and aspirated, and 10 ml of Growth Medium was added to each dish. The time of Growth Medium addition to HCM was noted in order to take a 24 h medium sample the following day (day 7). This rinse and feeding procedure was repeated on days 13 and 20 to provide day 25 14 and day 21 medium samples. The medium samples were assayed for hGH as indicated below. The HCM were also refed on days 10 and 17 without the rinse step.

Digestion of 3 HCM per ID for cell counts occurred on days 7, 14, and 21 after medium samples were taken, as 30 described in Example IV. Production of hGH by HCM at the indicated time points was measured by radioimmunoassay (Nichols Institute) of the 24 h medium samples, as described in Example XII below. Table 3 summarizes the cell numbers for triplicate HCM of each ID, and hGH 35 production by HCM at each ID on days 7 (n = 9), 14 (n =

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6), and 21 (n = 3). Values are presented as mean +/- standard deviation. As indicated, the equilibrium density determined at days 14 and 21 for HCM prepared as described above is approximately  $7-10 \times 10^6$  cells per 5 matrix. Per cell hGH production for fully formed matrices at day 21 is similar among the 3 ID levels tested.

**TABLE 3 Optimization of the Inoculum Density of HF165- 24 Embedded in Hybrid Matrices for Cell Density and hGH Production.**

10

HCM ID	Cell # Day 7 24h/matrix	$10^6$ cells	$\mu\text{g hGH/}$ 24h/matrix	$\mu\text{g hGH/24h/}$ $10^6$ cells
15	$5 \times 10^6$	$5,331,000 \pm 279,347$	$683 \pm 138$	$130 \pm 20$
	$10 \times 10^6$	$9,853,833 \pm 858,634$	$716 \pm 137$	$73 \pm 6$
	$20 \times 10^6$	$13,226,000 \pm 1,234,410$	$689 \pm 130$	$50 \pm 6$
20	HCM ID	Cell # Day 14	$\mu\text{g hGH/}$ 24h/matrix	$\mu\text{g hGH/24h/}$ $10^6$ cells
25	$5 \times 10^6$	$6,534,000 \pm 344,525$	$853 \pm 232$	$133 \pm 23$
	$10 \times 10^6$	$9,631,000 \pm 875,820$	$1037 \pm 277$	$108 \pm 12$
	$20 \times 10^6$	$10,360,000 \pm 706,541$	$840 \pm 280$	$81 \pm 16$

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HCM ID	Cell # Day 21	$\mu\text{g hGH/}$ 24h/matrix	$\mu\text{g hGH/24h/}$ $10^6$ cells
5	$5 \times 10^6$ 6,916,167 $\pm$ 608,352	730 $\pm$ 129	105 $\pm$ 10
	$10 \times 10^6$ 9,884,833 $\pm$ 1,475,327	1004 $\pm$ 279	101 $\pm$ 20
	$20 \times 10^6$ 10,207,750 $\pm$ 2,833,250	872 $\pm$ 333	83 $\pm$ 10

**EXAMPLE VI**

"Standard" collagen matrices (CM) do not include collagen microspheres. In order to compare CM with HCM, 15 CM were prepared by replacing the volume occupied by microspheres in HCM with additional soluble collagen, to give a ratio of 1 part 2x DMEM, 1 part calf serum, and 2 parts soluble collagen per CM. A direct comparison of CM with HCM was assessed as follows.

20 The clone of human fibroblasts stably transfected with the plasmid pXGH302, designated HF165-24, was used. Nine matrices of each type, at each of two ID ( $1 \times 10^6$  and  $5 \times 10^6$  cells per matrix), were produced. For both CM and HCM,  $9 \times 10^6$  cells (for  $1 \times 10^6$  ID) and  $45 \times 10^6$  25 cells (for  $5 \times 10^6$  ID) were resuspended in 9 ml of 2x DMEM + 9 ml of calf serum in 50 ml tubes. For CM, a total of 18 ml of rat tail type I collagen solution (4 mg/ml) was added to each ID set, and matrices were formed as described above in Example I. For HCM, 9 ml collagen 30 microspheres and 9 ml of rat tail type I collagen solution (4 mg/ml) were added to each ID set, and HCM were formed according to Example I. Matrices were kept in the original 60 mm dish and fed with a volume of 5 ml Growth Medium. Cell numbers per matrix, as well as hGH 35 production per matrix, were determined on days 7, 14, and

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30 as described for Example V. The maximum cell densities (measured on day 14) and hGH production achieved by the 2 types of matrices at the 2 densities are summarized in Table 4. As indicated in the table, 5 the hybrid type of matrix allowed for a higher density of cells and a substantially greater production of hGH per matrix, compared with the standard collagen matrix without microspheres.

10 **TABLE 4:** Comparison of "Standard" Collagen Matrices (CM) and Hybrid Collagen Matrices (HCM) for Maximum Cell Density and hGH Production by Embedded HF165-24 Cells

15	Matrix Type	ID	Maximum cell Density	Maximum hGH Production Per matrix
	CM	$1 \times 10^6$	$2.1 \times 10^6$	290 $\mu\text{g}$
	CM	$5 \times 10^6$	$3.3 \times 10^6$	299 $\mu\text{g}$
	HCM	$1 \times 10^6$	$6.2 \times 10^6$	983 $\mu\text{g}$
20	HCM	$5 \times 10^6$	$10.3 \times 10^6$	1221 $\mu\text{g}$

**EXAMPLE VII**

This example describes the production and analysis of precultured hybrid collagen matrices (PCHCM). Cells 25 of the clone of human fibroblasts stably transfected with the plasmid pXGH302 (HF165-24) were seeded onto collagen microspheres at a ratio of  $2 \times 10^6$  cells per ml of microspheres, in the following manner: A suspension of 48  $\times 10^6$  cells in 40 ml Growth Medium was obtained from 30 harvested monolayer cultures. 5 ml of this suspension was added to each of four 15 ml graduated tubes containing 6 ml of packed collagen microspheres, and each cell/microsphere mixture was transferred to a 125 ml Erlenmeyer flask. An additional 5 ml of cell suspension

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was added to the cell/microsphere mixture in the 125 ml Erlenmeyer flask to give a final suspension of  $12 \times 10^6$  cells with 6 ml microspheres and 10 ml Growth Medium per flask (4 flasks total). The flasks were placed in a tissue culture incubator and swirled gently for approximately 5 seconds each hour for 4 h. After the fourth hour, Growth Medium was added to each flask to the 50 ml mark, and flasks were left undisturbed for 24 h. At 24 h, the microspheres were transferred from each Erlenmeyer flask into a 250 ml spinner flask, Growth Medium was added to the 150 ml mark of each spinner flask, and flasks were placed on a magnetic stirrer plate set at 50 rpm in a tissue culture incubator. The following day, Growth Medium was added up to the 200 ml mark of each spinner flask, and flasks were refed 3 times weekly by aspirating medium to the 50 ml mark and adding fresh medium up to 200 ml.

On day 15 of the spinner flask culture, the density of cells per ml microspheres was determined. A small sample of microspheres (~0.1 - 0.2 ml) was removed from each flask and placed in pre-weighed 5 ml polystyrene tubes. Excess medium was removed from each tube by aspiration, and the tube containing the microsphere sample was weighed. One ml of a 2 mg/ml collagenase type IA solution in PBS was added to each tube, and the tubes were covered with parafilm, and placed in a 37°C waterbath. At 15 minute intervals, the tubes containing microspheres were tapped lightly to disperse clumps. After 1 h, cells were further dissociated by vigorous pipetting with a 5 ml glass pipette. To further dissociate clumps, a solution of 10x trypsin:EDTA was added to give a final trypsin concentration of 1x in the collagenase solution, and the tubes were incubated for an additional 10 minutes. The dissociated cell suspensions were diluted 1:2 with PBS

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and added to hemacytometer chambers for cell counting. The density of cells per ml microspheres was calculated using the following formula:

Total # of cells/ml microspheres =  
5       $1000 \text{ mg}/(\text{mg weight of sample}) \times (\text{cell\# in sample}) \times 0.5.$

This formula assumes that 1) wet collagen has a specific gravity of 1.0, and therefore the gram weight of collagen in the microsphere sample equals the collagen volume in 10 milliliters, and 2) half of the wet packed volume of microspheres is occupied by interstitial volume. The average number of cells per ml microspheres ( $n = 4$ ) for this experiment was  $19.2 \times 10^6$ . Microspheres were removed from each flask and pooled in a 15 ml graduated 15 tube. The entire volume of 6 ml microspheres containing  $19.2 \times 10^6$  cells per ml microspheres was used to produce hybrid collagen matrices.

In a 100 ml sterile bottle, 12 ml of modified 2x DMEM, 12 ml of calf serum, 6 ml of empty collagen 20 microspheres, and the 6 ml of precultured microspheres were carefully mixed using a 10 ml glass pipette. This mixture was placed on ice, and 12 ml of ice-cold rat tail Type I collagen was added and mixed carefully using a 10 ml glass pipette. 4 ml of this mixture was added to each 25 of twelve 60 mm petri dishes, and the dishes were placed at 37°C and left undisturbed for 24 h.

The final number of cells per matrix was  $9.6 \times 10^6$ , since each matrix was composed of 0.5 ml of microspheres containing  $19.2 \times 10^6$  cells per ml. These 30 precultured hybrid collagen matrices (PCHCM) were refed after 24 h by aspirating the medium and adding 5 ml of Growth Medium. The PCHCM were refed on days 4, 7, 11, 14, 18, and 20 with 6 ml of Growth Medium. On days 7, 14, and 20, the PCHCM were also rinsed with 4 ml of HBSS

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prior to addition of medium, and the time of medium addition was noted. On days 8, 15, and 21, a 24 h medium sample was taken for assay of hGH production, and PCHCM were digested to obtain cell counts as follows: A 5 solution of 2 mg/ml collagenase type IA in PBS was added at a volume of 6 ml per 15 ml tube. PCHCM were lifted from dishes with flat forceps and blotted on an absorbent paper towel prior to transfer into a collagenase solution. Tubes containing PCHCM and collagenase 10 solution were secured onto an orbital shaker in a tissue culture incubator, the speed was set to 40 rpm, and PCHCM were allowed to digest for 2 h. After the 2 h incubation, PCHCM were dissociated into single cells by vigorous pipetting with a 5 ml glass pipette. Further 15 dissociation was deemed necessary due to the presence of clumps, and a solution of 10x trypsin:EDTA (0.5% trypsin, 5.3 mM EDTA) was added to give a final trypsin concentration of 1X in the collagenase. The tubes were then incubated for an additional 10 min. Volumes in each 20 tube were noted, and cell suspensions were diluted 2-fold in PBS and placed in a hemacytometer chamber to obtain cell counts. Production of hGH by PCHCM at the indicated time points was measured by radioimmunoassay of the 24 h medium samples, as described in Example VIII. Table 5 25 summarizes the cell numbers for triplicate PCHCM at each time point, and hGH production by PCHCM on days 8 (n = 12), 15 (n = 9), and 21 (n = 6). Values are presented as mean  $\pm$  standard deviation. As Table 5 shows, these PCHCM support a higher density of cells than the HCM 30 described in Examples V and VI (Tables 3 and 4). The rate of hGH production per matrix and per cell was similar throughout the study period.

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**TABLE 5** HF165-24 Precultured on Collagen Microspheres and Embedded in Collagen to Form PCHCM: Cell Number and hGH Production Over Time in Culture.

Day	Cell Number	μg hGH/24h/matrix	μg hGH/24h/10 <sup>6</sup> cells
5	8 13,732,000 ± 1,786,565	1264 ± 155	94 ± 10
	15 12,573,000 ± 1,547,133	1317 ± 166	97 ± 14
10	21 13,706,000 ± 497,073	1254 ± 135	85 ± 10

**EXAMPLE VIII**

hGH expression was monitored by quantitative hGH measurement with a sandwich radioimmunoassay (Allegro hGH Assay, Nichols Institute, Cat. No. 40-2205), using conditions recommended by the manufacturer.

In order to determine the rate of hGH production, culture medium was changed 24 hours prior to harvesting the cells for passaging. At the time of passage an aliquot of the culture medium was removed for hGH assay, and the cells were then harvested, counted, and reseeded. hGH levels are calculated after counting the harvested cells, and are expressed as μg hGH/24 hr/10<sup>6</sup> cells.

**EXAMPLE IX**

This example describes *in vivo* implantation of hybrid collagen matrices (HCM) prepared as described in Example I, as well as standard collagen matrices (CM) prepared as described in Example VI.

For subcutaneous implantation of matrices, mice (*M. musculus* strains N:NIH(S)-nu/nu (nude; Taconic Farms, Germantown, NY) were given an intraperitoneal injection of avertin (solution of 2% w/v 2,2,2-tribromoethanol and 2% v/v 2-methyl, 2-butanol) at a dose of 0.0175 ml/g body weight. Anesthetized mice were placed in lateral

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recumbency, and the skin prepped with alcohol and Betadine. A 0.5 cm to 1 cm transverse incision was made on the animal's left flank. The subcutaneous space was enlarged by sharp dissection to an area slightly larger 5 than the size of the matrix to be implanted. The matrix was placed horizontally in the subcutaneous space and spread evenly with the use of Millipore forceps. The incision was closed, using stainless steel surgical staples.

10 Blood was collected by retroorbital bleed after placing the mouse in a large beaker containing methoxyflurane (Pittman-Moore) until light anesthesia was achieved. Serum hGH levels were determined using the commercially available sandwich radioimmunoassay 15 described above. The assay was performed as described as recommended, except that control serum from untreated mice was used to obtain corrected cpm for generating the standard curve.

CM and HCM were prepared for implantation into 20 nude mice as described in Examples I and VI, using hGH-expressing HF165-24 cells. In the first experiment (Experiment 1, Tables 6 and 7), 13 matrices of each type were prepared. HCM were produced with an inoculum density (ID) of  $5 \times 10^6$  HF165-24 cells per matrix, and standard 25 collagen matrices (CM) were produced with an ID of  $2 \times 10^6$  HF165-24 per matrix. Fewer cells were used to inoculate the CM since these matrices do not support as high a cell density as HCM (see Examples V and VI). In subsequent experiments (Experiments 2 and 3, Tables 6 and 7) only 30 HCM matrices were tested (13 in each of Experiments 2 and 3). Matrices were kept in the original 60 mm dishes and fed with 5 ml of growth medium. After 13 days in culture, all of the dishes were fed with fresh growth medium; 24 h later triplicate matrices of each set were 35 digested for cell counts, and medium samples from all 13

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matrices in each set were assayed for hGH.

For Experiment 1, at the time of implantation the average number of cells in the CM was  $2.4 \times 10^6$  cells/matrix, while the average number of cells in 5 the HCM was  $7.4 \times 10^6$  cells/matrix (Table 6). The cell number per matrix was similar to the latter for the HCM prepared in Experiments 2 and 3 ( $8.9 \times 10^6$  and  $9.2 \times 10^6$  cells per HCM matrix, respectively). Table 6 summarizes the cell number ( $n = 3$ ), *in vitro* hGH production per matrix 10 ( $n = 13$ ), and specific production rate ( $\mu\text{g}/10^6 \text{ cells}/24 \text{ h}$ ;  $n=3$ ) for each set of *in vitro* experiments. Values are presented as mean  $\pm$  standard deviation. As shown in Table 6, HCM supported a higher density of cells and produced a higher level of hGH on the day of implantation 15 than did the CM.

TABLE 6: HF165-24 Cell Density and *In Vitro* hGH Production per Matrix for Collagen Matrices and Hybrid Collagen Matrices on Day of Implantation

20	Experiment #	Cell # on Day of Implantation	$\mu\text{g hGH}/24\text{h}/\text{matrix}$	$\mu\text{g hGH}/24\text{h}/10^6 \text{ cells}$
	1/CM	$2.4 \pm 0.1 \times 10^6$	$241 \pm 33$	$98 \pm 8$
	1/HCM	$7.4 \pm 1.6 \times 10^6$	$983 \pm 239$	$109 \pm 16$
	2/HCM	$8.9 \pm 1.5 \times 10^6$	$1399 \pm 177$	$170 \pm 27$
	3/HCM	$9.2 \pm 0.9 \times 10^6$	$1279 \pm 115$	$137 \pm 19$

25 Eight matrices of each type were implanted into nude mice in Experiment 1, while five HCM were implanted into nude mice in each of Experiments 2 and 3. Serum hGH levels were measured at regular intervals after

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implantation. The results are shown in Table 7 and Fig. 3. In Experiment 1, HCM-implanted animals maintained substantially higher serum hGH levels than did CM-implanted animals for 186 days post-implantation.

5 Animals implanted with HCM in Experiments 2 and 3 showed similarly high serum hGH levels.

**TABLE 7:** *In Vivo Delivery of hGH by Implanted Collagen Hybrid Matrices Containing Transfected Human Skin Fibroblasts*

		serum hGH values (ng/ml $\pm$ standard error)			
		Experiment 1		Experiment 2	
Experiment 3		Days After Implantation	CM n=8	HCM n=8	HCM n=5
10		7	2.4 $\pm$ 0.4	6.8 $\pm$ 0.6	13.2 $\pm$ 2.0
15					16.5 $\pm$ 2.1
		14			8.5 $\pm$ 1.3
					8.3 $\pm$ 2.0
20	15		1.0 $\pm$ 0.1	4.2 $\pm$ 0.4	
		21	0.8 $\pm$ 0.1	3.7 $\pm$ 0.4	5.0 $\pm$ 0.4
					5.8 $\pm$ 1.6
		28			7.1 $\pm$ 2.3
					3.6 $\pm$ 1.0
25		29	0.7 $\pm$ 0.1	4.8 $\pm$ 1.0	
		35	0.4 $\pm$ 0.1	3.0 $\pm$ 0.7	3.2 $\pm$ 0.3
					2.4 $\pm$ 0.6
30	42		0.6 $\pm$ 0.1	2.3 $\pm$ 0.3	2.9 $\pm$ 0.7
					2.3 $\pm$ 0.6

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55				2.0±0.3
56		0.4±0.1	2.7±0.5	1.6±0.3
5				
70		0.3±0.0	1.2±0.2	1.7±0.4
85		0.4±0.1	1.4±0.2	
10	123	0.5±0.1	1.2±0.3	
154		0.5±0.1	1.0±0.3	
186		0.6±0.1	1.0±0.5	
15				

EXAMPLE X

The hybrid matrices of the invention would be  
20 prepared for implantation in humans as follows:

The desired cells, typically stably transfected autologous cells derived from the patient, are harvested from tissue culture dishes and processed for the production of HCM or PCHCM by any of the methods  
25 described in Examples I-IV. The dosage for a given patient (i.e. the physiologically effective quantity of therapeutic product produced by the matrix) can be varied by using a larger or smaller matrix, implanting a different number of matrices into the patient, and/or  
30 using cells which express a different level of the product per cell when constructing the matrix. The quantity of the therapeutic product produced in the

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patient may also be varied by exposing the cells in the matrix to a pharmacologic or physiologic signal which alters expression of the therapeutic gene. For example, if the therapeutic gene is under the control of a 5 glucocorticoid-responsive promoter, then *in vivo* exposure of the cells to a drug such as dexamethasone (by administering the drug to the patient in a manner that ensures the drug reaches the implant) will alter expression of the therapeutic gene.

10        Typically, a plurality of small matrices (approximately 1-2 cm) in diameter, produced in 60 mm petri dishes and containing on the order of  $10 \times 10^6$  cells per matrix, would be implanted. Thus, approximately 100 million cells could be implanted using 15 10 small matrices. The use of matrices with significantly higher cell densities (as produced by incorporating, for example, ascorbic acid 2-phosphate) would result in a smaller number of matrices needed for a given patient. Alternatively, a larger petri dish (> 150 20 mm diameter) may be used as a mold to produce larger matrices which could be either implanted directly or cut into smaller pieces which are implanted.

      Prior to implantation, the matrices may be stored or shipped in growth medium or any other solution which 25 allows the cells to remain viable. Alternatively, the matrices may be cryopreserved by freezing in an appropriate freezing medium, which can be washed away prior to implantation.

      Matrices may be implanted in a variety of sites, 30 including, but not limited to, subcutaneous, intraperitoneal, intrasplenic, intraomental, inguinal, intrathecal, intraventricular, and intramuscular sites, as well as within lymph nodes or within adipose tissue. A surgical incision at the appropriate site is made, the 35 matrix inserted, and the incision closed.

EXAMPLE XI

There are a number of static and perfusion large scale *in vitro* culture systems that can be adapted for use in protein manufacture using cells maintained in hybrid matrices of the invention. The choices offer varying levels of facility in the necessary steps of feeding and medium harvest prior to purification of target proteins. Several are described below.

1. After formation and maturation of hybrid collagen matrices (HCM) in conventional petri plates (e.g. after 10-25 days incubation), a number of these HCM can be aseptically transferred to a sterile Microcarrier Spinner Flask (250-100 ml capacity). These HCM are produced and maintained under conditions which maximize the viable cell density within each matrix. Typically this requires between 5 and 20 ml medium for every one ml of matrix volume. The protein production medium is formulated to comprise a minimum of undefined components (e.g., serum), and may include added factors intended to maximize the output of protein production per cell. The spinner flasks are placed into a  $37^\circ \pm 1^\circ\text{C}$ ,  $5\% \pm 1\%$   $\text{CO}_2$  humidified incubator on a magnetic stir platform set for 30-70 rpm. After 1-3 days, the flask is transferred to a class 100 biological safety cabinet, and the production medium containing the expressed protein is aseptically drawn off without disturbing the settled matrices. An equivalent volume of fresh protein production medium is added to the flask, and the flask is returned to the stir platform within the incubator.

2. The matrices described in (1) above may be aseptically transferred into a 1-5L bioreactor (e.g., Brunswick) with a controllable stirring impeller shaft. Production medium level is set by the control system of the bioreactor. Medium harvesting and replenishment is controlled within a sterile closed loop system to

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minimize contamination.

3. For high volume HCM production, the matrices are formed from the constituent components and allowed to gel within a tissue culture roller bottle. The bottles 5 are incubated in a static upright position until contraction of the matrix results in a free-floating structure (3-5 days). Growth medium is then replenished, and the bottles are gassed with 5% CO<sub>2</sub> and placed into a roller apparatus within a 37°C incubator. Growth medium 10 is replenished every 2-3 days until HCM are mature (10-25 days total incubation), at which time the HCM are exposed to protein production medium. After 1-3 days, the bottles are transferred to a class 100 biological safety cabinet and the production medium containing the 15 expressed protein is aseptically drawn off without disturbing the matrices. An equivalent volume of fresh protein production medium is added to the bottle, which is returned to the roller apparatus.

4. The constituents of the HCM can be 20 aseptically introduced into sterile gas-permeable Teflon™ bags through a sealable port. The components are allowed to gel within the bag and take on the shape and conformation therein. Bags are incubated in 37° ± 1°C, 5% ± 1% CO<sub>2</sub> humidified incubators. As the HCM contract 25 and reduce in volume, the growth medium volume is adjusted to compensate. Medium harvesting and replenishment is accomplished through sterile-connect tube systems built into the bags. The use of ported incubators and extended tubing would allow for the design 30 of a cyclic harvest/feed pumping system that could eliminate the need for removing the bags from incubators during a production run.

5. The constituents of the HCM can be 35 aseptically introduced into custom-designed thermoformed trays with a high volume capacity. The simplest

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conformation would be an open lidded rectangular tray with gas exchange capabilities designed for use in a CO<sub>2</sub> tissue culture incubator. Another design would include a closed loop system with ported access to the medium 5 reservoir for controlled feeding and medium harvest, akin to a bioreactor chamber.

Other Embodiments

The hybrid matrices of the invention are appropriate for delivery of a wide range of cellular 10 products, including not only hGH, but also Factor VIII, Factor IX, erythropoietin (EPO), albumin, hemoglobin, alpha-1 antitrypsin, calcitonin, glucocerebrosidase, low density lipoprotein (LDL) receptor, IL-2 receptor, globin, immunoglobulin, catalytic antibodies, the 15 interleukins, insulin, insulin-like growth factor 1 (IGF-1), parathyroid hormone (PTH), leptin, the interferons, the nerve growth factors, basic fibroblast growth factor (bFGF), acidic FGF (aFGF), epidermal growth factor (EGF), endothelial cell growth factor, platelet derived growth 20 factor (PDGF), transforming growth factors, endothelial cell stimulating angiogenesis factor (ESAF), angiogenin, tissue plasminogen activator (t-PA), granulocyte colony stimulating factor (G-CSF), and granulocyte-macrophage colony stimulating factor (GM-CSF). For example, the 25 cells embedded in the matrix can be pancreatic beta cells which naturally secrete insulin in response to a rise in blood glucose, and which therefore can supplement an inadequate insulin response in a diabetic or pre-diabetic patient. Alternatively, they can be any type of cell 30 genetically engineered to express and secrete high levels of a needed polypeptide, such as a clotting factor, within the patient. Such a construct may be under the control of a constitutively activated promoter, or of an appropriately physiologically or pharmacologically

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regulated promoter.

The collagen gel portion of the matrix can consist entirely of insoluble collagen fibrils, or can contain other components in addition to collagen: e.g., agarose; 5 alginate; a glycosaminoglycan such as hyaluronic acid, heparin sulfate, dermatan sulfate, or chondroitin sulfate; a sulfated proteoglycan; fibronectin; laminin; elastin; fibrin; or tenascin. Such components (particularly those which are found in the extracellular 10 matrix of animal tissues) contribute to the structural stability of the hybrid matrices of the invention, and/or provide additional attachment capacity for the cells in the matrices and the host tissue at the site of implantation. They would be incorporated into the 15 matrices by mixing with the collagen solution prior to gelling.

Other potential additives include cytokines and/or growth factors which are useful for optimizing maintenance of the cells or promoting beneficial 20 interaction with host tissue (e.g., vascularization), including bFGF, aFGF, endothelial cell growth factor, PDGF, endothelial cell stimulating angiogenesis factor (ESAF), leukotriene C<sub>4</sub>, prostaglandins (e.g., PGE<sub>1</sub>, PGE<sub>2</sub>), IGF-1, GCSF, angiogenin, TGF- $\alpha$ , TGF- $\beta$ , ascorbic 25 acid, EGF, and oncostatin M. These additives can be incorporated into the matrix by mixing them with the collagen solution prior to gelling, by introducing them into the interstices of the microspheres, or by including them in the medium which bathes the matrices. 30 Alternatively, the cells may be genetically engineered to express the desired product. For example, the cells of the matrix may be cotransfected with a DNA encoding an angiogenesis factor and a DNA encoding a second, therapeutic protein, or with a single vector encoding 35 both types of proteins linked to suitable expression

control sequences.

The collagen used in the gel may be any suitable type (e.g., type I-XI), or a mixture of any two or more. Fibers may be placed in the mold prior to gelling of the 5 collagen, so that they become an integral part of the matrix and contribute to the sturdiness and handling convenience of the matrix. Typically, the fibers would be made principally of collagen (e.g., cat gut) or a non-collagenous material such as nylon, dacron, 10 polytetrafluoroethylene (Gore-Tex™ or Teflon™), polyglycolic acid, polylactic/polyglycolic acid mixture (Vicryl™), polystyrene, polyvinylchloride co-polymer, cellulose (e.g., cotton or linen), polyester, rayon, or silk. The fibers may be woven into a mesh or cloth, or 15 used as individual threads.

Instead of the type I collagen microspheres described in the above examples, one could utilize microspheres consisting primarily of another type of collagen, polystyrene, dextran (e.g., Cytodex™, 20 Pharmacia), polyacrylamide, cellulose, calcium alginate, latex, polysulfone, glass (coated with a substance such as collagen which promotes cellular adherence), or combinations of collagen with any of the above. Such 25 microspheres are available commercially or can be made by standard methods, then sterilized for use in the hybrid matrices of the invention.

Other embodiments are within the following claims.

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What is claimed is:

1. An article comprising a body of matrix material comprising insoluble collagen fibrils and disposed therewithin
  - 5 (a) a plurality of vertebrate cells; and
  - (b) a plurality of microspheres each of which consists primarily of one or more substances selected from the list consisting of collagen, polystyrene, dextran, polyacrylamide, cellulose, calcium alginate, 10 latex, polysulfone, and glass.
2. The article of claim 1, wherein the cells are selected from the group consisting of adipocytes, astrocytes, cardiac muscle cells, chondrocytes, endothelial cells, epithelial cells, fibroblasts, 15 gangliocytes, glandular cells, glial cells, hematopoietic cells, hepatocytes, keratinocytes, myoblasts, neural cells, osteoblasts, pancreatic beta cells, renal cells, smooth muscle cells, striated muscle cells, and precursors thereof.
- 20 3. The article of claim 1, wherein the cells are human cells.
4. The article of claim 1, wherein the cells are transfected cells containing exogenous DNA encoding a medically useful polypeptide.
- 25 5. The article of claim 1, wherein the cells are transfected cells containing exogenous DNA which includes a regulatory sequence that activates expression of an endogenous gene encoding a medically useful polypeptide.
6. The article of claim 4, wherein the

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polypeptide is selected from the group consisting of enzymes, hormones, cytokines, colony stimulating factors, vaccine antigens, antibodies, clotting factors, regulatory proteins, transcription factors, receptors, 5 and structural proteins.

7. The article of claim 4, wherein the polypeptide is an angiogenesis factor.

8. The article of claim 4 wherein the polypeptide is selected from the group consisting of human growth 10 hormone, Factor VIII, Factor IX, erythropoietin, and insulin.

9. The article of claim 5 wherein the polypeptide is selected from the group consisting of human growth hormone, Factor VIII, Factor IX, erythropoietin, and 15 insulin.

10. The article of claim 4, wherein the polypeptide is selected from the group consisting of alpha-1 antitrypsin, calcitonin, glucocerebrosidase, low density lipoprotein (LDL) receptor, IL-2 receptor, 20 globin, immunoglobulin, catalytic antibodies, the interleukins, insulin-like growth factor 1 (IGF-1), parathyroid hormone (PTH), leptin, the interferons, the nerve growth factors, basic fibroblast growth factor (bFGF), acidic FGF (aFGF), epidermal growth factor (EGF), 25 endothelial cell growth factor, platelet derived growth factor (PDGF), transforming growth factors, endothelial cell stimulating angiogenesis factor (ESAF), angiogenin, tissue plasminogen activator (t-PA), granulocyte colony stimulating factor (G-CSF), and granulocyte-macrophage 30 colony stimulating factor (GM-CSF).

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11. The article of claim 1, wherein the microspheres are collagen type I beads.

12. The article of claim 1, wherein the majority of the microspheres have a diameter between approximately 5 0.1 and approximately 2 mm.

13. The article of claim 1, wherein the collagen in the matrix material is type I.

14. The article of claim 13, wherein the matrix material additionally comprises a substance selected from 10 the group consisting of a second type of collagen, agarose, alginate, fibronectin, laminin, hyaluronic acid, heparan sulfate, dermatan sulfate, sulfated proteoglycans, fibrin, elastin, and tenascin.

15. The article of claim 1, wherein non-collagen 15 fibers are disposed within the body.

16. The article of claim 15, wherein the fibers comprise a material selected from a group consisting of nylon, dacron, polytetrafluoroethylene, polyglycolic acid, polylactic/polyglycolic acid mixture, polystyrene, 20 polyvinylchloride co-polymer, collagen, cat gut, cotton, linen, polyester, and silk.

17. The article of claim 1, wherein the article is disposed within a mammal.

18. The article of claim 1, configured to be 25 implanted into a patient.

19. The article of claim 18, wherein the cells are derived from one or more cells removed from the

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patient.

20. The article of claim 18, wherein the cells consist of a clonal population.

21. The article of claim 18, wherein the cells 5 are transfected cells containing exogenous DNA encoding a medically useful polypeptide.

22. The article of claim 18, wherein the cells are transfected cells containing exogenous DNA which includes a regulatory sequence that activates expression 10 of an endogenous gene encoding a medically useful polypeptide.

23. The article of claim 11, wherein the cells are transfected human cells and the collagen in the matrix material is type I.

15 24. A method of making the article of claim 1, comprising

forming a mixture comprising (a) a plurality of vertebrate cells; (b) a plurality of microspheres, each of which consists primarily of one or more 20 substances selected from the list consisting of collagen, polystyrene, dextran, polyacrylamide, cellulose, calcium alginate, latex, polysulfone, and glass; and (c) a solution comprising soluble collagen;

causing the soluble collagen in the mixture 25 to form a gel containing the cells and the microspheres; and

exposing the gel to culture conditions which cause the gel to contract, thereby forming the body of the article.

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25. The method of claim 24, wherein the microspheres are porous collagen beads.

26. The method of claim 24, wherein the solution additionally comprises a substance selected from the 5 group consisting of a second type of collagen, agarose, alginate, fibronectin, laminin, hyaluronic acid, heparan sulfate, dermatan sulfate, sulfated proteoglycans, fibrin, elastin, and tenascin.

27. The method of claim 24, wherein the solution 10 is an acidic aqueous solution of soluble collagen, and gelation is accomplished by raising the pH of the solution.

28. The method of claim 24, wherein the gelation step takes place in a mold, so that, prior to the 15 contracting step, the gel is in the shape of the mold.

29. The method of claim 24, wherein the cells and the microspheres are cultured together prior to being mixed with the solution.

30. A method of administering a medically useful 20 polypeptide to a patient in need thereof, comprising providing the article of claim 18, wherein the cells secrete the polypeptide; and implanting the article in the patient.

31. The method of claim 30, wherein the cells are 25 derived from one or more cells removed from the patient, and have been transfected in vitro with exogenous DNA encoding the polypeptide.

32. The method of claim 30, wherein the

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implanting is carried out at a subcutaneous site in the patient.

33. The method of claim 30, wherein the implanting is carried out at an intraperitoneal, sub-  
5 renal capsular, inguinal, intramuscular, intraventricular, or intrathecal site in the patient.

34. The method of claim 30, wherein the polypeptide is one which promotes wound healing, and the implanting is carried out at the site of a preexisting  
10 wound of the patient.

35. A method of administering a medically useful polypeptide to a patient in need thereof, comprising providing an extra corporeal apparatus comprising  
15 (a) the article of claim 1, wherein the cells secrete the polypeptide; and (b) a means for shunting blood from a blood vessel of the patient to the article and then back into a blood vessel of the patient; and  
shunting a portion of the patient's blood through the apparatus and back into the patient's bloodstream, so  
20 that the polypeptide mixes with the blood.

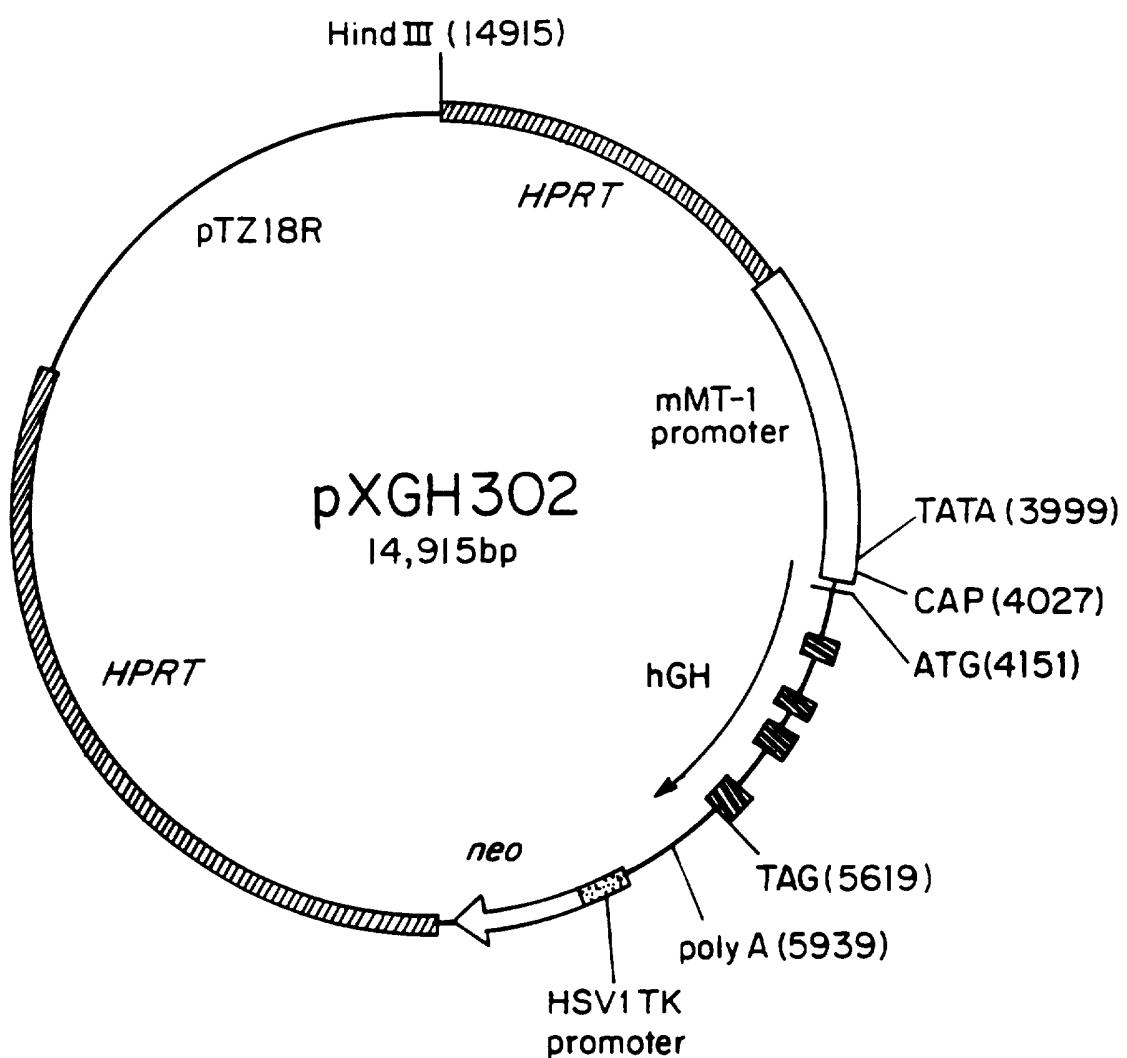
36. A method of producing a polypeptide, comprising providing the article of claim 1 under conditions whereby the cells express and secrete the polypeptide;  
25 contacting the article with a liquid such that the cells secrete the polypeptide into the liquid; and obtaining the polypeptide from the liquid.

37. A method of preserving cells, comprising providing the article of claim 1, and storing the article  
30 at a temperature below 0°C.

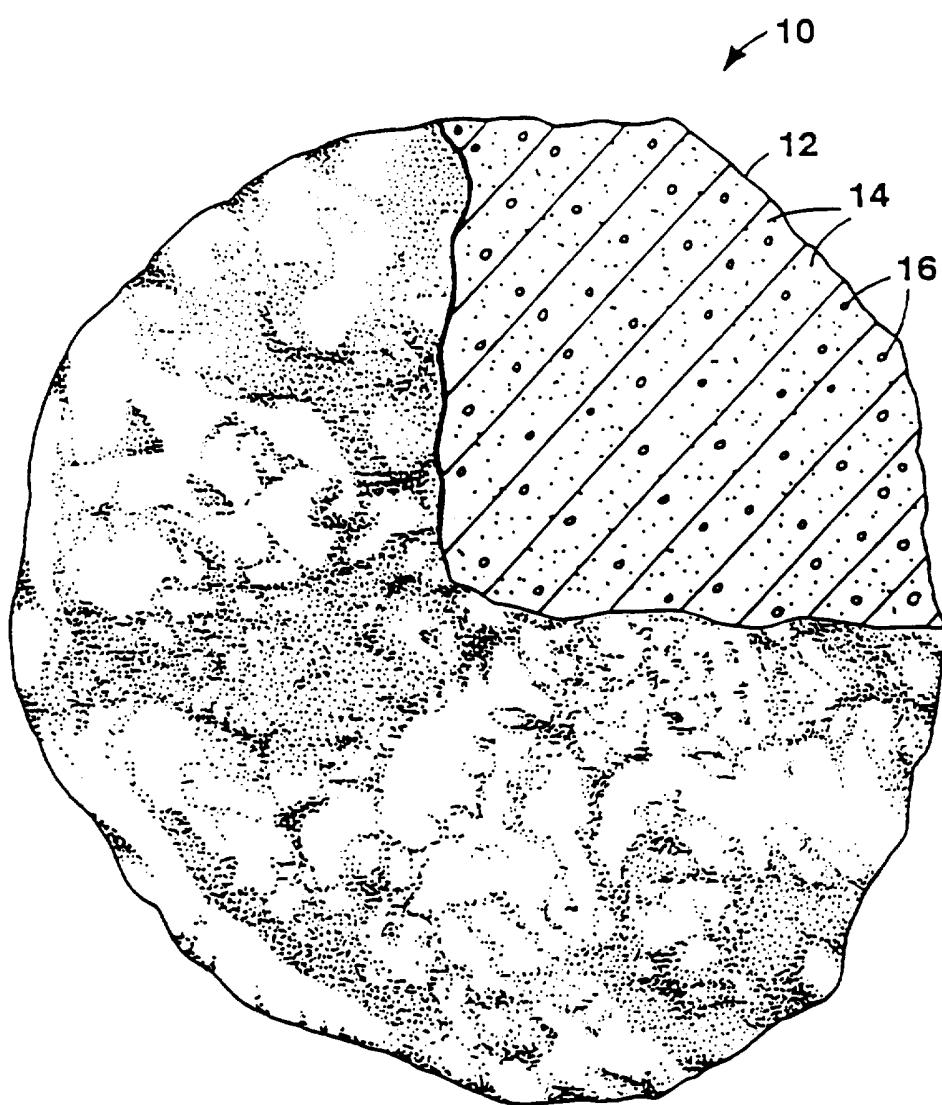
- 44 -

38. An extracorporeal apparatus comprising  
the article of claim 1; and  
a means for shunting blood from an animal to the  
article and then back into a blood vessel of the animal.

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**FIG. 1**

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**FIG. 2**

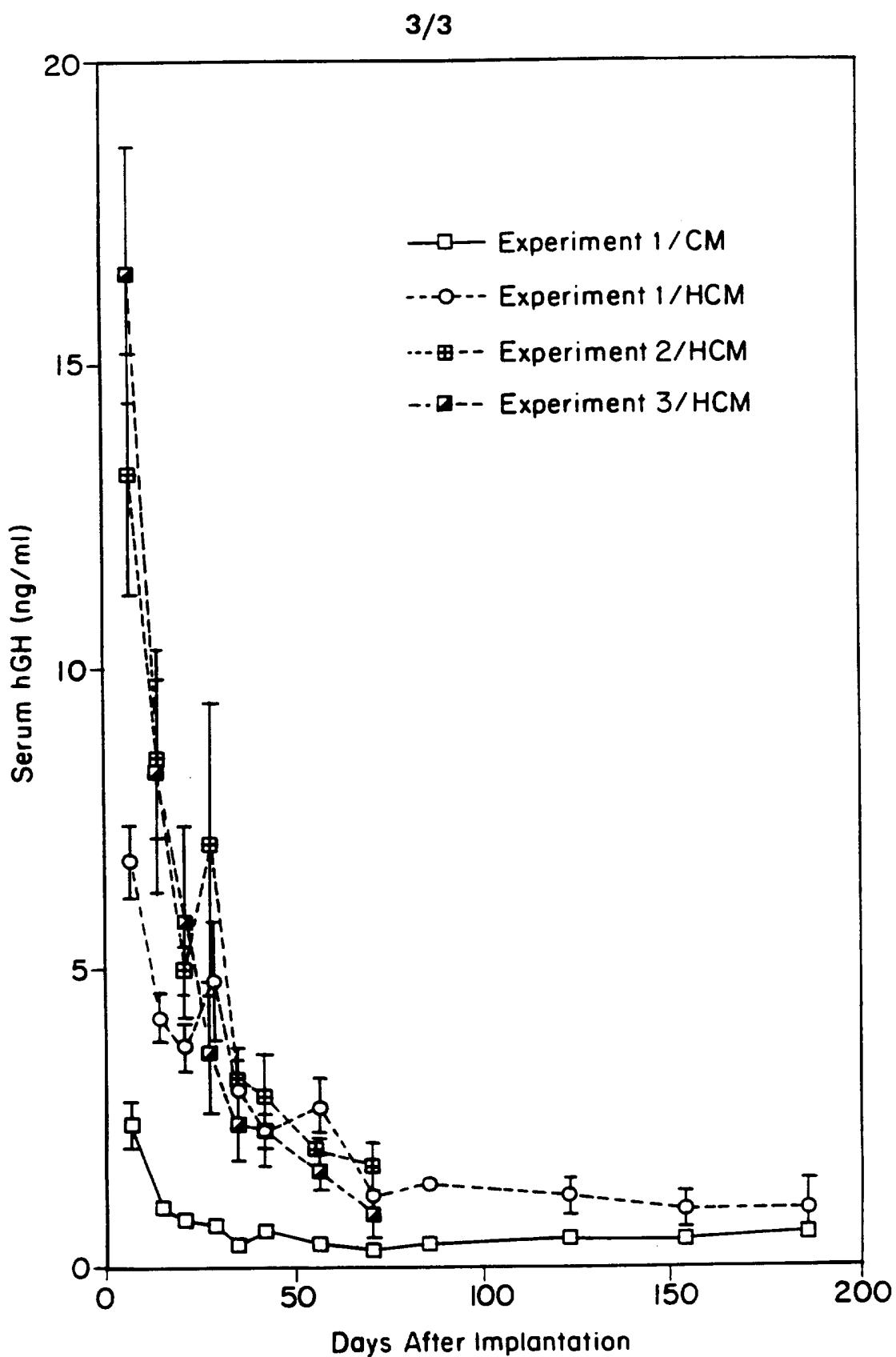


FIG. 3

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US96/17114

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :Please See Extra Sheet.

US CL :Please See Extra Sheet.

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)

U.S. : Please See Extra Sheet.

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)

Please See Extra Sheet.

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 94/24298 A1 (INSTITUT PASTEUR) 27 October 1994, see entire document.	1-38
Y	US 4,485,096 A (E. BELL) 27 November 1984.	1-38
Y	WO 94/10950 A1 (BROWN UNIVERSITY RESEARCH FOUNDATION) 26 May 1994, see entire document.	1-38
Y	US 4,861,714 A (DEAN, JR., ET AL.) 29 August 1989, see entire document.	1-38
Y	WO 93/09222 A1 (TRANSKARYOTIC THERAPIES) 13 May 1993, see entire document.	1-38

<input checked="" type="checkbox"/>	Further documents are listed in the continuation of Box C.	<input type="checkbox"/>	See patent family annex.
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• Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier document published on or after the international filing date	"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
"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 reasons (as specified)	"&"	document member of the same patent family
"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		

Date of the actual completion of the international search	Date of mailing of the international search report
18 NOVEMBER 1996	29 NOV 1996

Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer CHRISTOPHER S. F. LOW Telephone No. (703) 308-0196	
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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US96/17114

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	SULLIVAN et al. Biohybird Artificial Pancreas: Long-Term Implantation Studies in Diabetic, Pancreatectomized Dogs. Science. 03 May 1991, Vol. 252. pages 718-721, see entire reference.	1-38

**INTERNATIONAL SEARCH REPORT**

International application No.

PCT/US96/17114

**A. CLASSIFICATION OF SUBJECT MATTER:**

IPC (6):

**A01N 63/00, 65/00; A61K 48/00; A61F 13/00; C12N 5/16, 15/16, 15/85; B01D 63/00****A. CLASSIFICATION OF SUBJECT MATTER:**

US CL :

**424/93.1, 93.2, 93.21, 422, 423; 435/240.2, 172.3, 320.1; 210/321.71****B. FIELDS SEARCHED**

Minimum documentation searched

Classification System: U.S.

**424/93.1, 93.2, 93.21, 422, 423; 435/240.2, 240.23, 240.22, 172.3, 320.1, 269; 604/403; 210/321.71****B. FIELDS SEARCHED**

Electronic data bases consulted (Name of data base and where practicable terms used):

Automated Patent System - USPAT, JPOABS, EPOABS

DIALOG - files 654, 5, 73, 155, 357, 434, 159, 76, 399,

Search terms: transform transfet cell encapsulate encase skin microsphere vertebrate