1604087.8
IPOS copy.

RETINAL PIGMENT EPITHELIUM TRANSPLANTATION

BACKGROUND OF THE INVENTION

This application is a continuation-in-part of copending application Serial No. 07/566,996 filed August 13, 1990, which in turn is a continuation-in-part of application Serial No. 07/394,377, filed August 14, 1989, now abandoned.

The present invention relates in general to cell and tissue transplantation techniques. More particularly, the present invention is directed to techniques for transplanting populations of retinal pigment epithelium (RPE) cells as a monolayer to the subretinal region of the eye, and to methods for preparing implants comprising monolayers of RPE cells for transplantation.

The retina is the sensory epithelial surface that lines the posterior aspect of the eye, receives the image formed by the lens, transduces this image into neural impulses and conveys this information to the brain by the optic nerve. The retina comprises a number of layers, namely, the ganglion cell layer, inner plexiform layer, inner nuclear layer, outer plexiform layer, outer nuclear layer, photoreceptor inner segments and outer segments. The outer nuclear layer comprises the cell bodies of the photoreceptor cells with the inner and outer segments being extensions of the cell bodies. The choroid is a vascular membrane containing large branched pigment cells that lies between the retina and the sclerotic coat of the vertebrate eye. Atop the choroid is a membrane 1-5 microns in thickness essentially composed of collagen, known as Bruch's membrane.

Immediately between Bruch's membrane and the retina is the retinal pigment epithelium which forms an intimate structural and functional relationship with the

photoreceptor cells. Among the functions performed by RPE cells is the phagocytosis of outer segment debris produced by the photoreceptors. It is believed that failure of the RPE cells to properly perform their functions such as digestion of outer segment debris leads to the eventual degeneration and loss of photoreceptor cells.

In the leading causes of visual impairment in western industrialized countries, such as age-related macular degeneration (AMD), both photoreceptors and the underlying RPE are compromised, or have degenerated. A further aspect of AMD is the frequent appearance of subretinal neovascular membranes which grow through the Bruch's membrane and the RPE and tend to hemorrhage and leak fluids into the subretinal space.

In an effort to recover what was previously thought to be an irreparably injured retina, researchers have suggested various forms of grafts and transplantation techniques, none of which constitute an effective manner for reconstructing a dystrophic retina. The transplantation of retinal cells to the eye can be traced to a report by Royo et al., Growth 23: 313-336 (1959) in which embryonic retina was transplanted to the anterior chamber of the maternal eye. A variety of cells were reported to survive, including photoreceptors. Subsequently del Cerro was able to repeat and extend these experiments (del Cerro et al., Invest. Ophthalmol. Vis. Sci. 26: 1182-1185, 1985). Soon afterward Turner, et al. Dev. Brain Res. 26:91-104 (1986) showed that neonatal retinal tissue could be transplanted into retinal wounds.

Li and Turner, Exp. Eye Res. 47:911 (1988) have proposed the transplantation of retinal pigment epithelium (RPE) into the subretinal space as a therapeutic approach in the RCS dystrophic rat to replace defective mutant RPE cells with their healthy wild-type counterparts. According

to their approach, RPE were isolated from 6- to 8-day old black eyed rats and grafted into the subretinal space by using a lesion paradigm which penetrates through the sclera and choroid. A 1 ml bolus injection of RPE (40,000 - 60,000 cells) was made at the incision site into the subretinal space by means of a 10 ml syringe to which was attached a 30 gauge needle. However, while this technique is marginally appropriate for immature RPE cells, with mature cells it leads to activation and transformation of these cells which damages eye and retinal tissue.

Lopez et al., Invest. Ophthalmol. Vis. Sci. 30: 586-589, 1989, also reported a procedure for the transplantation of dissociated RPE cells. In this procedure, RPE cells were obtained from normal, congenic, pigmented rat eyes by trypsin digestion. These freshly harvested, dissociated RPE cells were injected into the subretinal area of the eyes of dystrophic RCS rats via an incision through the sclera, choroid and neural retina. Comparable to the Li and Turner approach discussed above, this procedure destroys the organized native structure of the transplanted RPE cells, which take the form of a confluent monolayer in a healthy eye. Moreover, the procedure is of questionable value for the transplantation of mature RPE cells. When mature RPE cells are transplanted in dissociated form, experimental results indicate that they are likely to become activated, migrate into the subretinal space, and as noted by Lane, C., et al., Eye (1989) 3, 27-32, invade the retina and vitreous. This activation of the transplanted, mature RPE cells can result in such pathologies as retinal pucker, massive subretinal fibrosis, retinal rosette formation, retinal detachment, and proliferative vitreoretinopathy.

The difficulties discussed above associated with the transplantation of mature RPE cells is problematic for

human transplantation since available supplies of immature human RPE donor tissue are extremely limited. Moreover, the inability to use mature cells effectively prevents transplantation using autologous RPE tissue, which otherwise would be desirable to avoid the complications involving potential immunological responses faced by non-autologous transplants. Since the victims of AMD are predominantly older adults, in most cases utilizing autologous tissues for transplants would necessarily entail the use of mature human RPE cells.

It is believed by the present inventor that it is necessary to maintain adult human RPE cells substantially as a monolayer to achieve their successful transplantation and to avoid the problems associated with activation of RPE cells. Although not wishing to be limited to a particular theory, it is thought that the cell-to-cell contact inhibition provided by an intact monolayer, supplemented by adherence to a substrate, mitigates against RPE cell activation. Moreover, a monolayer structure for the RPE provides a proper foundation for the maintenance of the photoreceptor cells in an organized outer nuclear layer structure and for proper growth and arrangement of inner and outer segments, believed by this inventor to be advantagous to restore a reasonable degree of vision. The requirement that the photoreceptors be maintained in an organized structure is based on the well known optical characteristics of photoreceptors (outer segments act as light guides) and clinical evidence showing that folds or similar, even minor, disruptions in the retinal geometry can severely degrade visual acuity.

Additionally, in cases of AMD where subretinal neovascular membranes have appeared, prior to RPE transplantation, such membranes will need to be removed to prevent subretinal edemas and hemorrhaging of these

membranes. In practice, removal of the neovascular membrane results in removal of the native RPE and Bruch's membrane as well.

A critical impediment to the transplantation of RPE cells as a monolayer is the fragility of the intercellular structure of RPE relative to the rigors of manipulation during transplantation to the subretinal area. Moreover, providing satisfactory support to the RPE cells during this process is complicated by the fact that the support must either be removed subsequent to transplantation, to avoid compromising metabolic exchange between the choroid and the overlying retina, or be compatible with such ongoing physiological activity. Thus, a method is needed wherein an implant comprising a monolayer of RPE cells is prepared and transplanted in which the component supporting the monolayer of RPE cells, upon transplantation to the subretinal area and exposure to a set of predetermined conditions, does not impede normal eye tissue function. Further, a Bruch's-like membrane for attachment of the transplanted RPE cells will be needed in those cases where neovascularization has occurred and the native Bruch's membrane is removed.

SUMMARY OF THE INVENTION

Among the objects of the present invention, therefore, may be noted the provision of a method for preparation of a population of RPE cells as a monolayer for use in the reconstruction of a dystrophic RPE; the provision of such a method which allows for use of mature, and in particular, autologous, mature RPE cells as donor tissue in the reconstruction of a dystrophic RPE; the provision of an implant for use in the reconstruction of a dystrophic retina; the provision of such an implant which does not interfere with normal eye tissue function after

transplantation and maintains photoreceptors and their inner and outer segments by allowing for maintenance of the native organization of the photoreceptor; the provision of such an implant which provides a membrane for attachment of the population of RPE cells especially when the native Bruch's membrane has been removed; and the provision of a method for transplantation of such implants to the subretinal area of an eye.

Briefly, therefore, the present invention is directed to a method for the preparation of a population of RPE cells for transplantation to the subretinal area of a host eye. The method comprises providing donor tissue comprising RPE cells, harvesting from that tissue RPE cells, and apposing the harvested RPE cells as a monolayer to a non-toxic, flexible support that, upon transplantation to the subretinal area and exposure to a set of predetermined conditions, will not impede normal eye tissue function of the host eye and the transplanted population.

The present invention is further directed to an implant for transplantation to the subretinal area of a host eye. The implant comprises a laminate of a monolayer of retinal pigment epithelium cells and a non-toxic, flexible support that, upon transplantation to the subretinal area and exposure to a set of predetermined conditions, will not impede normal eye tissue function.

The present invention is also directed to a method for transplanting to the subretinal area of a host's eye an implant comprising a monolayer of RPE cells. The method comprises providing an implant comprising a laminate of a monolayer of retinal pigment epithelium cells and a non-toxic, flexible support that, upon transplantation to the subretinal area and exposure to a set of predetermined conditions, will not impede normal eye tissue function, making an incision through the host's eye, at least

THIS SHEET HAS BEEN REPLACED

partially detaching the retina to permit access to the subretinal area, and positioning the implant in the accessed subretinal area.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a photograph (200X) of a cryostat section of a normal rat retina and sub-retinal area;

Fig. 2(a, b, c, d and e) is a schematic showing the preparation and transplantation of a preferred embodiment of an implant comprising a monolayer of RPE cells mounted to a support;

Fig. 3 is a schematic of an alternative embodiment of an implant comprising a monolayer of RPE cells mounted to a support;

Fig. 4 is a horizontal section through an eye illustrating a transchoroidal and scleral surgical approach;

Fig. 5 is a horizontal section through an eye illustrating a transcorneal surgical approach;

Fig. 6 is a photograph showing a view of the transplanted implant of an intact monolayer of mature human RPE cells positioned under the retina of a rodent whose cornea, pupil and lens have been removed, 2 weeks post-transplantation, as set forth in Example 1;

Fig. 7 is a photograph (40X) of a section of a rat retina and sub-retinal area showing an implant of an intact monolayer of a population of mature human RPE cells 14 days after transplantation, as set forth in Example 1;

Fig. 8 is a higher magnification photograph (400X) of a section of a rat retina and sub-retinal area showing an implant of an intact monolayer of a population of mature human RPE cells 14 days after transplantation, as set forth in Example 1;

Fig. 9 is a photograph (100X) of a section of a rat retina and sub-retinal area 14 days after

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

transplantation of dissociated mature human RPE cells, as set forth in Example 2; and

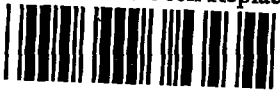
Fig. 10 is a higher magnification photograph (300X) of a section of a rat retina and sub-retinal area 14 days after transplantation of dissociated mature human RPE cells, as set forth in Example 2.

DETAILED DESCRIPTION

As used herein, the term "donor" shall mean the same or different organism relative to the host and the term "donor tissue" shall mean tissue harvested from or cultured from tissue harvested from the same or different organism relative to the host. Autologous tissue shall mean tissue harvested from or cultured from tissue harvested from the host organism. Mature RPE cells shall mean differentiated RPE cells derived from an organism that is not a fetus.

It is believed that in age-related macular degeneration (AMD), compromise or degeneration of the RPE cells which underlie and form a close structural and metabolic support for the photoreceptors, leads to the loss or destruction of viable photoreceptors. It has been discovered, however, that transplantation of a population of RPE cells as a monolayer, i.e., in essentially a two-dimensional array of cell bodies capable of engaging in cell-to-cell contact inhibition, allows the RPE cells to maintain largely normal characteristics of native, healthy retinal pigment epithelia, capable of providing structural and functional support to photoreceptor cells. Moreover, as illustrated in Example 2 below, it is believed that it is essential to transplant mature RPE cells as a monolayer in order to prevent activation of such cells. Activation leads RPE cells to transdifferentiate into wandering macrophages, fibroblast-like cells and other cell types,

This Sheet Has Been Replaced



THIS SHEET HAS BEEN REPLACED

which cause a number of dystrophic effects in the eye and retina.

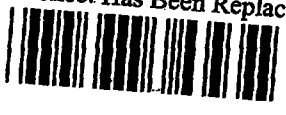
Fig. 1 is a photograph of a cryostat section of a normal rat retina and subretinal area. In Fig. 1 as well as subsequent figures, the retina or layers thereof, e.g., the ganglion cell layer ("G"), inner plexiform layer ("IPL"), inner nuclear layer ("INL"), outer plexiform layer ("OPL"), outer nuclear layer ("ONL"), inner segments ("IS"), outer segments ("OS"), and retinal pigment epithelium ("RPE"), are shown, respectively, from top to bottom.

Referring now to Figs. 2 and 3, implants comprising a monolayer of RPE cells are prepared, in general, by harvesting RPE cells from donor tissue and apposing the harvested RPE cells as an intact monolayer to a non-toxic, flexible composition, or by seeding such a composition with a monolayer of dissociated RPE cells and allowing them to grow into a confluent layer. The flexible composition serves as a stabilizing support for the RPE cells during transplantation.

The implant constitutes a laminate of a monolayer of RPE cells and a support composition approximately 100 to 500 microns thick, and preferably 150-250 microns thick. The surface of the implant has a surface area greater than about 1 square millimeter, preferably greater than 2 square millimeters, and most preferably greater than 4 square millimeters, or as large as may be practically handled. Thus constructed, the implant may subtend a considerable extent of the sub-retinal surface.

In selecting donor tissue for the harvesting of RPE cells, it is noted that previously, transplantation of RPE cells was effectively limited to immature cells. Mature RPE cells transplanted according to prior art methods have been shown to undergo activation resulting in

This Sheet Has Been Replaced



retinal pucker, sub-retinal fibrosis and proliferative vitreoretinopathy. However, by utilizing the procedures for implanting a monolayer of RPE cells according to this invention, transplanted mature RPE cells have successfully maintained essentially normal structure and function. Thus, the subject invention makes mature RPE cells available for transplantation, significantly increasing the supply of usable donor tissue beyond the narrowly limited supply of immature human donor tissue.

It is also noted that the RPE forms part of the blood-retinal barrier and is thus exposed to lymphocytic attack. Accordingly, use of autologous RPE cells, now possible even for mature RPE cells, is preferable, since it will avoid immunological complications in clinical applications. If non-autologous tissue is utilized, tissue typing and/or use of an immunosuppression regimen will generally be necessary to avoid rejection upon transplantation.

Donor tissue may be provided, for non-autologous, human RPE tissue, from eye banks, which make the RPE tissue available in connection with conducting corneal transplants. Harvesting donated tissue comprising non-autologous RPE cells can be accomplished by any suitable method. In general, harvesting of RPE cells may be carried out as set forth in Pfeffer, B.A., Chapter 10, "Improved Methodology for Cell Culture of Human and Monkey Retinal Pigment Epithelium", Progress in Retinal Research, Vol. 10 (1991); Ed. by Osborn, N. and Chader, J., or Mayerson, P.L., et al., "An Improved Method for Isolation and Culture of Rat Retinal Pigment Epithelial Cells", Investigative Ophthalmology & Visual Science, Nov., 1985, 26: 1599-1609, which are incorporated herein by reference. Specifically, to harvest non-autologous RPE cells, a donor eye is pinned by the optic nerve stump into an eye cage and

placed in an eye jar immediately after corneal removal. The jar is then flooded to capacity with cold Delbecco's modified essential medium (DMEM) supplemented with 5% fetal bovine serum. After loose connective tissue and muscle have been carefully trimmed from the eye, it is placed upright on a sterile plate and the anterior segment with the adherent vitreous is lifted out of the eye cup. The neural retina is separated at the optic disc and removed. The shell is then washed with Hanks' balanced salt solution, Ca++ and Mg++ free, and treated with 0.25% trypsin for 30 min. at 37° C. The trypsin solution is aspirated from the shell and DMEM (GIBCO) is added. The RPE cells are released from Bruch's membrane by gently pipetting the culture medium in the shell.

For implants containing autologous tissue, RPE cells may be harvested by performing a biopsy following the procedures disclosed by Lane, C., et al. in Eye (1989) 3, 27-32.

The implant also comprises a support for the RPE cells so that the monolayer of RPE cells is less likely to be damaged and is more easily manipulated during the transplantation process. The support consists of a substrate, an overlayer or both, comprising a sheet or sheets of a non-toxic, flexible composition selected to provide mechanical strength and stability to the easily damaged monolayer of RPE cells. Because the support composition will be inserted into the eye as a laminate with the monolayer of RPE cells, the support is also comprised so that, upon transplantation to the subretinal area and exposure to a set of predetermined conditions, described herein, the support composition will not impede normal eye tissue function of the host eye or the population of transplanted RPE cells. If the harvested RPE cells are to be cultured before transplantation, the

composition providing support to the monolayer of RPE cells during transplantation may optionally be capable of serving as the attachment substrate for the RPE cells during culturing.

A variety of compositions may be used as the support for the population of RPE cells, depending upon the specific set of conditions to which the composition will be exposed after transplantation. In short, the composition is selected either because any portion remaining within the subretinal area for more than approximately one week after transplantation is compatible with normal eye tissue function upon exposure to bodily fluids within the sub-retinal area, or for its susceptibility to elimination upon exposure to prescribed conditions.

An additional factor to consider in determining the make-up of compositions for support of the monolayer of RPE cells is whether Bruch's membrane has been or will be removed from the host eye prior to transplantation of the monolayer of RPE cells. Bruch's membrane serves to anchor the RPE cells in a healthy eye. Removal of Bruch's membrane may occur in cases of AMD where a subretinal neovascular membrane has formed and Bruch's membrane is removed as a consequence of the removal of the neovascular membrane.

In cases where Bruch's membrane is removed, the support composition will comprise a layer of collagen less than 100 microns in thickness, and preferably between 1 and 10 microns in thickness. The basal surfaces of the RPE cells attach readily to the collagen layer, which serves to anchor the RPE cells to the choroid in place of the removed Bruch's membrane. The layer of collagen also serves to inhibit the occurrence or reoccurrence of subretinal neovascularization through and around the transplanted RPE. Such a collagen layer is retained indefinitely in the

THIS SHEET HAS BEEN REPLACED

sub-retinal area. However, it is known that Bruch's membrane is essentially comprised of collagen, and such microthin layers of collagen are permeable enough to avoid impeding normal eye tissue functions such as the metabolic exchange between the choroid and the retina. However, collagen compositions of such a minimal thickness are not strong enough to prevent buckling or distortion of the monolayer of RPE cells during transplantation. Thus, such microthin collagen materials need to be used in combination with additional supporting materials which will be eliminated after transplantation, if they are to form part of the support for the transplanted RPE cells.

If transplantation is carried out with the native Bruch's membrane intact, the host's RPE cells covering the area to receive the transplant of RPE cells may be physically and/or chemically debrided from the Bruch's membrane, for example, by applying collagenase to the native Bruch's membrane to loosen the host's RPE cells in order to permit their removal. The transplanted RPE cells may then anchor themselves directly to the Bruch's membrane.

Either to supplement a layer of collagen, as discussed above, or in cases where inclusion of a collagen anchor is not required, a support composition may be selected which is dissipated, for example, by exposure to a sufficient amount of heat, selected enzymes, or bodily fluids. Gelatin is an example of a preferred support material which is flexible, lacks toxicity to neural tissue and has the ability to dissolve at body temperature. The support composition may also comprise a material such as activated low gelling temperature agarose (Type VII, #A 4018 Sigma Chemical Co., St. Louis) or fibrin, which are known to dissipate when exposed to selective enzymes which will not attack other compositions. For example, agarase is an enzyme known to specifically attack agarose, and

This Sheet Has Been Replaced

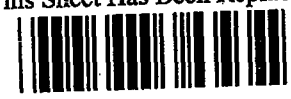
THIS SHEET HAS BEEN REPLACED

urokinase is an enzyme specific to fibrin. Another alternative is to use biodegradable polymers such as ethylene-vinyl acetate copolymer (Elvax 40W, DuPont Chemical Co., Delaware); poly(glycolic) acid, poly(L-lactide-co-glycolide)(70:30 ratio) or poly(L- or DL-lactic) acids (low mol. wt.) (Polysciences, Inc., Warrington, PA., Data Sheet #365, 1990), which are flexible, non-toxic materials that slowly dissipate upon implantation and exposure to bodily fluids. See, e.g., Powell, E.M., Brain Research, 515 (1990) 309-311 and references cited in Polysciences, Inc. Data Sheet #365.

Advantageously, the gelatin or other support composition may additionally serve as a carrier for any of a number of trophic factors such as pharmacologic agents including immunosuppressants such as cyclosporin A, anti-inflammation agents such as dexamethasone, anti-angiogenic factors, anti-glial agents and anti-mitotic factors. Upon dissolution of the support composition, the factor or agent becomes available to impart the desired effect upon the surrounding tissue. The dosage can be determined by established experimental techniques.

With appropriate enzymatic digestion, using techniques disclosed by Pfeffer, B.A., Chapter 10, "Improved Methodology for Cell Culture of Human and Monkey Retinal Pigment Epithelium", Progress in Retinal Research, Vol. 10 (1991), at p.264, RPE cells are removed from the Bruch's membrane as intact sheets rather than as dissociated cells. Such a freshly harvested intact monolayer of RPE cells may be immediately apposed as an intact monolayer to a support, such as a thin collagen sheet, supplemented with an overlayer or substrate of gelatin, allowing several hours for adhesion prior to transplantation. This procedure may be useful for transplantation of RPE cells obtained in a biopsy, provided

This Sheet Has Been Replaced



THIS SHEET HAS BEEN REPLACED

sufficient RPE tissue is obtained from the biopsy as an intact monolayer.

In most cases, however, it is preferable to culture the harvested RPE cells on an attachment substrate so that a monolayer of RPE cells may be prepared. Culturing the RPE cells before harvesting is also preferred both to allow for the production of larger populations of RPE cells from a small amount of harvested tissue and to allow for a period of observation to ensure that the RPE cells to be transplanted are healthy and functional.

For proper culturing, harvested RPE cells contained are apposed to a substrate to which they will attach and grow, and which is capable of being maintained in culture conditions appropriate for efficient growth of RPE cells. Apposition of RPE cells may be accomplished by pipetting a solution containing a population of RPE cells onto the substrate. Intact sheets of harvested RPE cells in a physiological solution may also be physically released via a wide-bore pipette onto the substrate and manipulated with a fine camel-hair brush if necessary. Since RPE cell cultures grow best at around 37° C, appropriate substrates are solids at this temperature. Attachment substrates which are suitable for growth of RPE cell cultures include plastic culture ware or glass culture chamber slides coated with collagen , laminin or fibronectin for cell attachment. Coatings such as collagen may be applied to a substratum such as fibrin or activated agarose.

Culturing harvested RPE cells can be accomplished by any suitable method for obtaining a confluent monolayer of RPE cells. Appropriate culturing techniques are described in Pfeffer, B.A., Chapter 10, "Improved Methodology for Cell Culture of Human and Monkey Retinal Pigment Epithelium", Progress in Retinal Research, Vol. 10 (1991); Ed. by Osborn, N. and Chader, J., or Mayerson,

This Sheet Has Been Replaced

P.L., et al., "An Improved Method for Isolation and Culture of Rat Retinal Pigment Epithelial Cells", Investigative Ophthalmology & Visual Science, Nov., 1985, 26: 1599-1609.

Fig. 2 depicts a schematic of the preparation and transplantation of a preferred embodiment of the implant according to the invention. An implant laminate 1 is formed as depicted in Figs. 2a and 2b. Gelatin 3 is preferred for use to provide monolayer support during transplantation because it is flexible, non-toxic to neural tissues, and because it dissolves away after exposure to body temperature (37° C). However, since RPE grows too slowly at temperatures below 37° C, gelatin is not an appropriate substrate for use in culturing RPE cells. Thus, a monolayer of RPE cells 5 is first cultured on a suitable substrate for growth. RPE cells will grow on plastic culture ware A. However, to aid in removal of the monolayer of RPE cells 5 from the culture ware A, the culture ware A may be coated with a substrate 9 for the RPE cells, such as agarose or fibrin. See Fig. 2b. The substrate 9 is in turn coated with a thin (@ 2-4 microns) layer of collagen 7, to which the monolayer of RPE cells 5 readily attach, and which will serve as an anchor for the RPE cells in the post-transplantation period. If agarose is used as the substrate 9, the agarose is activated so that the collagen 7 will adhere to it by treating the surface of the agarose with an activator such as cyanogen bromide, as disclosed by Axen, R. et al., Nature (1967) 214: 1302-1304, or p-nitrophenyl chloroformate as disclosed by Wilchek, M. and Miron, T., Biochemistry International (1982) 4: 629-635.

After a satisfactory culture of RPE cells has been grown, a 5 to 30% solution of molten gelatin is applied to the apical surface of the monolayer of RPE cells 5 in the culture. The culture ware containing the RPE

cells and gelatin solution is then cooled so that the gelatin 3 is solidified into a sheet of preferably about 150-250 mm in thickness, attached to the apical surface of the RPE cells 5. The implant laminate 1 comprising a monolayer of RPE cells 5, attached to the collagen anchor 7 and an overlayer of gelatin 3, may then be physically removed from the culture ware A by slicing between the culture ware A surface and the collagen 7 with a razor C, as depicted in Fig. 2a.

The implant laminate 1 may also be removed from the culture ware and substrate 9 enzymatically, as depicted in Fig. 2b. The underlying substrate 9 may be removed from the implant laminate 1 by application of an enzyme specific to the material comprising the substrate 9. If the substrate is agarose, agarase, an enzyme specific to agarose, may be used to dissipate the agarose. A concentration of 1 mg agarase/5 ml of culture medium will suffice to dissipate the agarose substrate. If the substrate consists of a fibrin coating, enzymes such as urokinase (2 activity units urokinase/ml of culture media) may be used to break apart the fibrin. To aid in dissipation of the substrate 9, the culture ware A may comprise a cell culture insert membrane, containing an inner membrane A-1 with a porous bottom, and an outer, solid membrane A-2. An example of such an insert membrane is the Falcon® Cyclopore™ membrane. The porous (e.g., pore size of .45 mm) inner membrane A-1 is coated with the substrate 9 during growth of the monolayer of RPE cells 5. These pores facilitate penetration of the solution B containing the enzyme into the substrate 9 so that it may be broken apart, and the implant laminate 1 removed from the culture ware A.

As depicted in Fig. 2c, the implant laminate 1 is cut to create an implant 1a sized so that it will fit into

THIS SHEET HAS BEEN REPLACED

a surgical instrument 20 which contains a carrier channel for protection of the implant 1a during the transplantation procedure. The implant 1a is transplanted to the subretinal area at the posterior pole 76 of the host eye after detachment of the retina, as portrayed in Fig. 2d, using surgical techniques more fully disclosed below. The gelatin overlayer dissolves within hours after insertion of the implant 1a into the host eye. After transplantation, the retina reattaches, and the monolayer of RPE cells, anchored to the layer of collagen, is sandwiched between the choroid and the retina. See Fig. 2e.

Fig. 3 depicts a schematic of an alternative embodiment of the implant according to the invention. As described in relationship to Fig. 2 above, a monolayer of RPE cells 5 is grown on culture ware coated with a substrate 9. However, in this embodiment, the substrate 9 remains laminated to and comprises part of the implant 1a during transplantation. The substrate 9 used for transplantation may comprise agarose, which is biologically inert and as discussed previously, may be dissipated by exposure to agarase, an enzyme which selectively attacks agarose. In this embodiment, activated agarose is coated with a thin layer of collagen 7, about 2-4 microns in thickness, which binds strongly to the activated agarose. A monolayer of RPE cells 5 is then apposed to the collagen 7 and attaches readily to form a laminate of the RPE cells 5 and the support composition (collagen 7 and substrate 9) to be used as an implant 1a for transplantation. Rather than adding an overlayer of gelatin as discussed in reference to Fig. 2, a razor is used to slice a sheet of the material comprising the substrate 9 about 150-250 mm thick to serve as a stabilizing support for the monolayer of RPE cells 5 and the collagen 7 during transplantation.

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

Once transplantation is completed and the monolayer of RPE cells has been stabilized in its proper position, an intraocular injection of an enzyme such as agarase (1 mg/5 ml vol. of vitreal chamber) if an agarose substrate is used may be administered to break down the substrate. Alternatively, the enzyme may be incorporated into a slow-release agent 11 such as ethylene-vinyl acetate copolymer (Elvax 40W, DuPont Chemical Co., Del.), which is added to the substrate 9 prior to transplantation. Methods for using biodegradable polymers as slow-release matrices for enzymes are known in the art, such as disclosed by Powell, E.M., Brain Research (1990) 515:309-311; Wise, et al.; Chapter 12, "Lactic/Glycolic Acid Polymers," Drug Carriers in Biology and Medicine (Ed., Gregoriades), 1979; Kitchell, J. and Wise, D., "Poly(lactic/glycolic acid) Biodegradable Drug - Polymer Matrix Systems," Methods in Enzymology, 112:436-448 (1985). Slow release of the enzyme causes gradual break up of the substrate support. The collagen 7 remaining after dissipation of the substrate 9 is physiologically permeable to and does not impede normal tissue function, and serves to anchor the monolayer of RPE cells 5, as well as to inhibit neovascularization in the subretinal area of the host eye.

Fibrin, discussed in connection with Fig. 2, may also be used as the substrate 9 in the embodiment depicted in Fig. 3. Fibrin is the fibrous, insoluble protein that forms the structural component for blood clots. Fibrin may be pressed to add tensile strength and is a material which provides a flexible, non-toxic support to which RPE cells will attach and grow as a monolayer. To prepare fibrin, fibrin clot suitable for substrate use is made by catalyzing the polymerization of fibrinogen into fibrin by the addition of thrombin. After transplantation, fibrin will dissipate upon exposure to naturally produced enzymes

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

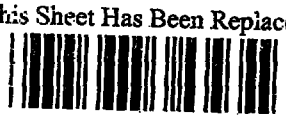
which dissolve blood clots. If the dissipation of the fibrin support composition is to be accelerated, enzymes which are specific for fibrin, such as tissue plasminogen activator (TPA), urokinase or streptokinase may be administered using one of the methods for application of enzymes discussed above.

To transplant the implant, the host eye is prepared so as to reduce bleeding and surgical trauma. A transcleral/transchoroidal surgical approach to the subretinal space is an example of a suitable approach and it will be understood that other surgical approaches, such as a transcorneal approach, may also be used. The preferred surgical approach in the human, Fig. 4, includes making a transverse incision 70 in a sclera and choroid 78 of sufficient size so as to allow insertion of a surgical instrument 20. The instrument 20 is advanced through the sclera and choroid 78 and to the ora serrata 74 as illustrated in Fig. 4. The instrument detaches the retina as it is advanced under the retina and into the sub-retinal space to the posterior pole 76 of the eye.

Preferably, an instrument comprising an elongate tube having a flat, wide cross-section may be used so that the implant may be drawn into the elongate tube for protection as it is transported through an appropriate sized incision in the sclera or choroid. The instrument is advanced to the ora serrata 74 of the host eye and if the instrument includes a lumen, the retina is detached by the gentle force of a perfusate such as a saline-like fluid, carboxymethylcellulose, or 1-2% hyluronic acid ejected from the lumen. Advantageously, the fluid may additionally contain anti-oxidants, anti-inflammation agents, anesthetics or agents that slow the metabolic demand of the host retina.

If the instrument does not include a lumen, the retina is detached by subretinal irrigation or by the walls

This Sheet Has Been Replaced



THIS SHEET HAS BEEN REPLACED

of the surgical instrument as it is advanced under the retina and into the subretinal space to the posterior pole 76 of the eye. The implant is then transplanted by retracting the tube containing the implant from the eye while simultaneously gently ejecting the implant from the tube. The instrument is then carefully withdrawn out of the eye. Retinal reattachment occurs rapidly and the monolayer of RPE cells is held in place in a sandwich-like arrangement between the retina and the choroid. The incision may require suturing.

Fig. 5 depicts a transcorneal surgical approach as an alternative to the transscleral and choroidal approaches described above. Except for the point of entry, the surgical technique is essentially the same as outlined for the transscleral or choroidal approaches. A transverse incision 70 is made in a cornea 72 and the instrument 20 containing the implant is advanced under the iris, through the cornea 72 and to the ora serrata 74 as illustrated in Fig. 5. The iris should be dilated for example, with topical atropine. The edges of the corneal incision are abutted and sutured if necessary to allow healing. The transcorneal approach is preferred for rodents because it has been found to reduce bleeding and surgical trauma. Nevertheless, a transscleral or choroidal approach is preferred for humans to avoid scarring of the cornea which may interfere with visual acuity.

A further surgical approach is to diathermize in the pars planna region to eliminate bleeding. The sclera is then incised and the choroidal and any native epithelial tissue is diathermized. The surgical tool is then inserted through the incision, the retina is intercepted at the ora serrata and the implant is deposited in the subretinal area otherwise as outlined elsewhere herein.

In yet a further surgical approach, entry is gained through the pars planna area as outlined above and

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

an incision is made in the retina adjacent to the retinal macula. The surgical tool is then inserted through the retinotomy and into the macular area.

As discussed previously in connection with the make up of the support compositions used in accordance with the invention, after transplantation, the implant is exposed to a predetermined set of conditions, such as exposure to heat, selected enzymes or bodily fluids. Upon the appropriate amount of exposure, the support composition is dissipated or will not otherwise impede normal eye tissue function of the host eye and the transplanted population of RPE cells.

The following examples illustrates the invention.

EXAMPLE 1

Experimental Animal and Materials

RPE cells were taken from the sub-retinal area of donated human eyes (obtained from the Missouri Lions and St. Louis Eye Banks) following corneal removal. Hosts were adult albino rats immune-suppressed with cyclosporin A 10 mg/kg/day IP injection).

Harvesting of RPE Cells

Immediately after corneal removal, the eye was pinned by the optic nerve stump into an eye cage and placed into an eye jar. The jar was flooded to capacity with cold Delbacco's modified essential medium (DMEM), supplemented with 5% fetal bovine serum. The eye was processed in a sterile environment. After loose connective tissue and muscle were carefully trimmed from the eye, it was placed upright on a sterile plate and the anterior segment with the adherent vitreous was lifted out of the eye cup. Four slits were cut radially toward the optic disc with the eye lying flat in a petri dish. The neural retina was then

This Sheet Has Been Replaced

separated at the optic disc and removed. The shell was then washed with Hanks' balanced salt solution, Ca++ and Mg++ free, and treated with 0.25% trypsin for 30 min. at 37° C. The trypsin solution was aspirated from the shell and DMEM (GIBCO) was added. The cells were released from Bruch's membrane by gently brushing the surface of the RPE cells with the polished tip of a pasteur pipette and pipetting the culture medium in the shell.

Culturing of RPE Cells

Glass culture chamber slides were prepared by coating them with liquid collagen obtained from Sigma Chemical Co., St. Louis. The collagen was allowed to solidify to about 150 microns in thickness. $3X10^5$ RPE cells were plated onto the prepared slides using a pasteur pipette. The RPE cells were then incubated in DMEM + F12 (1:1. GIBCO) supplemented with 20% fetal bovine serum (Sigma Chemical Co., St. Louis). The culture medium was changed every 3-4 days until a confluent monolayer of RPE cells had been cultivated. Implants comprising monolayers of RPE cells laminated to collagen were removed from the culture chamber slides and sheets of approximately 2 mm X 4 mm were cut out for transplantation.

Surgical Procedure

A transverse incision was made in the cornea sufficient to allow insertion of a surgical instrument that is 2.5 mm wide with a lumen 0.5 mm high. The instrument was advanced under the iris (dilated with topical atropine) to the ora serrata, detaching the retina. The carrier was then advanced under the retina into the subretinal space to the posterior pole of the eye. The instrument allowed an implant comprising a monolayer of RPE cells apposed to a 150 mm collagen substrate (up to 2.5 X 4 mm) to be guided

THIS SHEET HAS BEEN REPLACED

into the retinal space by advancement of the plunger with simultaneous retraction of the surgical instrument. The instrument was then removed. Following removal of the instrument, the edges of the corneal incision were abutted to allow rapid, sutureless healing. The eye was patched during recovery and a prophylactic dose of penicillin was administered. Upon removal of the patch, a veterinary ophthalmic antibiotic ointment was applied.

Transplant recipients were maintained on a 12 hr/12 hr light/dark cycle with an average light intensity of 50 lux. Following appropriate survival times, the animal was overdosed with pentobarbital.

Fig. 6 shows a view of the transplanted monolayer of RPE cells positioned under the retina, with the cornea, pupil and lens removed, two weeks post-transplantation. The arrows designate the edges of the implant.

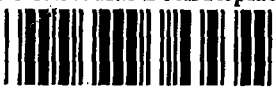
Histologic Preparation

For histologic evaluation, rat eyes with RPE cell implants were immersion-fixed in Bouin's solution for 5 hrs., then dehydrated in a graded ethanol series. The eyes were trimmed with a razor blade to include the transplanted area for implanted retinas, then processed through xylene and embedded in paraffin. Sections were cut at 8mm and stained with hematoxylin and eosin.

Results

By using the transcorneal approach, it was found that the positioning of the monolayer of RPE cells between the host's retina and the adjacent choroidal tissue layer of the eye could be accomplished while minimizing the vascular damage and subsequent bleeding into the eye. In addition, it was found that this approach does not appear to disrupt the integrity of the retina, which reattaches to

This Sheet Has Been Replaced



THIS SHEET HAS BEEN REPLACED

the back of the eye with the transplanted RPE cells interposed between the retina and the choroid. Using this insertion method, it was possible to position the RPE cells beneath the posterior pole of the retina (Fig. 7).

To determine the viability of the transplanted RPE cells, paraffin sections (8 mm) were made from the eye receiving the RPE cell transplant at 2 weeks, 4 weeks, and 3 months after transplantation. It was found that the monolayer of RPE cells survived transplantation at all times tested (10 out of 12 transplants).

With immune-suppression, successful transplants were seen at all survival times so far examined (2 weeks to 3 months), showing apparent physical integration with the host eye and maintaining morphological features of the RPE as illustrated in Fig. 7 which shows a transplant of a monolayer of human RPE cells from adult donor to adult rat host. (T, transplant). 40X.

Paraffin sections made at 2 weeks post-transplantation are shown in Figs. 7 and 8. Fig. 7 is a low-power photomicrograph showing the location of the RPE monolayer transplant (T) between arrowheads at the posterior pole of th host eye. Note the maintenance of normal retinal configuration as well as the normal appearance of the RPE cells, maintained in substantially a monolayer between the choroid and the outer segments of the photoreceptor cells. Figure 8 is a higher-power photomicrograph showing in detail the interface between the transplant and the adjacent retina. As shown in Fig. 8, the photoreceptor outer segments are shown to be in normal apposition to the apical microvillar processes (A) of transplanted RPE cells.

The functional capabilities of the transplanted RPE cells and reconstructed retina were ascertained by their maintenance of photoreceptor bodies, and the presence

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

of inner and outer segments with proper orientation to the apical processes of transplanted RPE cells. The success of these procedures for transplanting monolayers of RPE cells are reflected in Figs. 7 and 8.

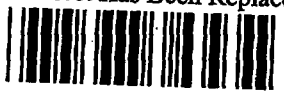
EXAMPLE 2

As a comparison, mature human RPE cells were transplanted in dissociated form using the bolus injection method as set forth by Li and Turner in Exp. Eye Res., 47:911 (1988). RPE cells from the same donor tissue used for the transplants conducted as set forth in Example 1 were harvested and cultured as set forth in Example 1. After culturing, the RPE cells were trypsonized to form dissociated RPE cells for transplantation by bolus injection according to the method of Li and Turner. Hosts were adult albino rats immune-suppressed with cyclosporin A 10 mg/kg/day IP injection) as set forth in Example 1.

Transplant recipients were maintained on a 12 hr/12 hr light/dark cycle with an average light intensity of 50 lux. Following appropriate survival times, the animal was overdosed with pentobarbital. Paraffin sections of the eye receiving the RPE cell implant were then cut (8 mm).

Paraffin sections made at 2 weeks post-transplantation are shown in Figs. 9 and 10. Fig. 9 is a low-power photomicrograph showing the location of the injection of dissociated RPE cells at the posterior pole of the host eye. Note the pathological configurations, including retinal detachment (RD), retinal pucker (RP), subretinal fibrosis (SF) and retinal rosette (RR) formation. Figure 10 is a higher-power photomicrograph showing in detail the pathological invasion of RPE cells into the adjacent retina, subretinal fibrosis and retinal pucker.

This Sheet Has Been Replaced



From the foregoing description those skilled in the art will appreciate that all aspects of the present invention are realized. The present invention provides an improved surgical implant that is adapted to provide cell organization during transplantation of the RPE cells. With the implant of this invention cell organization is maintained during and after RPE transplantation.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantages attained.

As various changes could be made in the above compositions and methods without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

THIS SHEET HAS BEEN REPLACED

WHAT IS CLAIMED

1. A method for the preparation of a population of RPE cells for transplantation to the subretinal area of an eye of a host comprising:

(a) providing donor tissue comprising RPE cells,

(b) harvesting RPE cells from the donor tissue, and

(c) apposing the harvested RPE cells as a monolayer to a non-toxic flexible support that, upon transplantation to the subretinal area and exposure to a set of predetermined conditions, will not impede normal eye tissue function of the eye of the host and the transplanted population.

2. A method as set forth in claim 1 further comprising culturing the harvested RPE cells.

3. A method as set forth in claim 1 wherein the donor tissue comprises mature RPE cells.

4. A method as set forth in claim 1 wherein the donor tissue is autologous to the host.

5. A method as set forth in claim 1 wherein the support comprises a layer of collagen less than about 100 microns in thickness.

6. A method as set forth in claim 1 wherein the harvested RPE cells have apical and basal surfaces, the support further comprises a substrate of collagen and an overlayer of gelatin, and the basal surfaces of the harvested RPE cells are apposed to the collagen and the apical surfaces of the harvested RPE cells are apposed to the gelatin.

This Sheet Has Been Replaced

* C L M S *

THIS SHEET HAS BEEN REPLACED

7. A method as set forth in claim 1 wherein the harvested RPE cells have an apical surface and apposition of the RPE cells to the support further comprises contacting the apical surface of the RPE cells to the support.

8. A method as set forth in claim 1 wherein said support comprises a material degradable by exposure to heat, bodily fluids or enzymatic action.

9. A method as set forth in claim 1 wherein the support further comprises an enzyme adapted to break down at least a portion of the support after positioning of the implant in the subretinal area.

10. A method as set forth in claim 9 wherein the enzyme is incorporated into a slow release agent.

11. A method as set forth in claim 10 wherein the slow release agent is a biodegradable polymer.

12. A method as set forth in claim 10 wherein the slow release agent is selected from the group consisting of polylactic acid, polyglycolic acid, polylactide-co-glycolide and ethylene-vinyl acetate copolymer.

13. A method as set forth in claim 1 wherein the support comprises a sheet of agarose coated with a layer of collagen between about 1 and about 100 microns in thickness and wherein the harvested RPE cells are apposed to the collagen prior to transplantation.

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

14. A method as set forth in claim 13 wherein the support further comprises agarase incorporated into a slow release agent.

15. A method as set forth in claim 1 wherein the support comprises fibrin.

16. A method as set forth in claim 15 wherein the support further comprises an enzyme selected from the group of tissue plasminogen activator, urokinase or streptokinase.

17. A method as set forth in claim 1 wherein the support comprised one or more of a trophic factor, an immunosuppressant, an anti-inflammation agent, an ant-angiogenic factor, an anti-glial agent or an anti-mitotic factor.

18. A method for the preparation of a population of RPE cells for transplantation to the subretinal area of an eye of a host comprising:

(a) providing donor tissue comprising RPE cells,

(b) harvesting RPE cells from the donor tissue,

(c) culturing the harvested RPE cells on a substrate suitable for attachment and growth of a monolayer of RPE cells,

(d) removing the monolayer of cultured RPE cells from the substrate, and

(e) apposing the monolayer of cultured RPE cells to a non-toxic flexible support that, upon transplantation to the subretinal area and exposure to a set of predetermined conditions, will not impede normal eye tissue function of the eye of the host and the transplanted population.

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

19. A method as set forth in claim 18 wherein the substrate is comprised of agarose, removing the monolayer from the substrate comprises contacting the agarose with agarase, the support comprises gelatin and apposing the monolayer to the support comprises contacting the monolayer with a molten solution of gelatin and cooling the gelatin so that the gelatin solidifies.

20. An implant for transplantation to the subretinal area of an eye of a host comprising a laminate of a monolayer of RPE cells and a non-toxic, flexible support that, upon transplantation to the subretinal area and exposure to a set of predetermined conditions, will not impede normal eye tissue function.

21. An implant as set forth in claim 16 wherein the RPE cells further comprise mature RPE cells.

22. An implant as set forth in claim 16 wherein the RPE cells are autologous to the host.

23. An implant as set forth in claim 20 wherein the predetermined conditions comprise exposure to heat, bodily fluids or enzymatic action to break down at least a portion of the composition.

24. An implant as set forth in claim 20 wherein the support comprises a material degradable by exposure to heat, bodily fluids or enzymatic action.

25. An implant as set forth in claim 20 wherein the support further comprises an enzyme adapted to break down at least a portion of the support after positioning of the implant in the subretinal area.

This Sheet Has Been Replaced

* C L M S *

THIS SHEET HAS BEEN REPLACED

26. An implant as set forth in claim 25 wherein the enzyme is incorporated into a slow release agent.

27. An implant as set forth in claim 26 wherein the slow release agent is a biodegradable polymer.

28. An implant as set forth in claim 26 wherein the slow release agent is selected from the group consisting of polylactic acid, polyglycolic acid, polylactide-co-glycolide and ethylene-vinyl acetate copolymer.

29. An implant as set forth in claim 20 wherein the support comprises a layer of collagen less than about 100 microns in thickness.

30. An implant as set forth in claim 20 wherein the monolayer of RPE cells have apical and basal surfaces, the support further comprises a substrate of collagen and an overlayer of gelatin, and the basal surfaces of the monolayer of RPE cells are laminated to the collagen and the apical surfaces of the monolayer of RPE cells are laminated to the gelatin.

31. An implant as set forth in claim 20 wherein the support comprises a sheet of agarose coated with a layer of collagen between about 1 and about 100 microns in thickness.

32. An implant as set forth in claim 31 wherein the support further comprises agarase incorporated into a slow release agent.

This Sheet Has Been Replaced

* C L M S *

THIS SHEET HAS BEEN REPLACED

33. An implant as set forth in claim 20 wherein the support comprises fibrin.

34. An implant as set forth in claim 33 wherein the support further comprises an enzyme selected from the group of tissue plasminogen activator, urokinase or streptokinase.

35. An implant as set forth in claim 20 wherein the support comprises one or more of a trophic factor, an immunosuppresant, an anti-inflamation agent, an anti-angiogenic factor, an anti-glial agent or an anti-mitotic factor.

36. A method for transplanting a monolayer of RPE cells to the subretinal area of an eye of a host comprising:

(a) providing an implant comprising a laminate of a monolayer of RPE cells and a non-toxic, flexible support that, upon transplantation to the subretinal area and exposure to a set of predetermined conditions, will not impede normal eye tissue function,

(b) making an incision through the eye of the host,

(c) at least partially detaching the retina to permit access to the subretinal area, and

(d) positioning the implant in the accessed subretinal area.

37. A method for transplanting as set forth in claim 36 in which the predetermined conditions comprise exposing the support to heat, bodily fluids, or enzymatic action.

This Sheet Has Been Replaced

* C L M S *

THIS SHEET HAS BEEN REPLACED

38. A method for transplanting as set forth in claim 36 further comprising infusing the subretinal area of the eye of the host with an enzyme to break down at least a portion of the support.

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

RETINAL PIGMENT EPITHELIUM TRANSPLANTATION

ABSTRACT

An implant is provided for transplantation to the subretinal area of a host eye comprising a laminate of a monolayer of retinal pigment epithelium (RPE) cells and a non-toxic, flexible support that, upon exposure to a set of predetermined conditions, will not impede normal eye tissue function. A method for preparing a population of RPE cells for transplantation to the subretinal area of a host eye is also provided. The method includes the steps of providing donor tissue comprising RPE cells, harvesting from that tissue RPE cells, and apposing the harvested RPE cells as a monolayer to a non-toxic, flexible support that, upon transplantation to the subretinal area and exposure to a set of predetermined conditions, will not impede normal eye tissue function of the host eye and the transplanted population. A method for transplanting the above implant is also provided, comprising providing the implant, making an incision through a host's eye, at least partially detaching the retina to permit access to the subretinal area, and positioning the implant in the accessed area.

(Figure 2d)

This Sheet Has Been Replaced

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

FIG.1

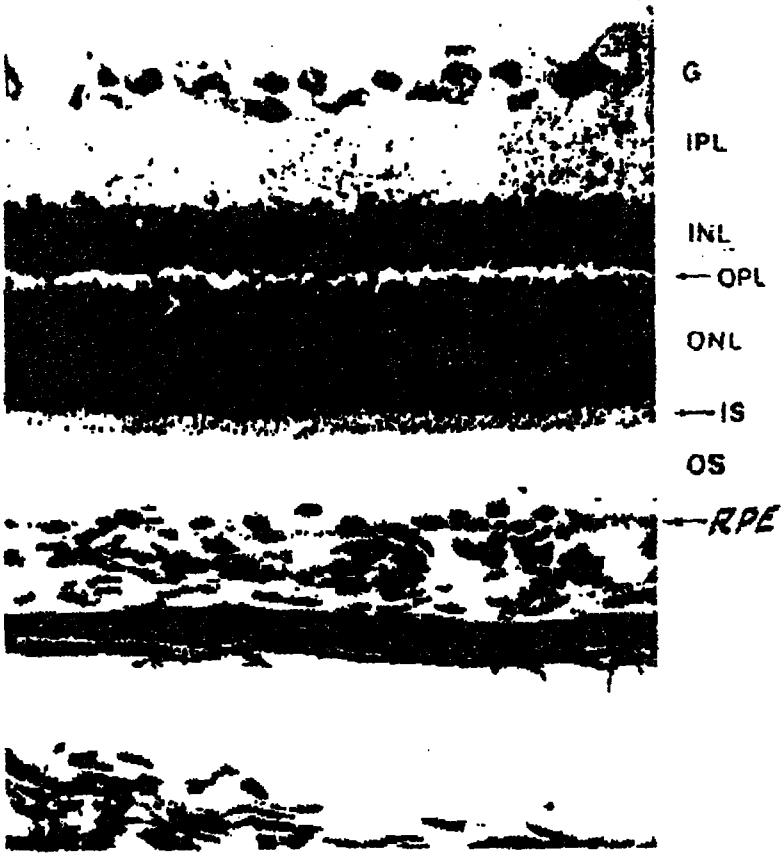


FIG.2a

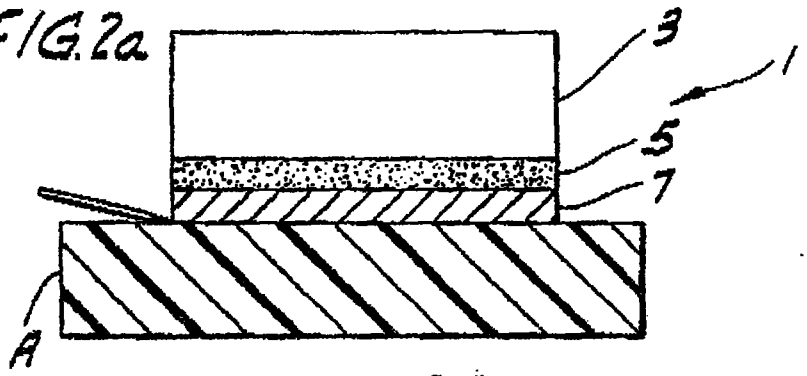
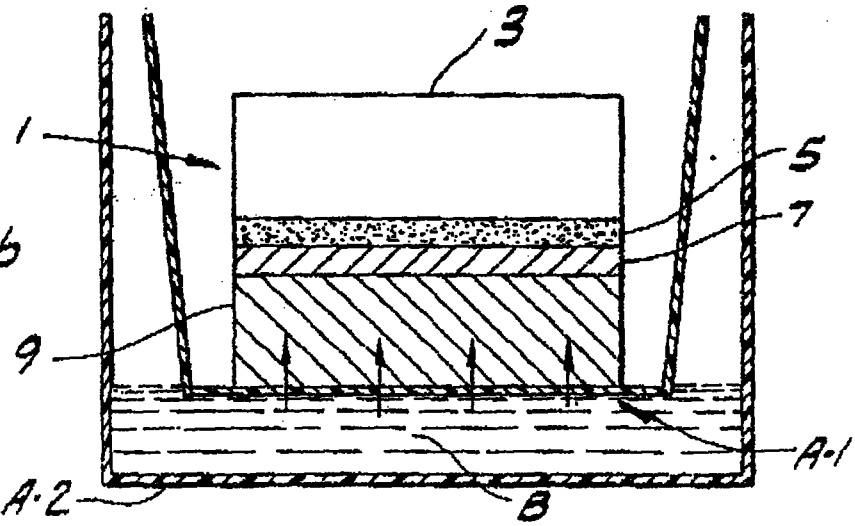


FIG.2b



THIS SHEET HAS BEEN REPLACED

FIG. 2c

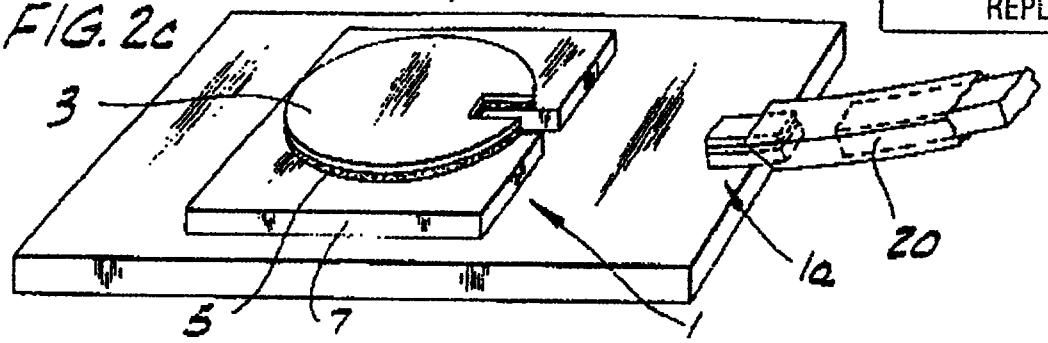


FIG. 2d

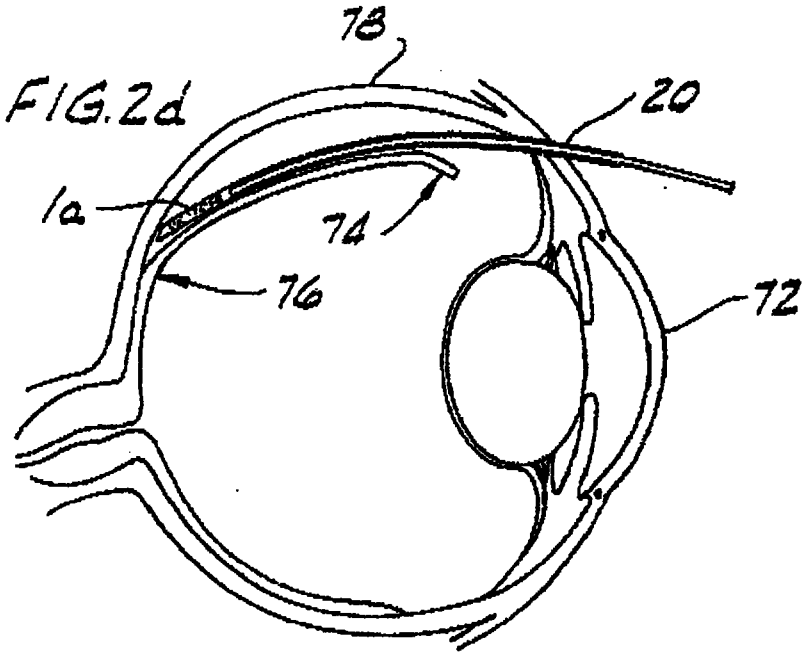
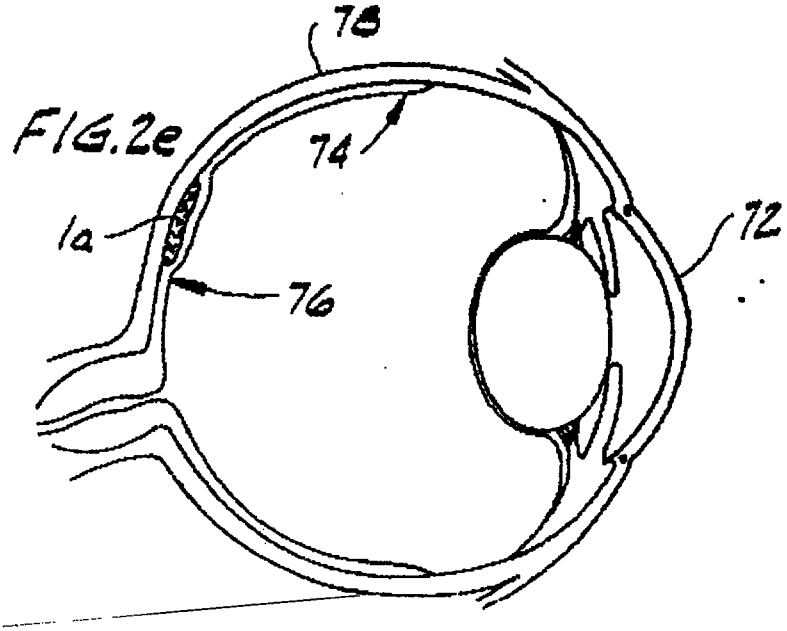


FIG. 2e



This Sheet Has Been Replaced

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

FIG. 3

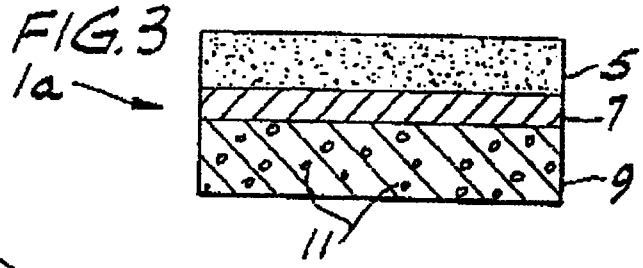


FIG. 4

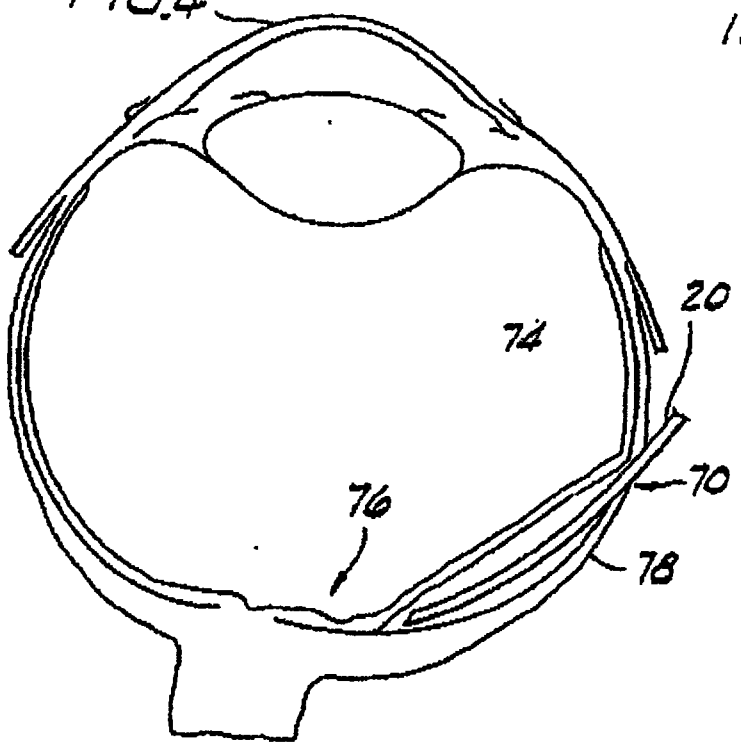
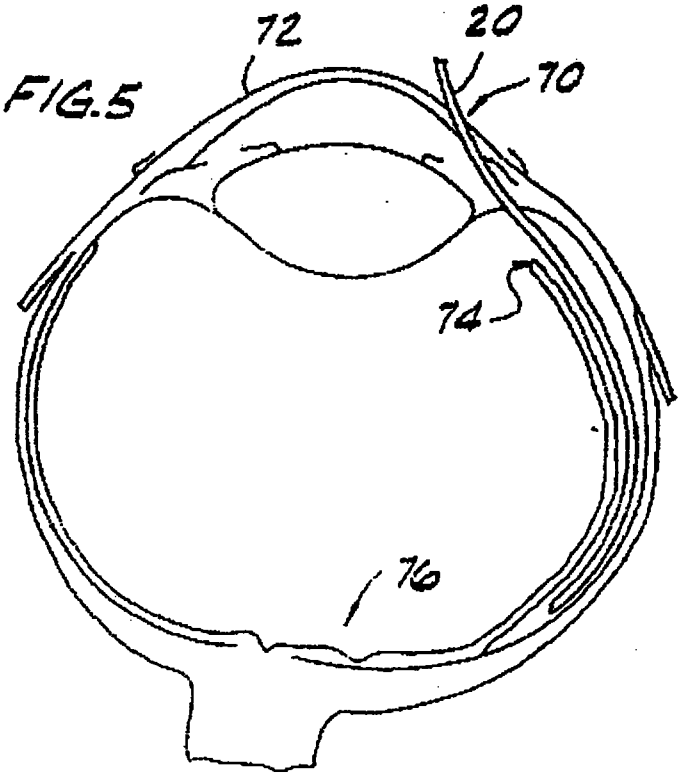
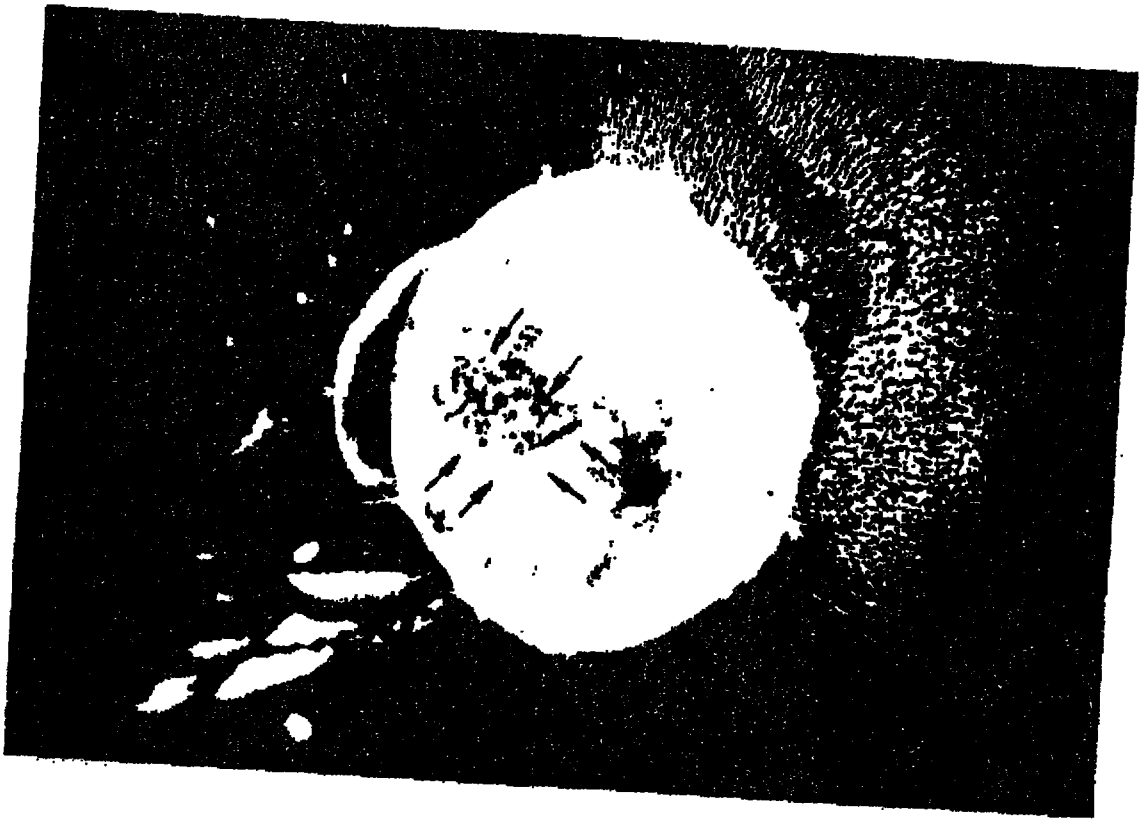


FIG. 5



THIS SHEET HAS BEEN REPLACED

FIG. 6



This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

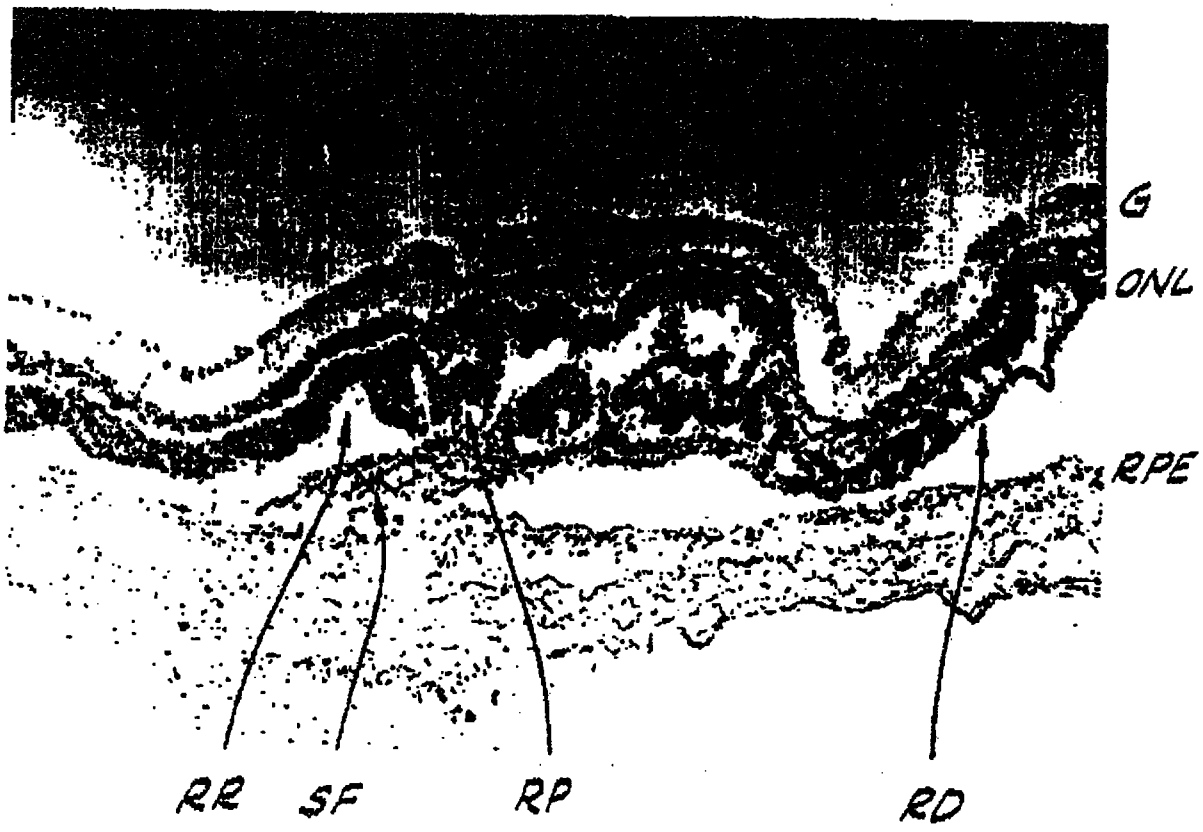
FIG. 7

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

FIG.8

FIG.9



This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

FIG.10

This Sheet Has Been Replaced

REPLACEMENT SHEET
19 DEC 1997

partially detaching the retina to permit access to the subretinal area, and positioning the implant in the accessed subretinal area.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a photograph (200X) of a cryostat section of a normal rat retina and sub-retinal area;

Fig. 2(a, b, c, d and e) is a schematic showing the preparation and transplantation of a preferred embodiment of an implant comprising a monolayer of RPE cells mounted to a support;

~~Fig. 3 is a schematic of an alternative~~ embodiment of an implant comprising a monolayer of RPE ~~cells mounted to a support~~;

Fig. 3 is a horizontal section through an eye illustrating a transchoroidal and scleral surgical approach;

Fig. 4 is a horizontal section through an eye illustrating a transcorneal surgical approach;

Fig. 5 is a photograph showing a view of the transplanted implant of an intact monolayer of mature human RPE cells positioned under the retina of a rodent whose cornea, pupil and lens have been removed, 2 weeks post-transplantation, as set forth in Example 1;

Fig. 6 is a photograph (40X) of a section of a rat retina and sub-retinal area showing an implant of an intact monolayer of a population of mature human RPE cells 14 days after transplantation, as set forth in Example 1;

Fig. 7 is a higher magnification photograph (400X) of a section of a rat retina and sub-retinal area showing an implant of an intact monolayer of a population of mature human RPE cells 14 days after transplantation, as set forth in Example 1;

Fig. 8 is a photograph (100X) of a section of a rat retina and sub-retinal area 14 days after

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

transplantation of dissociated mature human RPE cells, as set forth in Example 2; and

Fig. 9~~10~~ is a higher magnification photograph (300X) of a section of a rat retina and sub-retinal area 14 days after transplantation of dissociated mature human RPE cells, as set forth in Example 2.

DETAILED DESCRIPTION

As used herein, the term "donor" shall mean the same or different organism relative to the host and the term "donor tissue" shall mean tissue harvested from or cultured from tissue harvested from the same or different organism relative to the host. Autologous tissue shall mean tissue harvested from or cultured from tissue harvested from the host organism. Mature RPE cells shall mean differentiated RPE cells derived from an organism that is not a fetus.

It is believed that in age-related macular degeneration (AMD), compromise or degeneration of the RPE cells which underlie and form a close structural and metabolic support for the photoreceptors, leads to the loss or destruction of viable photoreceptors. It has been discovered, however, that transplantation of a population of RPE cells as a monolayer, i.e., in essentially a two-dimensional array of cell bodies capable of engaging in cell-to-cell contact inhibition, allows the RPE cells to maintain largely normal characteristics of native, healthy retinal pigment epithelia, capable of providing structural and functional support to photoreceptor cells. Moreover, as illustrated in Example 2 below, it is believed that it is essential to transplant mature RPE cells as a monolayer in order to prevent activation of such cells. Activation leads RPE cells to transdifferentiate into wandering macrophages, fibroblast-like cells and other cell types,

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

which cause a number of dystrophic effects in the eye and retina.

Fig. 1 is a photograph of a cryostat section of a normal rat retina and subretinal area. In Fig. 1 as well as subsequent figures, the retina or layers thereof, e.g., the ganglion cell layer ("G"), inner plexiform layer ("IPL"), inner nuclear layer ("INL"), outer plexiform layer ("OPL"), outer nuclear layer ("ONL"), inner segments ("IS"), outer segments ("OS"), and retinal pigment epithelium ("RPE"), are shown, respectively, from top to bottom.

Referring now to Figs. 2 ~~and 3,~~ implants comprising a monolayer of RPE cells are prepared, in general, by harvesting RPE cells from donor tissue and apposing the harvested RPE cells as an intact monolayer to a non-toxic, flexible composition, or by seeding such a composition with a monolayer of dissociated RPE cells and allowing them to grow into a confluent layer. The flexible composition serves as a stabilizing support for the RPE cells during transplantation.

The implant constitutes a laminate of a monolayer of RPE cells and a support composition approximately 100 to 500 microns thick, and preferably 150-250 microns thick. The surface of the implant has a surface area greater than about 1 square millimeter, preferably greater than 2 square millimeters, and most preferably greater than 4 square millimeters, or as large as may be practically handled. Thus constructed, the implant may subtend a considerable extent of the sub-retinal surface.

In selecting donor tissue for the harvesting of RPE cells, it is noted that previously, transplantation of RPE cells was effectively limited to immature cells. Mature RPE cells transplanted according to prior art methods have been shown to undergo activation resulting in

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

sub-retinal area. However, it is known that Bruch's membrane is essentially comprised of collagen, and such microthin layers of collagen are permeable enough to avoid impeding normal eye tissue functions such as the metabolic exchange between the choroid and the retina. However, collagen compositions of such a minimal thickness are not strong enough to prevent buckling or distortion of the monolayer of RPE cells during transplantation. Thus, such microthin collagen materials need to be used in combination with additional supporting materials which will be eliminated after transplantation, if they are to form part of the support for the transplanted RPE cells.

If transplantation is carried out with the native Bruch's membrane intact, the host's RPE cells covering the area to receive the transplant of RPE cells may be physically and/or chemically debrided from the Bruch's membrane, for example, by applying collagenase to the native Bruch's membrane to loosen the host's RPE cells in order to permit their removal. The transplanted RPE cells may then anchor themselves directly to the Bruch's membrane.

Either to supplement a layer of collagen, as discussed above, or in cases where inclusion of a collagen anchor is not required, a support composition may be selected which is dissipated, for example, by exposure to a sufficient amount of heat, selected enzymes, or bodily fluids. Gelatin is an example of a preferred support material which is flexible, lacks toxicity to neural tissue and has the ability to dissolve at body temperature. ~~The support composition may also comprise a material such as~~ activated low gelling temperature agarose (Type VII, #A 4018 Sigma Chemical Co., St. Louis) or fibrin, which are known to dissipate ~~when~~ exposed to selective enzymes which will not ~~attack~~ other compositions. For example, agarase ~~is an enzyme known to specifically attack agarose, and~~

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

~~urokinase is an enzyme specific to fibrin.~~ Another alternative is to use biodegradable polymers such as ethylene-vinyl acetate copolymer (Elvax 40W, DuPont Chemical Co., Delaware); poly(glycolic) acid, poly(L-lactide-co-glycolide)(70:30 ratio) or poly(L- or DL-lactic) acids (low mol. wt.) (Polysciences, Inc., Warrington, PA., Data Sheet #365, 1990), which are flexible, non-toxic materials that slowly dissipate upon implantation and exposure to bodily fluids. See, e.g., Powell, E.M., Brain Research, 515 (1990) 309-311 and references cited in Polysciences, Inc. Data Sheet #365.

Advantageously, the gelatin or other support composition may additionally serve as a carrier for any of a number of trophic factors such as pharmacologic agents including immunosuppressants such as cyclosporin A, anti-inflammation agents such as dexamethasone, anti-angiogenic factors, anti-glial agents and anti-mitotic factors. Upon dissolution of the support composition, the factor or agent becomes available to impart the desired effect upon the surrounding tissue. The dosage can be determined by established experimental techniques.

With appropriate enzymatic digestion, using techniques disclosed by Pfeffer, B.A., Chapter 10, "Improved Methodology for Cell Culture of Human and Monkey Retinal Pigment Epithelium", Progress in Retinal Research, Vol. 10 (1991), at p.264, RPE cells are removed from the Bruch's membrane as intact sheets rather than as dissociated cells. Such a freshly harvested intact monolayer of RPE cells may be immediately apposed as an intact monolayer to a support, such as a thin collagen sheet, supplemented with an overlayer or substrate of gelatin, allowing several hours for adhesion prior to transplantation. This procedure may be useful for transplantation of RPE cells obtained in a biopsy, provided

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

sufficient RPE tissue is obtained from the biopsy as an intact monolayer.

In most cases, however, it is preferable to culture the harvested RPE cells on an attachment substrate so that a monolayer of RPE cells may be prepared. Culturing the RPE cells before harvesting is also preferred both to allow for the production of larger populations of RPE cells from a small amount of harvested tissue and to allow for a period of observation to ensure that the RPE cells to be transplanted are healthy and functional.

For proper culturing, harvested RPE cells contained are apposed to a substrate to which they will attach and grow, and which is capable of being maintained in culture conditions appropriate for efficient growth of RPE cells. Apposition of RPE cells may be accomplished by pipetting a solution containing a population of RPE cells onto the substrate. Intact sheets of harvested RPE cells in a physiological solution may also be physically released via a wide-bore pipette onto the substrate and manipulated with a fine camel-hair brush if necessary. Since RPE cell cultures grow best at around 37° C, appropriate substrates are solids at this temperature. Attachment substrates which are suitable for growth of RPE cell cultures include plastic culture ware or glass culture chamber slides coated with collagen , ~~laminin or fibronectin~~ for cell attachment. ~~Coatings such as collagen may be applied to a substratum such as fibrin or activated agarose~~.

Culturing harvested RPE cells can be accomplished by any suitable method for obtaining a confluent monolayer of RPE cells. Appropriate culturing techniques are described in Pfeffer, B.A., Chapter 10, "Improved Methodology for Cell Culture of Human and Monkey Retinal Pigment Epithelium", Progress in Retinal Research, Vol. 10 (1991); Ed. by Osborn, N. and Chader, J., or Mayerson,

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

a surgical instrument 20 which contains a carrier channel for protection of the implant 1a during the transplantation procedure. The implant 1a is transplanted to the subretinal area at the posterior pole 76 of the host eye after detachment of the retina, as portrayed in Fig. 2d, using surgical techniques more fully disclosed below. The gelatin overlayer dissolves within hours after insertion of the implant 1a into the host eye. After transplantation, the retina reattaches, and the monolayer of RPE cells, anchored to the layer of collagen, is sandwiched between the choroid and the retina. See Fig. 2e.

~~Fig. 3 depicts a schematic of an alternative~~ embodiment of the implant according to the invention. As described in relationship to Fig. 2 above, a monolayer of RPE cells 5 is grown on culture ware coated with a substrate 9. However, in this embodiment, the substrate 9 remains laminated to and comprises part of the implant 1a during transplantation. The substrate 9 used for transplantation may comprise agarose, which is biologically inert and as discussed previously, may be dissipated by exposure to agarase, an enzyme which selectively attacks agarose. In this embodiment, activated agarose is coated with a thin layer of collagen 7, about 2-4 microns in thickness, which binds strongly to the activated agarose. A monolayer of RPE cells 5 is then apposed to the collagen 7 and attaches readily to form a laminate of the RPE cells 5 and the support composition (collagen 7 and substrate 9) to be used as an implant 1a for transplantation. Rather than adding an overlayer of gelatin as discussed in reference to Fig. 2, a razor is used to slice a sheet of the material comprising the substrate 9 about 150-250 mm thick to serve as a stabilizing support for the monolayer ~~of RPE cells 5 and the collagen 7 during transplantation~~.

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

~~Once transplantation is completed and the~~ monolayer of RPE cells has been stabilized in its proper position, an intraocular injection of an enzyme such as agarase (1 mg/5 ml vol. of vitreal chamber) if an agarose substrate is used may be administered to break down the substrate. Alternatively, the enzyme may be incorporated into a slow-release agent 11 such as ethylene-vinyl acetate copolymer (Elvax 40W, DuPont Chemical Co., Del.), which is added to the substrate 9 prior to transplantation. Methods for using biodegradable polymers as slow-release matrices for enzymes are known in the art, such as disclosed by Powell, E.M., Brain Research (1990) 515:309-311; Wise, et al.; Chapter 12, "Lactic/Glycolic Acid Polymers," Drug Carriers in Biology and Medicine (Ed., Gregoriades), 1979; Kitchell, J. and Wise, D., "Poly(lactic/glycolic acid) Biodegradable Drug - Polymer Matrix Systems," Methods in Enzymology, 112:436-448 (1985). Slow release of the enzyme causes gradual break up of the substrate support. The collagen 7 remaining after dissipation of the substrate 9 is physiologically permeable to and does not impede normal tissue function, and serves to anchor the monolayer of RPE cells 5, as well as to inhibit neovascularization in the subretinal area of the host eye.

Fibrin, discussed in connection with Fig. 2, may also be used as the substrate 9 in the embodiment depicted in Fig. 3. Fibrin is the fibrous, insoluble protein that forms the structural component for blood clots. Fibrin may be pressed to add tensile strength and is a material which provides a flexible, non-toxic support to which RPE cells will attach and grow as a monolayer. To prepare fibrin, fibrin clot suitable for substrate use is made by catalyzing the polymerization of fibrinogen into fibrin by the addition of thrombin. After transplantation, fibrin ~~will dissipate upon exposure to naturally produced enzymes~~

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

~~which dissolve blood clots. If the dissipation of the~~ fibrin support composition is to be ~~accelerated~~, enzymes which are specific for fibrin, ~~such~~ as tissue plasminogen activator (TPA), ~~urokinase~~ or streptokinase may be administered using one of the methods for application of ~~enzymes discussed above~~.

To transplant the implant, the host eye is prepared so as to reduce bleeding and surgical trauma. A transcleral/transchoroidal surgical approach to the subretinal space is an example of a suitable approach and it will be understood that other surgical approaches, such as a transcorneal approach, may also be used. The preferred surgical approach in the human, Fig. 4, includes making a transverse incision 70 in a sclera and choroid 78 of sufficient size so as to allow insertion of a surgical instrument 20. The instrument 20 is advanced through the sclera and choroid 78 and to the ora serrata 74 as illustrated in Fig. 4. The instrument detaches the retina as it is advanced under the retina and into the sub-retinal space to the posterior pole 76 of the eye.

Preferably, an instrument comprising an elongate tube having a flat, wide cross-section may be used so that the implant may be drawn into the elongate tube for protection as it is transported through an appropriate sized incision in the sclera or choroid. The instrument is advanced to the ora serrata 74 of the host eye and if the instrument includes a lumen, the retina is detached by the gentle force of a perfusate such as a saline-like fluid, carboxymethylcellulose, or 1-2% hyluronic acid ejected from the lumen. Advantageously, the fluid may additionally contain anti-oxidants, anti-inflammation agents, anesthetics or agents that slow the metabolic demand of the host retina.

If the instrument does not include a lumen, the retina is detached by subretinal irrigation or by the walls

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

of the surgical instrument as it is advanced under the retina and into the subretinal space to the posterior pole 76 of the eye. The implant is then transplanted by retracting the tube containing the implant from the eye while simultaneously gently ejecting the implant from the tube. The instrument is then carefully withdrawn out of the eye. Retinal reattachment occurs rapidly and the monolayer of RPE cells is held in place in a sandwich-like arrangement between the retina and the choroid. The incision may require suturing.

Fig.4B depicts a transcorneal surgical approach as an alternative to the transscleral and choroidal approaches described above. Except for the point of entry, the surgical technique is essentially the same as outlined for the transscleral or choroidal approaches. A transverse incision 70 is made in a cornea 72 and the instrument 20 containing the implant is advanced under the iris, through the cornea 72 and to the ora serrata 74 as illustrated in Fig.4B. The iris should be dilated for example, with topical atropine. The edges of the corneal incision are abutted and sutured if necessary to allow healing. The transcorneal approach is preferred for rodents because it has been found to reduce bleeding and surgical trauma. Nevertheless, a transscleral or choroidal approach is preferred for humans to avoid scarring of the cornea which may interfere with visual acuity.

A further surgical approach is to diathermize in the pars planna region to eliminate bleeding. The sclera is then incised and the choroidal and any native epithelial tissue is diathermized. The surgical tool is then inserted through the incision, the retina is intercepted at the ora serrata and the implant is deposited in the subretinal area otherwise as outlined elsewhere herein.

In yet a further surgical approach, entry is gained through the pars planna area as outlined above and

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

an incision is made in the retina adjacent to the retinal macula. The surgical tool is then inserted through the retinotomy and into the macular area.

As discussed previously in connection with the make up of the support compositions used in accordance with the invention, after transplantation, the implant is exposed to a predetermined set of conditions, such as exposure to heat, ~~selected enzymes~~ or bodily fluids. Upon the appropriate amount of exposure, the support composition is dissipated or will not otherwise impede normal eye tissue function of the host eye and the transplanted population of RPE cells.

The following examples illustrates the invention.

EXAMPLE 1

Experimental Animal and Materials

RPE cells were taken from the sub-retinal area of donated human eyes (obtained from the Missouri Lions and St. Louis Eye Banks) following corneal removal. Hosts were adult albino rats immune-suppressed with cyclosporin A 10 mg/kg/day IP injection).

Harvesting of RPE Cells

Immediately after corneal removal, the eye was pinned by the optic nerve stump into an eye cage and placed into an eye jar. The jar was flooded to capacity with cold Delbecco's modified essential medium (DMEM), supplemented with 5% fetal bovine serum. The eye was processed in a sterile environment. After loose connective tissue and muscle were carefully trimmed from the eye, it was placed upright on a sterile plate and the anterior segment with the adherent vitreous was lifted out of the eye cup. Four slits were cut radially toward the optic disc with the eye lying flat in a petri dish. The neural retina was then

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

into the retinal space by advancement of the plunger with simultaneous retraction of the surgical instrument. The instrument was then removed. Following removal of the instrument, the edges of the corneal incision were abutted to allow rapid, sutureless healing. The eye was patched during recovery and a prophylactic dose of penicillin was administered. Upon removal of the patch, a veterinary ophthalmic antibiotic ointment was applied.

Transplant recipients were maintained on a 12 hr/12 hr light/dark cycle with an average light intensity of 50 lux. Following appropriate survival times, the animal was overdosed with pentobarbital.

Fig.5~~6~~ shows a view of the transplanted monolayer of RPE cells positioned under the retina, with the cornea, pupil and lens removed, two weeks post-transplantation. The arrows designate the edges of the implant.

Histologic Preparation

For histologic evaluation, rat eyes with RPE cell implants were immersion-fixed in Bouin's solution for 5 hrs., then dehydrated in a graded ethanol series. The eyes were trimmed with a razor blade to include the transplanted area for implanted retinas, then processed through xylene and embedded in paraffin. Sections were cut at 8mm and stained with hematoxylin and eosin.

Results

By using the transcorneal approach, it was found that the positioning of the monolayer of RPE cells between the host's retina and the adjacent choroidal tissue layer of the eye could be accomplished while minimizing the vascular damage and subsequent bleeding into the eye. In addition, it was found that this approach does not appear to disrupt the integrity of the retina, which reattaches to

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

the back of the eye with the transplanted RPE cells interposed between the retina and the choroid. Using this insertion method, it was possible to position the RPE cells beneath the posterior pole of the retina (Fig.6A).

To determine the viability of the transplanted RPE cells, paraffin sections (8 mm) were made from the eye receiving the RPE cell transplant at 2 weeks, 4 weeks, and 3 months after transplantation. It was found that the monolayer of RPE cells survived transplantation at all times tested (10 out of 12 transplants).

With immune-suppression, successful transplants were seen at all survival times so far examined (2 weeks to 3 months), showing apparent physical integration with the host eye and maintaining morphological features of the RPE as illustrated in Fig. 6A which shows a transplant of a monolayer of human RPE cells from adult donor to adult rat host. (T, transplant). 40X.

Paraffin sections made at 2 weeks post-transplantation are shown in Figs.6A and 8A. Fig.6A is a low-power photomicrograph showing the location of the RPE monolayer transplant (T) between arrowheads at the posterior pole of th host eye. Note the maintenance of normal retinal configuration as well as the normal appearance of the RPE cells, maintained in substantially a monolayer between the choroid and the outer segments of the photoreceptor cells. Figure 7B is a higher-power photomicrograph showing in detail the interface between the transplant and the adjacent retina. As shown in Fig.7B, the photoreceptor outer segments are shown to be in normal apposition to the apical microvillar processes (A) of transplanted RPE cells.

The functional capabilities of the transplanted RPE cells and reconstructed retina were ascertained by their maintenance of photoreceptor bodies, and the presence

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

of inner and outer segments with proper orientation to the apical processes of transplanted RPE cells. The success of these procedures for transplanting monolayers of RPE cells are reflected in Figs.6 and 7.

EXAMPLE 2

As a comparison, mature human RPE cells were transplanted in dissociated form using the bolus injection method as set forth by Li and Turner in Exp. Eye Res., 47:911 (1988). RPE cells from the same donor tissue used for the transplants conducted as set forth in Example 1 were harvested and cultured as set forth in Example 1. After culturing, the RPE cells were trypsonized to form dissociated RPE cells for transplantation by bolus injection according to the method of Li and Turner. Hosts were adult albino rats immune-suppressed with cyclosporin A 10 mg/kg/day IP injection) as set forth in Example 1.

Transplant recipients were maintained on a 12 hr/12 hr light/dark cycle with an average light intensity of 50 lux. Following appropriate survival times, the animal was overdosed with pentobarbital. Paraffin sections of the eye receiving the RPE cell implant were then cut (8 mm).

Paraffin sections made at 2 weeks post-transplantation are shown in Figs.8 and 9. Fig.8 is a low-power photomicrograph showing the location of the injection of dissociated RPE cells at the posterior pole of the host eye. Note the pathological configurations, including retinal detachment (RD), retinal pucker (RP), subretinal fibrosis (SF) and retinal rosette (RR) formation. Figure 9 is a higher-power photomicrograph showing in detail the pathological invasion of RPE cells into the adjacent retina, subretinal fibrosis and retinal pucker.

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

* C L M S *

CLAIMS

1. A method for the preparation of a population of retinal pigment epithelial cells for transplantation to the subretinal area of a host's eye comprising:

providing donor tissue comprising retinal pigment epithelial cells;

harvesting retinal pigment epithelial cells from the donor tissue; and

apposing the harvested retinal pigment epithelial cells as a monolayer to a non-toxic flexible support comprising gelatin that, upon transplantation to the subretinal area, will not impede normal eye tissue function of the host's eye and of the transplanted retinal pigment epithelial cells.

2. The method as set forth in claim 1 further comprising, prior to said apposing step and after said step of harvesting, culturing said retinal epithelial cells to form a monolayer.

3. The method as set forth in claim 1 wherein the donor tissue comprises mature RPE cells.

4. The method as set forth in claim 1 wherein the donor tissue is autologous to the host.

5. The method as set forth in claim 1, wherein the support further comprises a layer of collagen between about 1 micron and about 100 microns in thickness.

6. The method as set forth in claim 1 wherein the harvested RPE cells have apical and basal surfaces, the support further comprises a substrate of collagen and an overlayer of gelatin, and the basal surfaces of the harvested RPE cells are apposed to the collagen and the apical surfaces of the harvested RPE cells are apposed to the gelatin.

This Sheet Has Been Replaced

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

* C L M S *

7. The method as set forth in claim 1 wherein the harvested RPE cells have an apical surface and apposition of the RPE cells to the support comprises contacting the apical surface of the RPE cells to the support.

8. The method as set forth in claim 1 wherein the support further comprises one or more of a trophic factor, an immunosuppressant, an anti-inflammation agent, an anti-angiogenic factor, an anti-glial agent or an anti-mitotic factor.

9. A method for the preparation of a population of retinal pigment epithelial cells for transplantation to the subretinal area of a host's eye comprising:

providing donor tissue comprising retinal pigment epithelial cells;

harvesting retinal pigment epithelial cells from the donor tissue;

culturing the harvested retinal pigment epithelial cells on a substrate to attach and grow a monolayer of retinal pigment epithelial cells on the substrate;

removing the monolayer of cultured retinal pigment epithelial cells from the substrate; and

apposing the monolayer of cultured retinal pigment epithelial cells to a non-toxic flexible support comprising gelatin that, upon transplantation to the subretinal area, will not impede normal eye tissue function of the host's eye and of the transplanted retinal pigment epithelial cells.

10. An implant for transplantation to the subretinal area of a host's eye comprising a laminate of a monolayer of retinal pigment epithelial cells and a non-toxic, flexible support comprising gelatin that, upon transplantation to the subretinal area, will not impede normal eye tissue function of the host's eye and of the transplanted retinal pigment epithelial cells.

This Sheet Has Been Replaced

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

* C L M S *

11. The implant as set forth in claim 10 wherein the retinal pigment epithelial cells further comprise mature retinal pigment epithelial cells.

12. The implant as set forth in claim 10 wherein the retinal pigment epithelial cells are autologous to the host.

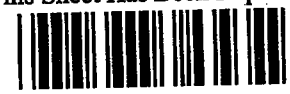
13. The implant as set forth in claim 10 wherein the support further comprises an enzyme which breaks down at least a portion of the support after positioning of the implant in the subretinal area.

14. The implant as set forth in claim 10 wherein the support further comprises a layer of collagen between about 1 micron and about 100 microns in thickness.

15. The implant as set forth in claim 10 wherein the monolayer of RPE cells has apical and basal surfaces, the support comprises a substrate of collagen and an overlayer of gelatin, and the basal surfaces of the monolayer of RPE cells are laminated to the collagen and the apical surfaces of the monolayer of RPE cells are laminated to the gelatin.

16. The implant as set forth in claim 10 wherein the support further comprises one or more of a trophic factor, an immunosuppresant, an anti-angiogenic factor, an anti-glial agent or an anti-mitotic factor.

This Sheet Has Been Replaced



AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

35

RETINAL PIGMENT EPITHELIUM TRANSPLANTATION

ABSTRACT

An implant is provided for transplantation to the subretinal area of a host's eye comprising a laminate of a monolayer of retinal pigment epithelium (RPE) cells and a non-toxic, flexible support that, upon exposure to a set of predetermined conditions, will not impede normal eye tissue function. A method for preparing a population of RPE cells for transplantation to the subretinal area of a host's eye is also provided. The method includes the steps of providing donor tissue comprising RPE cells, harvesting from that tissue RPE cells, and apposing the harvested RPE cells as a monolayer to a non-toxic, flexible support that, upon transplantation to the subretinal area and exposure to a set of predetermined conditions, will not impede normal eye tissue function of the host's eye and the transplanted population. A method for transplanting the above implant is also provided, comprising providing the implant, making an incision through a host's eye, at least partially detaching the retina to permit access to the subretinal area, and positioning the implant in the accessed area.

(Figure 2d)

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

FIG.3

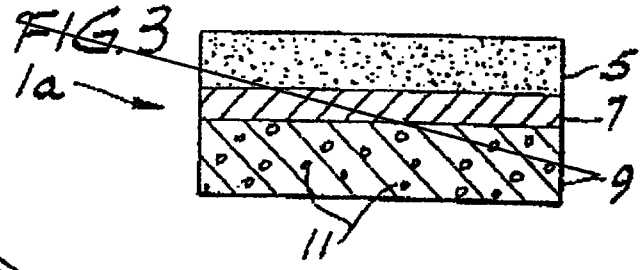


FIG.4 Fig 3

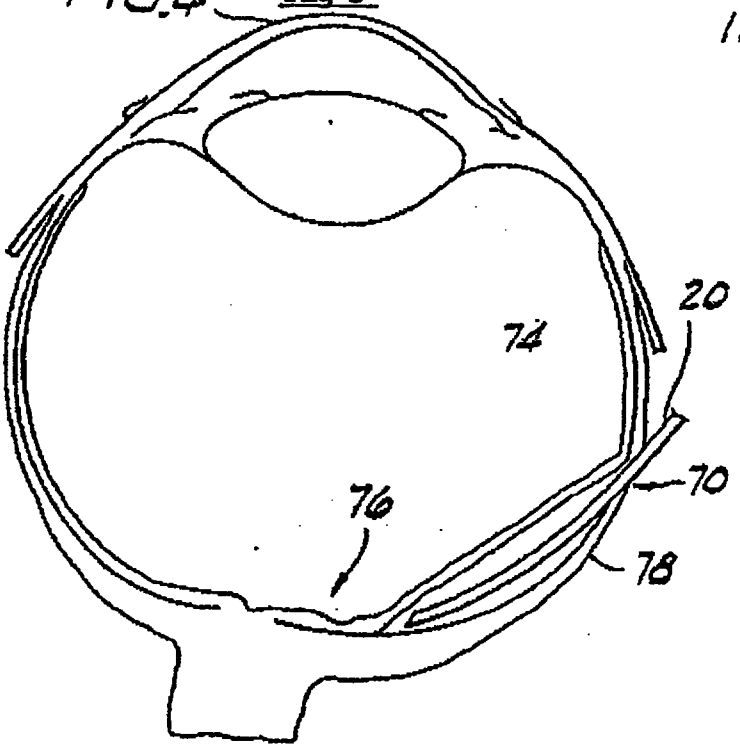
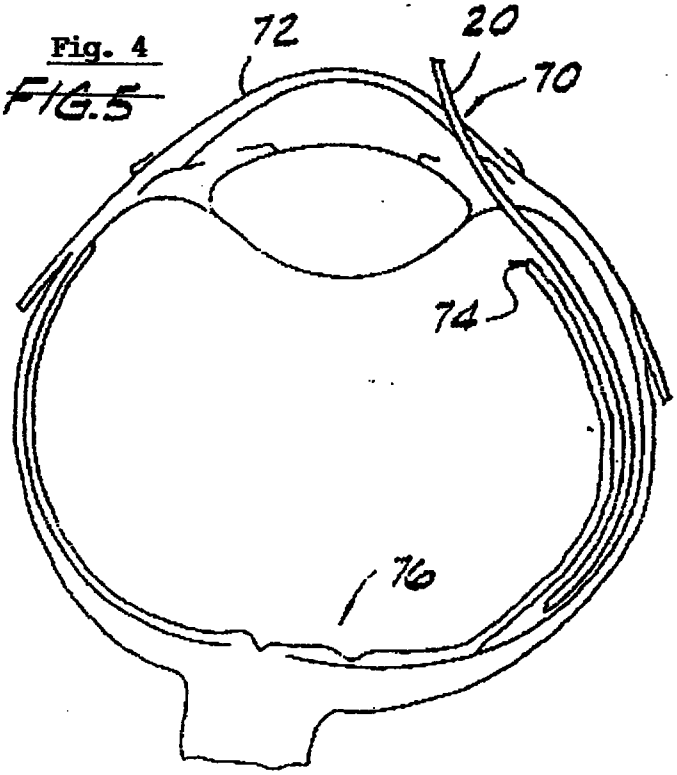


Fig. 4

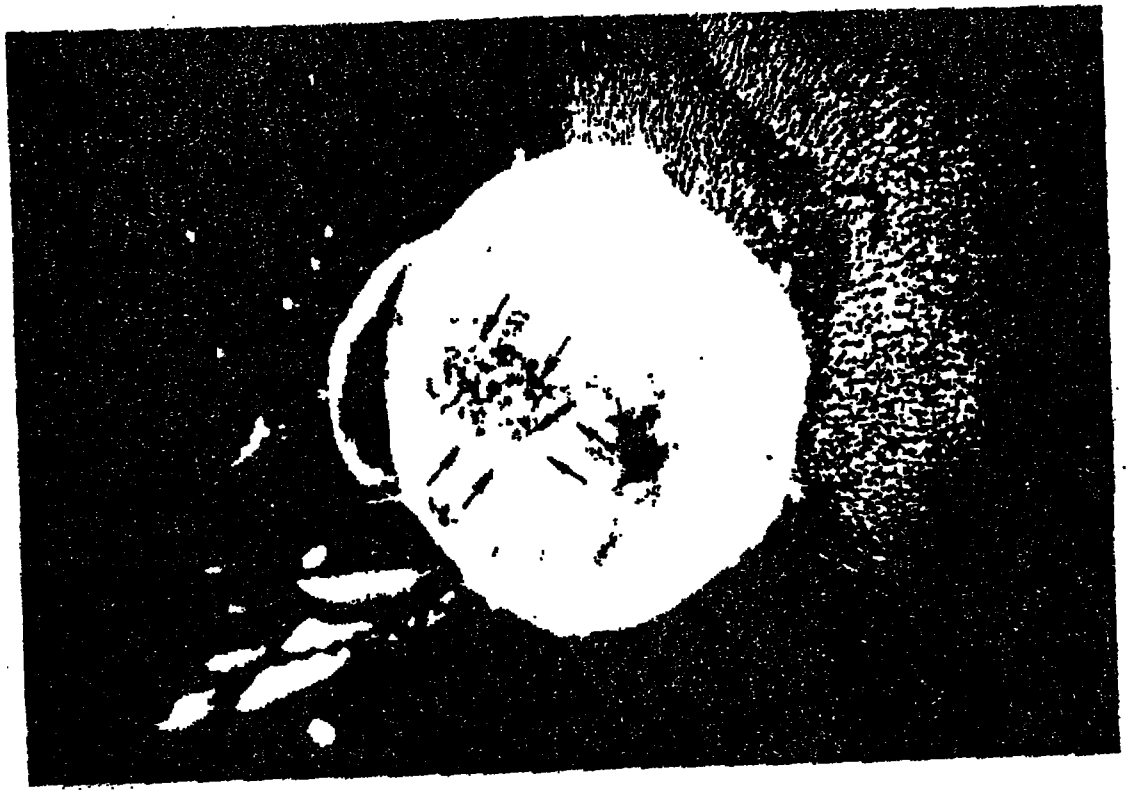
FIG.5



AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

FIG.6 Fig. 5



AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

Fig. 6

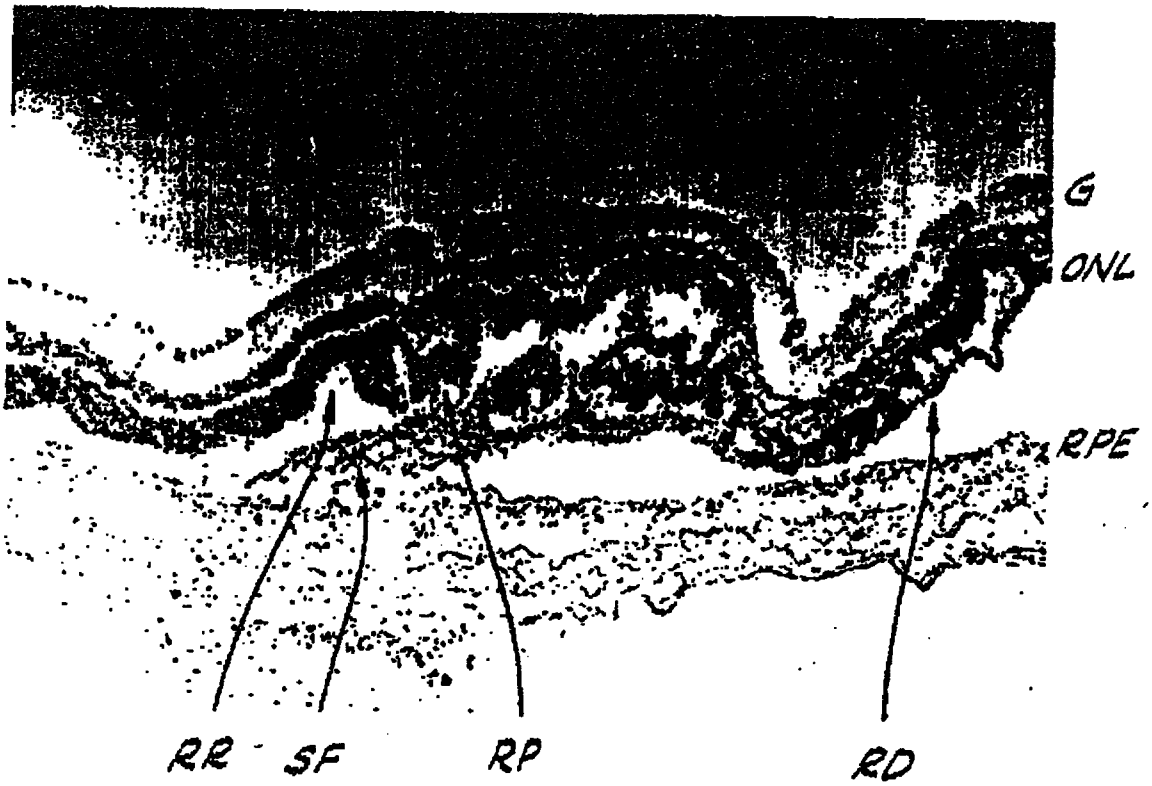
FIG. 7

AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

FIG.8 Fig. 7

FIG.9 Fig. 8



AMENDED SHEET

REPLACEMENT SHEET
19 DEC 1997

~~FIG.10~~

Fig. 9

AMENDED SHEET

REPLACEMENT SHEET
16 JUL 1998

* C L M S *

1. A method for the preparation of a population of retinal pigment epithelial cells for transplantation to the subretinal area of a host's eye comprising:

providing donor tissue comprising retinal pigment epithelial cells;

harvesting retinal pigment epithelial cells from the donor tissue; and

apposing the harvested retinal pigment epithelial cells as a monolayer to a non-toxic flexible support comprising gelatin that, upon transplantation to the subretinal area, will not impede normal eye tissue function of the host's eye and of the transplanted retinal pigment epithelial cells, and the support including an enzyme which breaks down at least a portion of the support after positioning of the implant in the subretinal area.

2. The method as set forth in claim 1 further comprising, prior to said apposing step and after said step of harvesting, culturing said retinal epithelial cells to form a monolayer.

3. The method as set forth in claim 1 wherein the donor tissue comprises mature RPE cells.

4. The method as set forth in claim 1 wherein the donor tissue is autologous to the host.

5. The method as set forth in claim 1, wherein the support further comprises a layer of collagen between about 1 micron and about 100 microns in thickness.

6. The method as set forth in claim 1 wherein the harvested RPE cells have apical and basal surfaces, the support further comprises a substrate of collagen and an overlayer of gelatin, and the basal surfaces of the

This Sheet Has Been Replaced

AMENDED SHEET

REPLACEMENT SHEET
16 JUL 1998

* C L M S *

harvested RPE cells are opposed to the collagen and the apical surfaces of the harvested RPE cells are opposed to the gelatin.

7. The method as set forth in claim 1 wherein the harvested RPE cells have an apical surface and apposition of the RPE cells to the support comprises contacting the apical surface of the RPE cells to the support.

8. The method as set forth in claim 1 wherein the support further comprises one or more of a trophic factor, an immunosuppressant, an anti-inflammation agent, an anti-angiogenic factor, an anti-glial agent or an anti-mitotic factor.

9. A method for the preparation of a population of retinal pigment epithelial cells for transplantation to the subretinal area of a host's eye comprising:

providing donor tissue comprising retinal pigment epithelial cells;

harvesting retinal pigment epithelial cells from the donor tissue;

culturing the harvested retinal pigment epithelial cells on a substrate to attach and grow a monolayer of retinal pigment epithelial cells on the substrate;

removing the monolayer of cultured retinal pigment epithelial cells from the substrate; and

apposing the monolayer of cultured retinal pigment epithelial cells to a non-toxic flexible support comprising gelatin that, upon transplantation to the subretinal area, will not impede normal eye tissue function of the host's eye and of the transplanted retinal pigment epithelial cell, and the support including an enzyme which breaks down at least a portion of the support after positioning of the implant in the subretinal area.

10. An implant for transplantation to the subretinal area of a host's eye comprising a laminate of a monolayer of retinal pigment epithelial cells and

This Sheet Has Been Replaced

AMENDED SHEET

REPLACEMENT SHEET
16 JUL 1998

* C L M S *

a non-toxic, flexible support comprising gelatin that, upon transplantation to the subretinal area, will not impede normal eye tissue function of the host's eye and of the transplanted retinal pigment epithelial cells.

11. The implant as set forth in claim 10 wherein the retinal pigment epithelial cells further comprise mature retinal pigment epithelial cells.

12. The implant as set forth in claim 10 wherein the retinal pigment epithelial cells are autologous to the host.

13. The implant as set forth in claim 10 wherein the support further comprises a layer of collagen between about 1 micron and about 100 microns in thickness.

14. The implant as set forth in claim 10 wherein the monolayer of RPE cells has apical and basal surfaces, the support comprises a substrate of collagen and an overlayer of gelatin, and the basal surfaces of the monolayer of RPE cells are laminated to the collagen and the apical surfaces of the monolayer of RPE cells are laminated to the gelatin.

15. The implant as set forth in claim 10 wherein the support further comprises one or more of a trophic factor, an immunosuppressant, an anti-angiogenic factor, an anti-glial agent or an anti-mitotic factor.

This Sheet Has Been Replaced

AMENDED SHEET

REPLACEMENT SHEET
22 OCT 1998

* C L M S *

1. A method for the preparation of a population of retinal pigment epithelial cells for transplantation to the subretinal area of a host's eye comprising:

providing donor tissue comprising retinal pigment epithelial cells;

harvesting retinal pigment epithelial cells from the donor tissue; and

apposing the harvested retinal pigment epithelial cells as a monolayer to a non-toxic flexible support comprising gelatin that, upon transplantation to the subretinal area, will not impede normal eye tissue function of the host's eye and of the transplanted retinal pigment epithelial cells, and the support including an enzyme which breaks down at least a portion of the support after positioning of the implant in the subretinal area.

2. The method as set forth in claim 1 further comprising, prior to said apposing step and after said step of harvesting, culturing said retinal epithelial cells to form a monolayer.

3. The method as set forth in claim 1 wherein the donor tissue comprises mature RPE cells.

4. The method as set forth in claim 1 wherein the donor tissue is autologous to the host.

5. The method as set forth in claim 1, wherein the support further comprises a layer of collagen between about 1 micron and about 100 microns in thickness.

6. The method as set forth in claim 1 wherein the harvested RPE cells have apical and basal surfaces, the support further comprises a substrate of collagen and an overlayer of gelatin, and the basal surfaces of the

This Sheet Has Been Replaced

AMENDED SHEET

REPLACEMENT SHEET
22 OCT 1998

* C L M S *

harvested RPE cells are apposed to the collagen and the apical surfaces of the harvested RPE cells are apposed to the gelatin.

7. The method as set forth in claim 1 wherein the harvested RPE cells have an apical surface and apposition of the RPE cells to the support comprises contacting the apical surface of the RPE cells to the support.

8. The method as set forth in claim 1 wherein the support further comprises one or more of a trophic factor, an immunosuppressant, an anti-inflammation agent, an anti-angiogenic factor, an anti-glial agent or an anti-mitotic factor.

9. A method for the preparation of a population of retinal pigment epithelial cells for transplantation to the subretinal area of a host's eye comprising:

providing donor tissue comprising retinal pigment epithelial cells;

harvesting retinal pigment epithelial cells from the donor tissue;

culturing the harvested retinal pigment epithelial cells on a substrate to attach and grow a monolayer of retinal pigment epithelial cells on the substrate;

removing the monolayer of cultured retinal pigment epithelial cells from the substrate; and

apposing the monolayer of cultured retinal pigment epithelial cells to a non-toxic flexible support comprising gelatin that, upon transplantation to the subretinal area, will not impede normal eye tissue function of the host's eye and of the transplanted retinal pigment epithelial cell, and the support including an enzyme which breaks down at least a portion of the support after positioning of the implant in the subretinal area.

10. An implant for transplantation to the subretinal area of a host's eye comprising a laminate of a monolayer of retinal pigment epithelial cells and

AMENDED SHEET

This Sheet Has Been Replaced

REPLACEMENT SHEET
22 OCT 1998

* C L M S *

a non-toxic, flexible support comprising gelatin that, upon transplantation to the subretinal area, will not impede normal eye tissue function of the host's eye and of the transplanted retinal pigment epithelial cells, the support including an enzyme which breaks down at least a portion of the support after positioning of the implant in the subretinal area.

11. The implant as set forth in claim 10 wherein the retinal pigment epithelial cells further comprise mature retinal pigment epithelial cells.

12. The implant as set forth in claim 10 wherein the retinal pigment epithelial cells are autologous to the host.

13. The implant as set forth in claim 10 wherein the support further comprises a layer of collagen between about 1 micron and about 100 microns in thickness.

14. The implant as set forth in claim 10 wherein the monolayer of RPE cells has apical and basal surfaces, the support comprises a substrate of collagen and an overlayer of gelatin, and the basal surfaces of the monolayer of RPE cells are laminated to the collagen and the apical surfaces of the monolayer of RPE cells are laminated to the gelatin.

15. The implant as set forth in claim 10 wherein the support further comprises one or more of a trophic factor, an immunosuppressant, an anti-angiogenic factor, an anti-glial agent or an anti-mitotic factor.

This Sheet Has Been Replaced

REPLACEMENT SHEET
22 OCT 1998

AMENDED SHEET

REPLACEMENT SHEET
23 AUG 1999

1. A method for the preparation of a population of RPE cells for transplantation to the subretinal area of an eye of a host comprising:

(a) providing donor tissue comprising RPE cells,

(b) harvesting RPE cells from the donor tissue, and

(c) apposing the harvested RPE cells as a monolayer to a non-toxic flexible support that, upon transplantation to the subretinal area and exposure to conditions which result in a breakdown of at least a portion of the non-toxic flexible support, will not impede normal eye tissue function of the eye of the host and the transplanted population.

2. A method as set forth in claim 1 further comprising culturing the harvested RPE cells.

3. A method as set forth in claim 1 wherein the donor tissue comprises mature RPE cells.

4. A method as set forth in claim 1 wherein the donor tissue is autologous to the host.

5. A method as set forth in claim 1, wherein the support comprises a layer of collagen less than about 100 microns in thickness.

6. A method as set forth in claim 1 wherein the harvested RPE cells have apical and basal surfaces, the support further comprises a substrate of collagen and an overlayer of gelatin, and the basal surfaces of the

* C L M S *

AMENDED SHEET

REPLACEMENT SHEET
23 AUG 1999

* C L M S *

harvested RPE cells are apposed to the collagen and the apical surfaces of the harvested RPE cells are apposed to the gelatin.

7. A method as set forth in claim 1 wherein the harvested RPE cells have an apical surface and apposition of the RPE cells to the support further comprises contacting the apical surface of the RPE cells to the support.

8. A method as set forth in claim 1 wherein said support comprises a material degradable by exposure to heat, or bodily fluids.

9. A method of Claim 1 wherein said support comprises a material which degrades upon transplantation.

10. A method as set forth in claim 1 wherein the support comprises one or more of a trophic factor, an immunosuppressant, an anti-inflammation agent, an anti-angiogenic factor, an anti-glial agent or an anti-mitotic factor.

11. A method for the preparation of a retinal pigment epithelial cell graft for transplantation to the subretinal space of a host's eye comprising the steps of:

a) providing donor tissue comprising retinal pigment epithelial cells;

b) harvesting retinal pigment epithelial cells from the donor tissue;

AMENDED SHEET

REPLACEMENT SHEET
23 AUG 1999

* C L M S *

space and upon transplantation will not impede normal eye tissue function; and

d) apposing the cultured retinal pigment epithelial cell monolayer to a non-toxic flexible support that, upon transplantation to the subretinal space, will not impede the host's normal eye tissue function nor will it impeded the normal eye tissue function of the transplanted retinal epithelial cells.

12. An implant capable of transplantation to the subretinal space formed by the method of Claim 1.

13. An implant capable of transplantation to the subretinal space formed by the method of Claim 11.

14. An implant for transplantation to the subretinal area of an eye of a host comprising a laminate of a monolayer of RPE cells and a non-toxic, flexible support that, upon transplantation to the subretinal area and exposure to conditions which result in a breakdown of at least a portion of the non-toxic, flexible support, will not impede normal eye tissue function.

15. An implant as set forth in claim 14 wherein the RPE cells further comprise mature RPE cells.

16. An implant as set forth in claim 14 wherein the RPE cells are autologous to the host.

17. An implant as set forth in claim 14 wherein the support comprises a material degradable by exposure to heat or bodily fluids.

This Sheet Has Been Replaced

AMENDED SHEET

REPLACEMENT SHEET
23 AUG 1999

* C L M S *

18. An implant as set forth in claim 14 wherein the support comprises a layer of collagen less than about 100 microns in thickness.

19. An implant as set forth in claim 14 wherein the monolayer of RPE cells have apical and basal surfaces, the support further comprises a substrate of collagen and an overlayer of gelatin, and the basal surfaces of the monolayer of RPE cells are laminated to the collagen and the apical surfaces of the monolayer of RPE cells are laminated to the gelatin.

20. A method for transplanting a monolayer of RPE cells to the subretinal area of an eye of a host comprising:

a) providing an implant comprising a laminate of a monolayer of RPE cells and a non-toxic, flexible support that, upon transplantation to the subretinal area and exposure to conditions which result in a breakdown of at least a portion of the non-toxic, flexible support, will not impede normal eye tissue function,

b) making an incision through the eye of the host,

c) at leasst partially detaching the retina to permit access to the subretinal area, and

d) positioning the implant in the accessed subretinal area.

21. A method for transplanting as set forth in claim 20 in which the conditions comprise exposing the support to heat or bodily fluids.

AMENDED SHEET

REPLACEMENT SHEET
23 AUG 1999

* C L M S *

22. An implant capable of transplantation to the subretinal space formed by the method of Claim 21.

23. An implant for transplantation to the subretinal area of an eye of a host comprising a monolayer of RPE cells, characterized in that said RPE cells comprise cultured RPE cells.

AMENDED SHEET

* C L M S *

REPLACEMENT SHEET
15 SEP 1999
960487-8

~~space and upon transplantation will not impede normal eye tissue function; and~~

(d) apposing the cultured retinal pigment epithelial cell monolayer to a non-toxic flexible support that, upon transplantation to the subretinal space, will not impede the host's normal eye tissue function nor will it ~~impeded~~ impede the normal eye tissue function of the transplanted retinal epithelial cells.

12. An implant capable of transplantation to the subretinal space formed by the method of Claim 1.

13. An implant capable of transplantation to the subretinal space formed by the method of Claim 11.

14. An implant for transplantation to the subretinal area of an eye of a host comprising a laminate of a monolayer of RPE cells and a non-toxic, flexible support that, upon transplantation to the subretinal area and exposure to conditions which result in a breakdown of at least a portion of the non-toxic, flexible support, will not impede normal eye tissue function.

15. An implant as set forth in claim 14 wherein the RPE cells further comprise mature RPE cells.

16. An implant as set forth in claim 14 wherein the RPE cells are autologous to the host.

17. An implant as set forth in claim 14 wherein the support comprises a material degradable by exposure to heat or bodily fluids.

AMENDED SHEET