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(57) **Abrégé/Abstract:**

Compositions and methods are described for treating hyperplasia of vascular smooth muscle cells and restenosis of blood vessels or accelerated arteriopathy following vascular injury or disease. Endothelial cells are cultured in a biocompatible polymeric matrix which is then implanted or wrapped around the exterior of a blood vessel. The engrafted matrix-associated endothelial cells inhibit progression or promote regression of intimal hyperplasia or smooth muscle cell proliferation in the vicinity of the blood vessel's inner surface and decreases the incidence of restenosis often associated with vascular hyperplasia.

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(54) Title: INHIBITION OF VASCULAR OCCLUSION FOLLOWING VASCULAR INTERVENTION (57) Abstract Compositions and methods are described for treating hyperplasia of vascular smooth muscle cells and restenosis of blood vessels or accelerated arteriopathy following vascular injury or disease. Endothelial cells are cultured in a biocompatible polymeric matrix which is then implanted or wrapped around the exterior of a blood vessel. The engrafted matrix-associated endothelial cells inhibit progression or promote regression of intimal hyperplasia or smooth muscle cell proliferation in the vicinity of the blood vessel's inner surface and decreases the incidence of restenosis often associated with vascular hyperplasia.		

reestablishing blood flow. However, angioplasty treatment can injure the vessel, especially when the balloon is overinflated or the mesh overextended, causing a variety of undesirable results, such as denudation (removal) of the endothelial cell layer in the region of the angioplasty, dissection of part of the inner vessel wall from the remainder of the vessel with accompanying occlusion of the vessel, or rupture of the *tunica intima* layer of the vessel.

Though the hallmark of the rapidly accelerating lesions following angioplasty, vascular bypass grafting, and organ transplantation is the proliferation of smooth muscle cells and their accumulation within the *tunica intima*, it is the loss of normal endothelial function that heralds these events and may stimulate them to occur. The arterial endothelium serves as a transport barrier, a biochemical filter and as a regulator of many vascular phenomena. The most potent vasodilators, thromboresistant compounds and inhibitors of smooth muscle cell proliferation, are endothelial derived. Vascular smooth muscle cell accumulation within the intima ceases with restoration of the endothelium (Schwartz et al., *Am. J. Pathol.*, 81: 15-42 (1975); Fishman et al., *Lab. Invest.*, 32: 339-51 (1975)) and regression of intimal hyperplasia is maximized where endothelial restoration is maximized (Bjornsson et al., *Proc. Natl. Acad. Sci. USA*, 88: 8651-8655 (1991)). Confluent, and not exponentially growing, endothelial cells produce a series of compounds that are the most potent vasodilators, inhibitors of spasm, and inhibitors of smooth muscle cell proliferation. Heparan sulfate proteoglycan produced by the endothelial cells has multitudinous effects on the smooth muscle cells including interfering with binding of heparin-binding growth factors (Nugent et al., *Circulation Research*, 73: 1051-1060 (1993), which are known to stimulate vascular smooth muscle cell growth (Nugent et al., *Circulation Research*, 73: 1051-1060 (1993); Castellot et al., *J. Cell Biol.*, 90: 372-9 (1991)). It appears, therefore, that restoring the endothelial monolayer of a blood vessel restores the agents or compounds responsible for biochemical control of vascular cell proliferation.

Other efforts at limiting the undesirable proliferative and disease states of vascular endothelium have focused on the isolated administration of analogs of endothelial compounds. Certain drugs, such as heparin, are especially effective inhibitors of vascular smooth muscle cell proliferation in tissue culture and animal models of arterial diseases precisely because they mimic the activity of natural endothelial-derived compounds like heparan sulfate proteoglycan, Edelman, E.R. & Karnovsky, M.J. *Circ.* 89: 770-776 (1994). However, despite cell culture and small animal data supporting the regulatory role of heparin-like compounds, exogenous heparin preparations have shown no benefit in human trials. For example, when patients were randomized to heparin or dextrose infusion over the first 18 to 24 hours post angioplasty, 41.2% of the heparinized patients and only 36.7% of the dextrose infusion patients had evidence for restenosis (Ellis et al., *Am. Heart. J.*, 117: 777-782 (1989)). Moreover, bleeding complications were twice as frequent in the heparinized group. In another trial, angioplasty patients injected subcutaneously with heparin at 10,000 IU/day had 2.5 fold more restenosis and significantly more ischemic complications than patients treated in the standard fashion (Lehmann et al., *J. Am. Coll. Cardiol.*, 17: 181A (abstract) (1991)).

Non-heparin endothelial compounds such as nitric oxide and the prostaglandins are potent regulators of a range of biologic effects involving smooth muscle cells. Inhibitors of these compounds have been shown to control intimal hyperplasia following experimental vascular injury (Cooke et al., *Curr. Opin. Cardiol.*, 7: 799-804 (1992); Moncada et al., *N. Engl. J. Med.*, 329: 2002-2012 (1993); McNamara, et al., *Biochem. Biophys. Res. Comm.*, 193: 291-296 (1993)). This is indicative that the vascular endothelium is a powerful regulator of the blood vessel wall, not because of the production and secretion of one compound alone, but because of its presence as an intact unit. While concerns have been raised as to the difference in protocols allowing for benefit in animals and worsening of disease in man (Edelman et al., *Circulation*, 89: 770-776 (1994)), it appears likely that a single endothelial product, such as

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heparin, is incapable of replacing the entire endothelium in the control of complex human vascular lesions.

Accordingly, there is a need for means and methods of promoting healing of vascular tissue and controlling vascular muscle cell proliferation (hyperplasia) to prevent restenosis of blood vessels after angioplasty, vascular bypass, organ transplantation, or vascular disease without the risk of rapid reocclusion.

It is therefore an object of the present invention to provide a means of preventing occlusion following vascular intervention.

It is a further object of the present invention to provide methods for understanding and controlling the mechanisms of restenosis and vascular occlusion.

Summary of the Invention

Compositions and methods for inhibiting excessive intimal growth (hyperplasia) and/or vascular smooth muscle cell proliferation (hyperplasia) following intravascular intervention or injury are disclosed. In the preferred embodiment, endothelial cells are present in or on a biocompatible, biodegradable or non-biodegradable matrix, which allows the cells to reside and secrete products into the surrounding tissue or into the matrix, from which they can diffuse into the surrounding tissue. The endothelial cell-matrix composition is juxtaposed with the target blood vessel, which might be injured, for example, from angioplasty, surgery, transplantation or atherosclerosis, to inhibit subsequent restenosis or occlusion of the blood vessel.

More specifically, one aspect of the invention involves the use of a composition for inhibiting mechanisms involving restenosis of a blood vessel following injury to vascular tissue in a region of the blood vessel of a patient in need of treatment thereof. The composition includes a biocompatible matrix having seeded therein or thereon dissociated endothelial cells implantable at a site exterior to and adjacent to or at the injury to or blockage of vascular tissue. The endothelial cells are provided in an amount effective to inhibit smooth muscle cell proliferation at the site of the injury or blockage.

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The matrix may be formed of a material selected from the group consisting of polyhydroxy acids, polyorthoesters, polyanhydrides, proteins, carbohydrates or polysaccharides, polyphosphazenes, polyalkylene oxides and combinations thereof.

Alternatively, the matrix may be formed of a material selected from the group consisting of ethylene vinyl acetate, polyvinyl alcohol, silicone, polyurethane, non-biodegradable polyesters, polyethyleneoxide-polypropyleneoxide and combinations thereof.

The matrix may further comprise biologically active compounds selected from the group consisting of anti-inflammatory agents, prostaglandin, prostanoids, compounds regulating the renin-angiotensin axis, tyrosine kinase inhibitors, immunosuppressants, vitamins, glucocorticoids, anti-oxidants, free radical scavengers, peptide hormones, angiogenic and angiogenic inhibitory factors, and combinations thereof.

Brief Description of the Drawings

Figure 1 is a graph of the growth (measured as cell number) of bovine aortic endothelial (BAE) cells (open circles) and Chinese Hamster Ovary 745 cells (controls which do not produce regulators of smooth muscle cell proliferation) (dark circles) on Gelfoam™ (The Upjohn Co., Kalamazoo, MI) collagen matrix over time (days).

Figure 2 is a graph of inhibition (% control) of binding (dark circles) and mitogenesis (dark squares) of the potent vascular cell growth promoter bFGF for vascular smooth muscle cells by endothelial cell-Gelfoam® conditioned media, compared with inhibition of bFGF binding (open circles) and mitogenesis (hatched squares) for vascular smooth muscle cells by CHO-745 cell-Gelfoam® conditioned media.

Figure 3 is a graph of the ratio of the area of the *tunica intima* to the area of the *tunica media* after balloon denudation of the endothelium (BI) when the balloon injured arteries were exposed to Gelfoam® alone (Gel), Gelfoam® engrafted with CHO-745 cells (CHO), Gelfoam® containing heparin (Hep), and Gelfoam® containing endothelial cells (EC).

Figure 4 is a graph showing cell proliferation within both the *tunicae intima* and *media*, when exposed to either Gelfoam® engrafted with endothelial cells (EC), Gelfoam® with heparin (Hep), Gelfoam® engrafted with CHO-745 cells (CHO), Gelfoam® control or untreated following balloon angioplasty (BI), comparing the % proliferating cells for the *tunica intima* (open bar) and *tunica media* (dark bar).

Detailed Description of the Invention

The compositions described herein for inhibition of intimal hyperplasia consist of a matrix, most preferably a hydrogel, seeded with endothelial cells which can be xenografts, allografts or autografts, which is implanted at a site near to or at the region of hyperplasia at the time of vascular intervention or upon diagnosis of restenosis or other occlusion of a blood vessel.

Compositions to Inhibit Intimal Hyperplasia

The compositions described herein are used to inhibit undesired response to vascular injury that includes hyperplasia of smooth muscle vascular cells which occurs in response to injury to the endothelial tissue of blood vessels, for example, as a result of angioplasty, coronary artery bypass used to open a stenotic or occluded vessel. Vascular smooth muscle cell hyperplasia triggered by the injured endothelium can result in

restenosis of the blood vessel due to the excessive proliferation of vascular smooth muscle cells.

Cells

Endothelial cells are isolated by standard methods, for example, as described by Gimbrone, M. Culture of vascular endothelium. *Progress Hemostasis and Thrombosis* 3:1-28 (1976). Cells can be obtained at the time of the procedure using standard biopsy techniques, whether the procedure is angioplasty, open field surgery or for diagnostic purposes. The cells can be dissociated with collagenase or trypsin and seeded directly into a matrix as described below for immediate implantation, or cultured *in vitro* as required to generate the number of cells to be implanted. The cells are typically seeded into or onto the matrix at a density of between approximately 10^3 and 10^{12} cells/cm³. Cell densities can be determined using visual methods or a Coulter counter. The effective amount of cells and matrix to be administered is that which prevents or inhibits hyperplasia at the site of vascular injury.

Other cells which are genetically engineered, using oligonucleotides resulting in ribozyme-mediated cleavage of targeted genes or regulatory elements, or antisense to block transcription of targeted genes, or sequences encoding defective, missing or insufficient genes, can also be used. For example, cells transfected with genes for synthesis of heparan sulfate, regulators of heparan sulfate, nitric oxide synthase, growth factors, cytokines and other vasoregulatory products could be seeded into the matrix and implanted. Genes can be transfected into the cells using standard methodology such as viral vectors, microinjection and calcium phosphate precipitation.

Other materials can also be administered via the matrix, including anti-inflammatory agents, prostaglandins, prostanoids, angiotensin and related compounds, tyrosine kinase inhibitors, immunosuppressants, vitamins, glucocorticoids, anti-oxidants, free radical scavengers, peptide hormones, angiogenic and angiogenic inhibitory factors.

The Matrix

The endothelial cells are seeded onto or into a biocompatible matrix which is suitable for implanting in contact adjacent to or at the site of the vascular injury, for example, by wrapping around the blood vessel.

5 The matrix can be in the form of a gel, foam, suspension, microcapsules, solid polymeric support, or fibrous structure. The matrix may also serve in a physically supporting role. There is no specific requirement as to thickness, size or shape. When the cells are seeded within the matrix, it is preferred that the matrix be sufficiently porous to allow free diffusion
10 of nutrients and gases into the matrix to maintain cell viability, while allowing the secretory products of the cells to diffuse out of the matrix into the surrounding tissue in roughly physiologically quantities. The matrix may also serve to protect non-autologous cells from immune attack.

15 Preferably, the matrix is a biodegradable material, such as a synthetic polymer degrading by hydrolysis, for example, polyhydroxy acids like polylactic acid, polyglycolic acid and copolymers thereof, polyorthoesters, polyanhydrides, proteins such as gelatin and collagen, or carbohydrates or polysaccharides such as cellulose and derivatized
20 celluloses, chitosan, alginate, or combinations thereof, so that over the course of several days or weeks after implantation of the matrix material, the matrix gradually disappears. In a preferred embodiment, the matrix is a hydrogel, defined as a matrix wherein typically approximately 90% by weight of the matrix is absorbed water. Hydrogels can be formed by
25 ionic or covalent crosslinking of a variety of water soluble polymers such as polyphosphazenes, polysaccharides such as alginate, and proteins such as gelatin. As demonstrated in the following examples, a presently preferred matrix material is purified gelatin-based Gelfoam™ (The Upjohn Co., Kalamazoo, MI) surgical sponge.

30 The use of biodegradable matrices eliminates the need for surgery to remove undegraded implanted matrix, after regression of the hyperplasia and healing of the endothelial injury. However, synthetic

non-biodegradable matrices may also be used. Useful materials include ethylene vinyl acetate, polyvinyl alcohol, silicone, polyurethane, non-biodegradable polyesters, and polyethyleneoxide-polypropyleneoxide, and tetrafluoroethylene meshes (Teflon®).

5 Attachment of the cells to the matrix can be enhanced by coating or chemically modifying, attaching or derivatizing the polymer with a material such as collagen, laminin, fibronectin, fibrin, basement membrane components, and attachment peptides (RGD and many others are known and described in the literature).

10 Culturing of Cells in Matrix

The matrix material seeded with endothelial cells can be cultured *in vitro* to promote cell growth throughout the matrix. At various times during incubation of the seeded matrix in the culture medium, samples of seeded matrix can be removed and examined, for example, by cell
15 staining and microscopic observation, to determine the extent of cell growth and proliferation in the matrix, as well as production of total sulfated glycosaminoglycans and, specifically, heparan sulfate.

When the cells have reached the desired cell density in the matrix or have confluent grown over most of the interstices of the cultured
20 matrix, the matrix is removed from the culture medium and either used in the procedures to treat vascular smooth muscle cell hyperplasia described below, or stored for subsequent implantation.

Alternatively, the matrix is seeded with the cells immediately prior to implantation of the matrix.

25 Methods of Treating Intimal Hyperplasia

Patients can be diagnosed for vascular endothelial cell injury using known methods, such as X-ray fluoroscopic examination of dye flowing through a particular region of a blood vessel or other visual techniques, the presence of symptoms such as pain, based on clinical judgment, or
30 signs evidenced physical examination. Alternatively, it can be assumed that injury will arise due to performance of procedures such as angioplasty, arterial bypass graft, peripheral bypass surgery, or organ

transplantation and the patient treated based on the assumption that injury or disease will inevitably arise.

In a preferred embodiment, endothelial cell-matrix strips are applied to the site of injury during open field surgery. In this
5 embodiment, the strips of cultured matrix are applied to the exterior of the injured blood vessel over the internal site of injury, usually by wrapping the matrix strips around the vessel. After implantation, the cells remain viable and produce factors such as sulfated
glycosaminoglycan, including heparan sulfate.

10 If intimal hyperplasia had been observed prior to implanting or wrapping the strips of matrices, the regression of hyperplasia is typically evidenced by a decrease in pain or other symptoms of decreased blood flow, or through the use of imaging techniques. The decrease in hyperplasia or increase in flow rate through the injured vessel can be
15 monitored by the same methods used to initially diagnose the injury to the vascular endothelium or blockage of the blood vessel.

The following non-limiting examples illustrate some of the various aspects of compositions and methods used to treat vascular smooth muscle cell hyperplasia and restenosis of blood vessels.

20 **Example 1: Cell Engraftment and Characterization of Cells Cultured in the Seeded Matrix.**

Bovine aortic endothelial (BAE) and mutant Chinese hamster ovary (CHO-745) cells were cultured on GelfoamTM matrices. The mutant cells, obtained from Dr. J. Esko (University of Alabama, Birmingham, AB),
25 served as control cells as they produce no demonstrable heparan sulfate (Esko 1992¹) and, as a result, unlike endothelial cells, do not inhibit bFGF binding to or mitogenesis of cultured vascular smooth muscle cells (Nugent, et al., 1993²). GelfoamTM has long been used as an implantable surgical sponge and more recently as a scaffolding for cell growth
30 (Centra, et al., 1992³). This material, isolated from porcine dermal gelatin, was supplied in blocks (UpJohn Inc.), cut into 2.5 x 1 x 0.3 cm³ pieces and hydrated by autoclaving for 10 min in Hanks balanced salt solution (HBSS). Upon cooling, the blocks were placed in 17 x 100 mm

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polypropylene tubes to which 2 mL of cell suspension (0.6×10^5 cells/mL) was added. The endothelial cells were suspended in Dulbecco's modified Eagle's medium (DMEM) and the CHO-745 cells were suspended in Ham's F-12 medium. Media was supplemented with 1 g/L glucose and 10% calf serum.

Culture tubes were gently agitated to disperse the cells and then incubated at a 45° angle, 37°C , humidified, 5% CO_2 and 95% air, for up to 15 days. Growth medium was changed on days 3, 7 and 12. On days 0, 2, 4, 7, 10 and 15, the number of cells in the media (non-adherent cells) and those attached to the GelfoamTM were determined using a hemocytometer. Prior to counting the attached cells, the GelfoamTM blocks were washed four times with HBSS to remove non-attached cells and serum. Collagenase (1 mg/mL) was used to digest the GelfoamTM, releasing all the cells from the matrix. An 80 μL aliquot was removed for cell counting and the viability was checked by trypan blue exclusion.

The results are shown in Figure 1. Each data point represents the average cell number $\pm$ the standard error (SEM) of duplicate determinations.

Cells lined the interstices of this three dimensional collagen-like matrix (Centra, et al., 1992³), and remained within the matrices without migrating outward. Cell growth followed a pattern similar to that observed on tissue culture polystyrene. Cell viability as evaluated by trypan blue exclusion remained at $90 \pm 2.3\%$ for the BAE cells and $93.1 \pm 1.7\%$ for the CHO-745 over the course of the culture.

The preservation of the immune identity of cells within GelfoamTM blocks recovered 14 days after placement in tissue culture or around rat carotid arteries was determined by immunostaining for the endothelial marker von Willebrand's factor as described by Edelman, et al., *J. Clin. Invest.* 89:465-471 (1992).

The amount of heparan sulfate in conditioned media produced by cells cultured on GelfoamTM or tissue culture polystyrene was measured. GelfoamTM films containing endothelial cells or CHO-745 cells were

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incubated in culture medium containing no antibiotics and no calf serum for 24 hours at 37°C. As a control, identical Gelfoam™ films without cells were incubated in the respective media. The medium was collected, centrifuged (5,000 x g), dialyzed exhaustively against water, and concentrated by lyophilization. Total sulfated glycosaminoglycan was determined using dimethylmethylene blue (Farndale, et al., *Biochimica et Biophysica Acta* 883:173-177 (1986), and the amount of heparan sulfate was assessed after samples were treated with heparinase. The endothelial and CHO-745 cells grown on Gelfoam™ were also radiolabeled with ³⁵SO₄ (100 μCi/mL, 24 h) to visualize the metabolic synthesis of heparan sulfate by the cells. The medium was collected, centrifuged, and ³⁵SO₄-proteoglycan separated from the free ³⁵SO₄ by vacuum filtration through cationic nylon membranes (Rapraeger and Yeaman, *Anal. Biochem.* 179:361-365 (1989)). Filters containing ³⁵SO₄-proteoglycan were incubated in nitrous acid (0.48 M sodium nitrite combined with 3.6 M acetic acid) and counted to determine the amount of radioactivity incorporated within heparan sulfate.

Engrafted cells remained viable with full retention of biochemical secretory ability and biologic potency as well as immunoidentity. Cells cultured on Gelfoam™ produced nearly identical amounts of total sulfated glycosaminoglycan and heparan sulfate as that produced when the same cells were grown on polystyrene dishes. In addition, there was no significant difference in the profile of the proteoglycan when resolved on 5% SDS-PAGE. For both cells grown on Gelfoam™ and tissue culture polystyrene, the majority of the proteoglycan migrated as a band greater than 600 kDa relative to protein standards. When compared to CHO-745 cells grown on Gelfoam™, the engrafted endothelial cells produced an 11.1-fold greater amount of glycosaminoglycan (4.1 ± 0.3 microgram/10⁶ cells/day for endothelial cells versus 0.37 ± 0.02 microgram/10⁶ cells/day for CHO-745 cells). While 29.1% of the glycosaminoglycan produced by the endothelial cells was heparan sulfate (1.2 ± 0.05 microgram/10⁶ cells/day), CHO-745 cells produced no detectable heparan

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sulfate. Conditioned media from Gelfoam™ engrafted endothelial cells also inhibited both binding of ¹²⁵I-bFGF to heparan sulfate proteoglycan and the mitogenic effect of bFGF on vascular smooth muscle cells in a dose dependent fashion, as shown by Figure 2. In contrast, conditioned
5 media from CHO-745 cells had no effect on binding, and similarly no effect on growth factor induced mitogenesis, as shown by Figure 2.

Example 2: Inhibition of Intimal Hyperplasia in Rats.

Implantation of Matrix Strips Containing BAE Cells into Rats.

The *in vivo* effects of engrafted cells in matrix strips were
10 evaluated in an endothelial denuding arterial injury model in Sprague-Dawley rats. Strips of Gelfoam™ gelatin matrix (2.5 x 1 x 0.3 cm³ each) containing BAE cells or CHO-745 cells, or no cells, were wrapped around carotid arteries denuded with a balloon catheter, and their effect on smooth muscle cell proliferation and intimal hyperplasia was
15 determined two weeks later.

Endothelial denudation of the left common carotid artery in Sprague-Dawley rats was performed with a 2 French Fogarty balloon catheter introduced through an external carotid arteriotomy and passed three times in its inflated state over the endothelium of the common
20 carotid artery (Edelman, et al., 1992⁴, Clowes, et al., 1983⁵, Edelman, et al., 1990⁶). Strips of Gelfoam™ (2.5 x 1 x 0.3 cm³ each) containing BAE cells, CHO-745 cells, or no cells were wrapped around denuded arteries. The strip ends overlapped, ensuring complete encircling of the artery. Fascial planes were sutured closed to further immobilize the devices.

25 To compare the results of anticipated physiologic secretion of endothelial cell products to the pharmacologic dosing of a proven endothelial-cell analog, hydrogel films were formulated (Nathan, et al., 1994⁷) to release heparin alone at a dose, 2.5 ± 0.1 microgram/day. This dose and mode of delivery has previously been demonstrated to maximize
30 heparin's inhibition of neointimal hyperplasia (Edelman, et al., 1990⁶; Edelman, et al., 1993⁸; Edelman and Karnovsky 1994⁹).

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On the 14th post-operative day, animals were euthanized and perfused clear via the left ventricle with Ringer's lactate solution followed by immersion fixation with Carnoy's fixative (60% methanol, 30% chloroform, 10% glacial acetic acid). The location of the implanted matrices was noted and the matrices recovered with the entire length of the intact arteries. The carotid arteries were harvested and cut into five equal segments, three including the GelfoamTM wrap and segments above and below. Segments were paraffin embedded and 6 micron sections obtained along the length of each segment.

After staining with hematoxylin/eosin or verHoeff's elastin stain, the intimal, medial and adventitial areas, the intima:media area ratio and the percent of luminal occlusion were calculated using computerized digital planimetry with a dedicated video microscope and customized software. Cell proliferation was assayed using immunocytochemical identification of proliferating cell nuclear antigenicity (PCNA) and the thymidine analog 5-bromo-2'-deoxyuridine (BrdU, New England Nuclear, Dupont Corp., Wilmington, DE) which had been injected intraperitoneally, at 50 mg/kg body weight, 3 and 7 days post-surgery and one hour prior to sacrifice.

Segments of the unwrapped balloon injured artery were compared to GelfoamTM wrapped segments. Comparisons were made across treatment groups and within treatment groups to allow each animal to serve as its own control. Statistical comparisons were performed using analysis of variance (ANOVA) and subsequent differences among groups using Student's t test. Data was rejected as not significantly different if p values of greater than 0.05 were observed. Data line fits were established using a linear regression and correlation model.

The *in vivo* potency of the endothelial cell engrafts was retained in addition to their *in vitro* effects. Balloon denudation of the carotid arterial endothelium led to an increase in the ratio of the area of the *tunica intima* to the area of the *tunica media* (I:M) to 1.44 ± 0.16 , as shown by Figure 3. Arterial wall segments exposed to GelfoamTM

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containing endothelial cells showed minimal hyperplastic disease. Intimal hyperplasia in arterial segments beneath endothelial cell grafted Gelfoam™ was reduced to 0.17 ± 0.07 . This modulating effect was specific to endothelial cells. Control CHO-745 cell engrafts had no statistically significant effect on intimal hyperplasia (I:M 1.36 ± 0.32) compared to balloon injury, alone or empty Gelfoam™ matrices (I:M 1.20 ± 0.11), as shown by Figure 3.

Heparin has been identified as the gold standard inhibitor of smooth muscle cell proliferation and intimal hyperplasia, in major part because it resembles endothelial-cell-derived heparan sulfate proteoglycan. Indeed the perivascular release of heparin alone from hydrogel films reduced proliferation to an I:M of 0.55 ± 0.11 . This result, however, was 3.2 fold less effective than the control exerted by engrafted endothelial cells despite hydrogel release of heparin at twice the rate of release of heparan sulfate proteoglycan from the endothelial implants.

Gelfoam™ engrafted endothelial cells reduced proliferation as well as intimal hyperplasia. The number of proliferating cells relative to the total number of cells in the *tunicae media* and *intima* were used as an index of proliferation. Gelfoam™ implants with engrafted endothelial cells caused a statistically significant decrease in cell proliferation in both the *tunica intima* (20.4% reduction) and the *tunica media* (26.3% reduction) relative to empty Gelfoam™ implants, as shown by Figure 4. Heparin infusion also decreased proliferation but the effect was not statistically significant at the number of animals and sections examined. Relative to balloon injury alone, heparin infusion reduced BrdU immunostaining in the *tunica intima* by 11.0% and 12.2% in the *tunica media*, as shown by Figure 4.

There was no evidence that the implants induced cellular or systemic rejection. The general health and appearance of the animals with the implants was unchanged from controls. Rats subjected to balloon injury alone gained 52.9 ± 3.6 gms over the 14 day experimental period, and those animals that received a cell-free implant hydrated in either

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DMEM or HAMS-F12 gained 48.0 ± 7.3 gms. The animals implanted with endothelial-seeded implants gained 51.3 ± 2.8 gms and the animals with CHO-745 laden implants gained 53.4 ± 6.5 gms. Rats receiving perivascular heparin gained 56.7 ± 6.2 gms, indicating that the treatment had no side effects.

The results demonstrate the engraftment of endothelial cells on three dimensional biopolymer scaffoldings with preservation of cell viability, normal growth characteristics, immunologic markers, biochemical activity and physiologic effects.

The biologic effects of the engrafted endothelial cells were cell-specific and superior to the infusion of a single pharmacologic analog of an endothelial product, heparin. Conditioned media from implant engrafted endothelial cells, but not heparan sulfate proteoglycan-deficient CHO-745 cells, inhibited bFGF binding to and mitogenesis for vascular smooth muscle cells in a dose dependent fashion. Similarly, only endothelial cell engrafts inhibited intimal hyperplasia. The implant alone or seeded with CHO-745 cells had no statistically significant effect on cell proliferation or intimal hyperplasia. Heparin is one of the most effective anti-proliferative agents for vascular smooth muscle cells, yet even when released at twice the rate of heparan sulfate proteoglycan production by the endothelial cells, intimal hyperplasia and smooth muscle cell proliferation were reduced 3.2 fold less effectively than with the endothelial cell implants.

The control exerted by the endothelial cell implants appears to result solely from the biochemical effects of the engrafted cells. Immunostaining with endothelial cell-specific markers detected no evidence for early recovery of endogenous endothelial cells or the migration of engrafted cells from their biopolymer scaffoldings to the arterial lining in any of the recovered arterial segments. The effects of the implants were localized in a similar manner to the focal effects observed with the perivascular release of other compounds. There was no evidence of a systemic or local immune response or graft rejection.

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Claims:

1. Use of a composition for inhibiting mechanisms involved in restenosis of a blood vessel following injury to vascular tissue in a region of the blood vessel of a patient in need of treatment thereof, the composition comprising a biocompatible matrix having seeded therein or thereon dissociated endothelial cells, the matrix being implantable in contact with an exterior surface of the vascular tissue and adjacent to or at the injury to or blockage of the vascular tissue, wherein the endothelial cells are provided at a cell density of about 10^3 to 10^{12} cells/cm³.
2. The composition of claim 1 wherein the injury arises from angioplasty, coronary artery bypass surgery, peripheral bypass surgery, or organ transplantation.
3. The composition of claim 1 wherein the matrix is in a form selected from the group consisting of gels or foams, suspensions, microcapsules, solid polymeric supports, or fibrous structures.
4. The composition of claim 1 wherein the cells are obtained by biopsy of the patient into which the matrix is implanted.
5. The composition according to claim 1 wherein the matrix is biodegradable.
6. The composition of claim 5 wherein the matrix is formed of a material selected from the group consisting of polyhydroxy acids, polyorthoesters, polyanhydrides, proteins, carbohydrates or polysaccharides, polyphosphazenes, polyalkylene oxides and combinations thereof.
7. The composition of claim 1 wherein the matrix is formed of a material selected from the group consisting of ethylene vinyl acetate, polyvinyl alcohol, silicone, polyurethane, non-biodegradable polyesters, polyethyleneoxide-polypropyleneoxide, tetrafluoroethylene and combinations thereof.
8. The composition of claim 1 wherein the matrix further comprises biologically active compounds selected from the group consisting of anti-inflammatory agents, prostaglandin, prostanoids, compounds regulating the renin-angiotensin axis, tyrosine kinase inhibitors, immunosuppressants, vitamins,

glucocorticoids, anti-oxidants, free radical scavengers, peptide hormones, angiogenic and angiogenic inhibitory factors, and combinations thereof.

9. The composition of claim 1 wherein the cells are first cultured in the matrix *in vitro*, then implanted *in vivo*.

10. The composition of claim 1 wherein the matrix is surgically implanted around the blood vessel.

11. A composition for inhibiting intimal smooth muscle cell proliferation or restenosis of a blood vessel following injury to vascular tissue of the blood vessel in a patient in need of treatment thereof, comprising a biocompatible matrix shaped for implantation in contact with an exterior surface of the vascular tissue and adjacent to or at the injury to or blockage of the vascular tissue, the matrix having seeded therein or thereon dissociated endothelial cells at a cell density of about 10^3 to 10^{12} cells/cm³.

12. The composition of claim 11 wherein the cell density is effective to treat an injury arising from angioplasty, coronary artery bypass surgery, peripheral bypass surgery, or organ transplantation.

13. The composition of claim 11 wherein the matrix is in a form selected from the group consisting of gels or foams, suspensions, microcapsules, solid polymeric supports, or fibrous structures.

14. The composition of claim 11 wherein the cells are selected from the group consisting of autologous cells, allograft cells, xenograft cells, and genetically engineered cells.

15. The composition according to claim 11 wherein the matrix is biodegradable.

16. The composition of claim 15 wherein the matrix is formed of a material selected from the group consisting of polyhydroxy acids, polyorthoesters, polyanhydrides, proteins, carbohydrates or polysaccharides, polyphosphazenes, and combination thereof.

17. The composition of claim 11 wherein the matrix is formed of a material selected from the group consisting of ethylene vinyl acetate, polyvinyl alcohol, silicone,

polyurethane, non-biodegradable polyesters, polyethyleneoxide-polypropyleneoxide, tetrafluoroethylene, and combinations thereof.

18. The composition of claim 11 wherein the matrix further comprises biologically active compounds selected from the group consisting of anti-inflammatory agents, prostaglandins, prostanoids, compounds regulating the renin-angiotensin axis, tyrosine kinase inhibitors, immunosuppressants, vitamins, glucocorticoids, anti-oxidants, free radical scavengers, peptide hormones, angiogenic and angiogenic inhibitory factors.

19. The composition of claim 11 wherein the matrix surface is modified to alter cell-matrix interactions.

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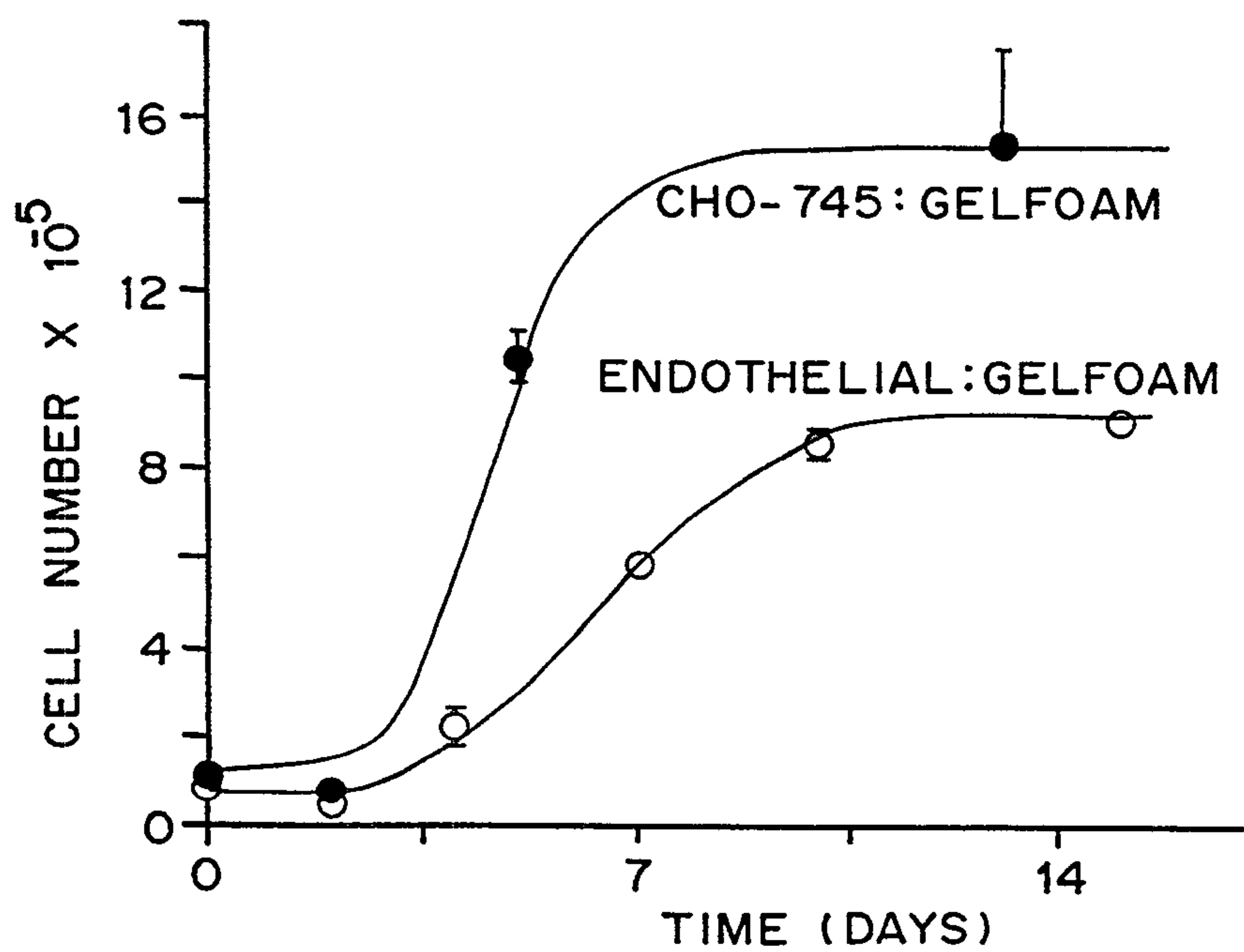


FIG. 1

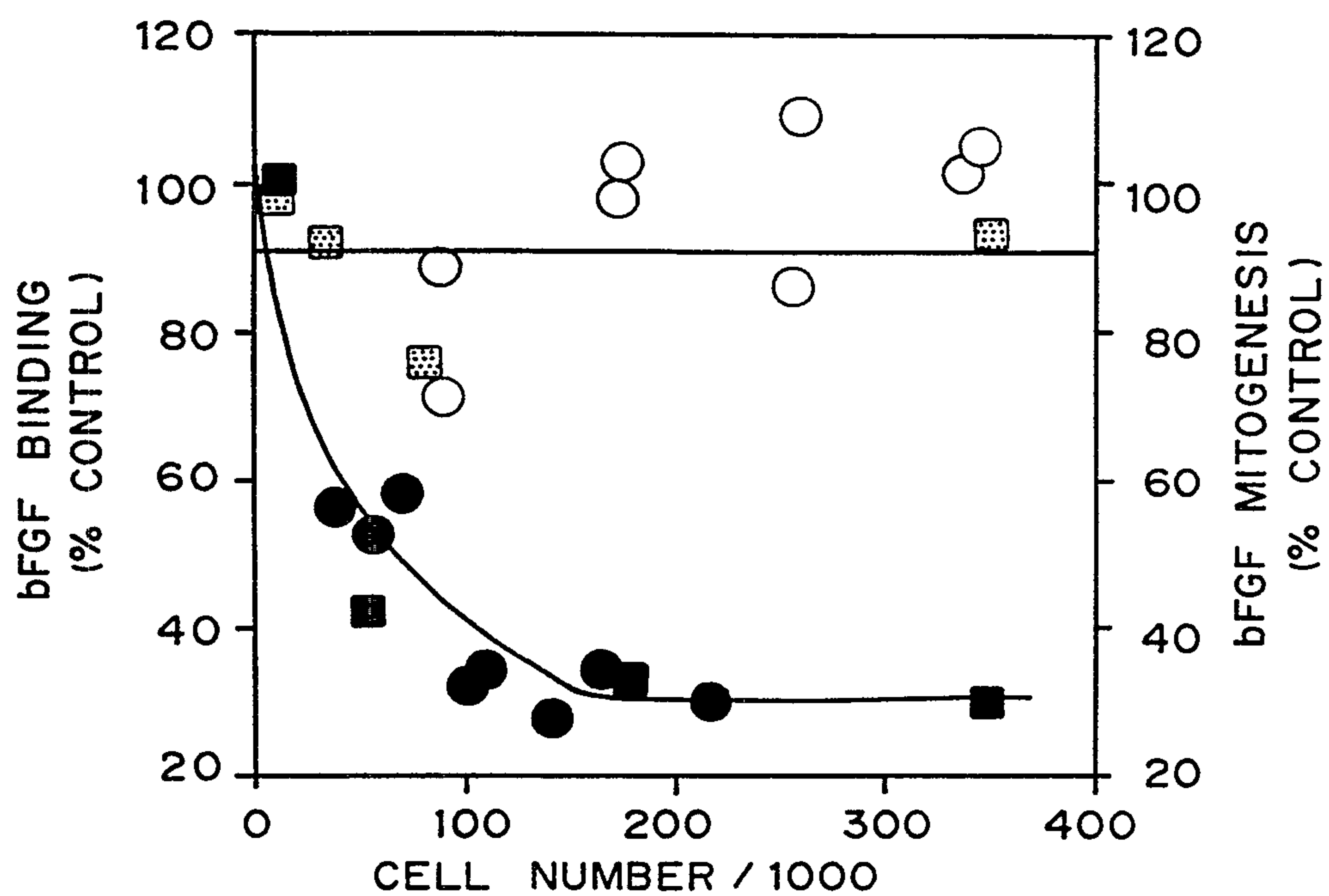


FIG. 2

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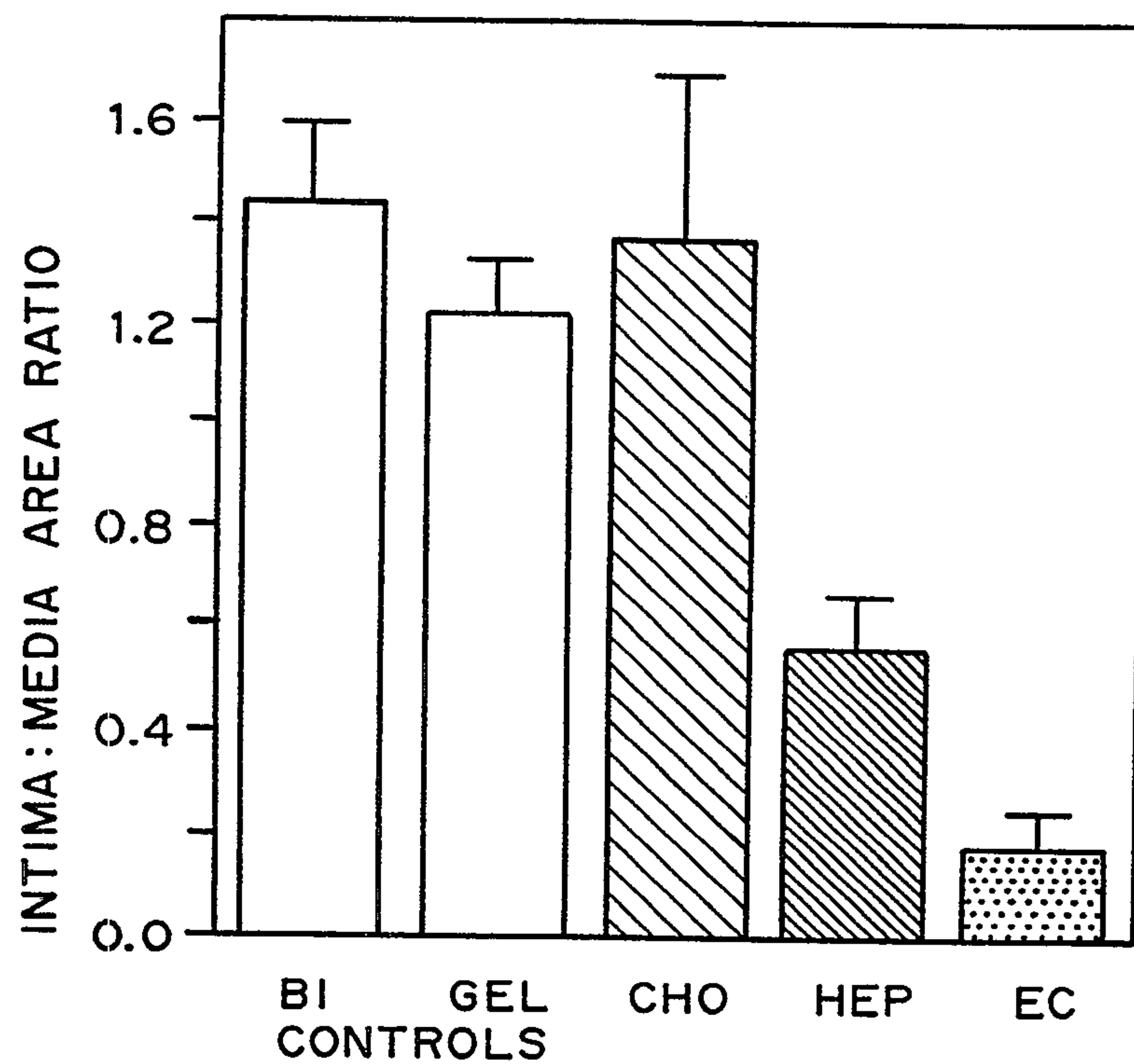
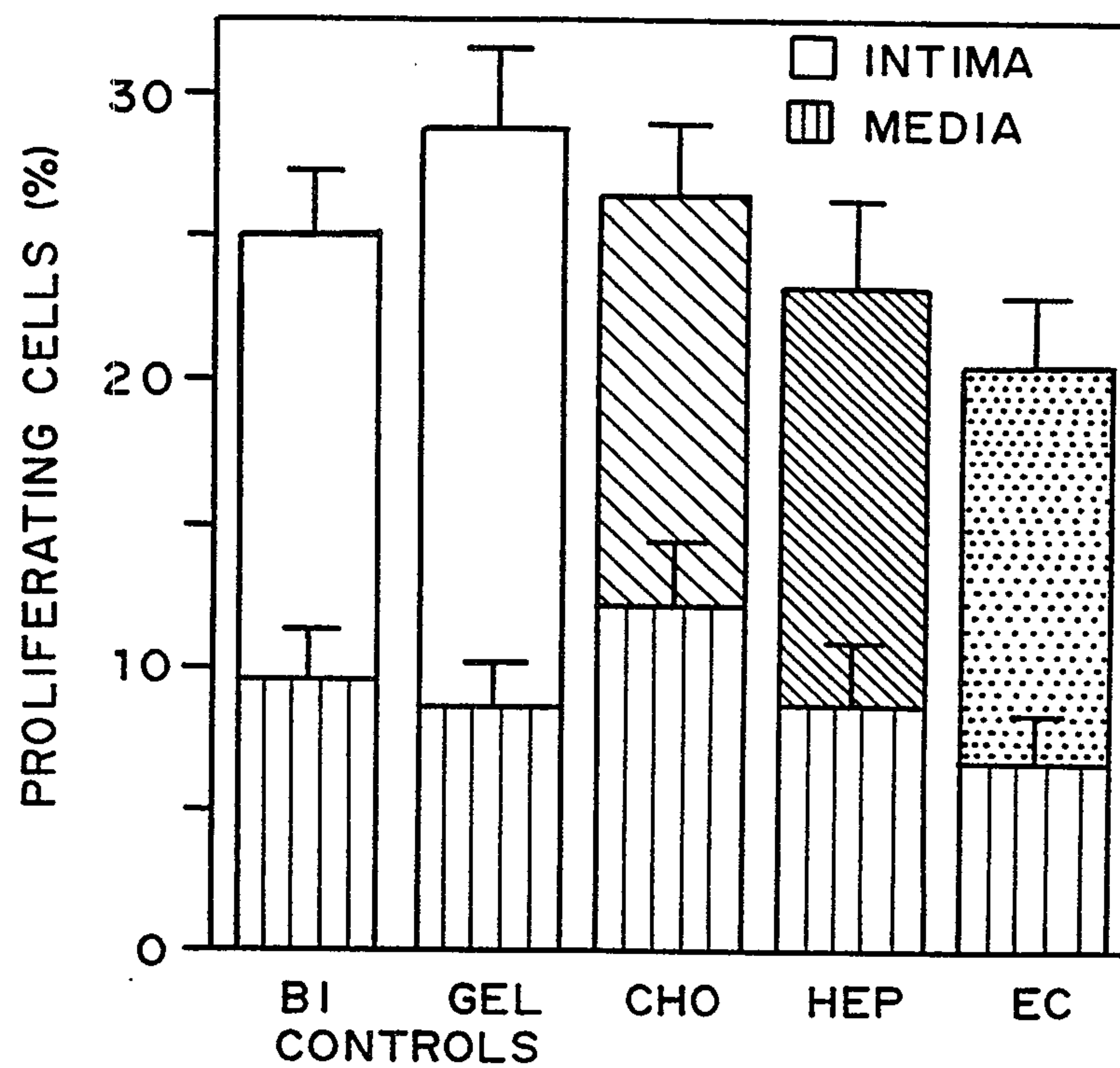


FIG. 3

FIG. 4
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