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(54) **PULSATILE SUCTION RING FOR VISUALIZING AND TREATING DRAINAGE PATHWAYS OF THE EYE AND METHODS OF USE**

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(52) **U.S. Cl.**

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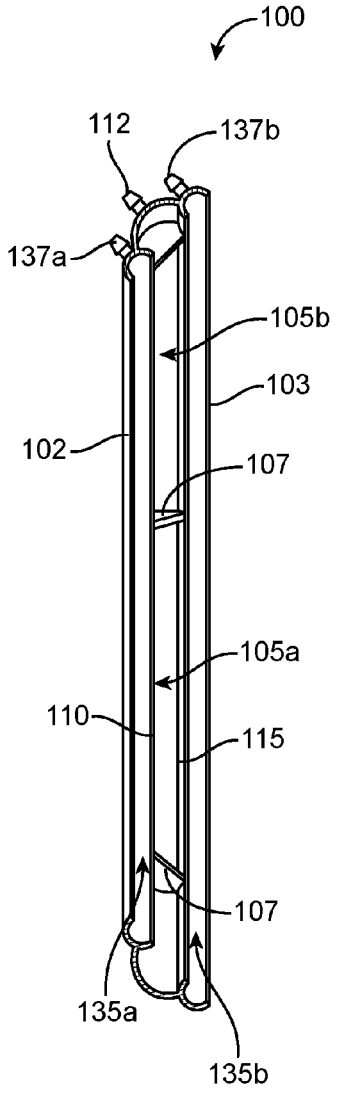
(57) **ABSTRACT**

An ophthalmic device for use on an anterior surface of an eye including a treatment chamber defined at least in part by an anterior ring, a posterior ring, and an upper surface connecting the anterior ring and the posterior ring, the treatment chamber configured to transmit a force against the anterior surface of the eye; and a fixation chamber configured to be in fluid communication with a vacuum source and in fluid communication with the anterior surface of the eye. Related devices, systems, and methods are provided.



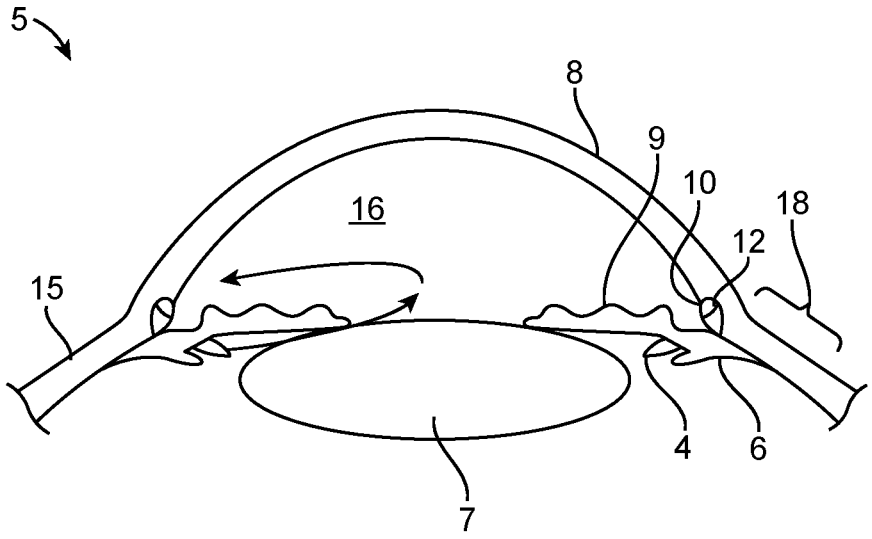


FIG. 1A

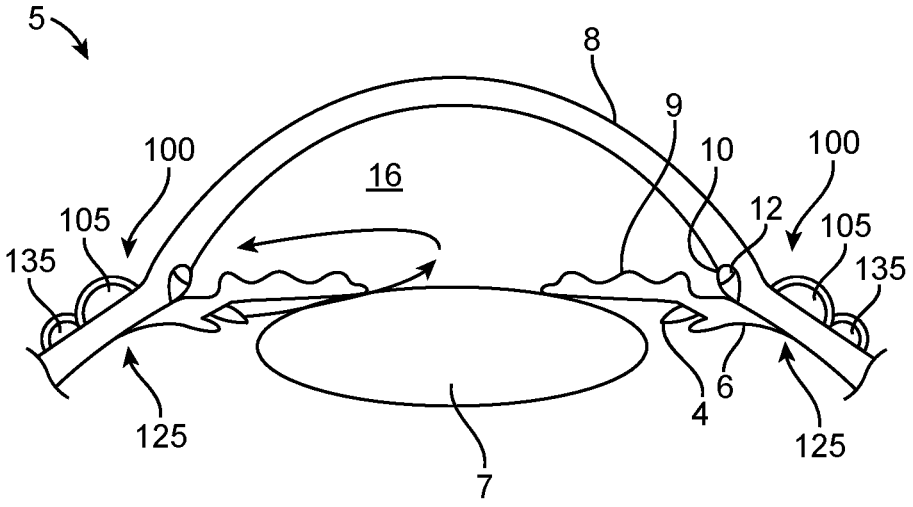


FIG. 1B

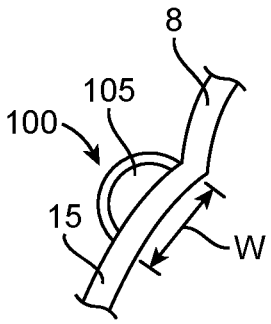


FIG. 1C

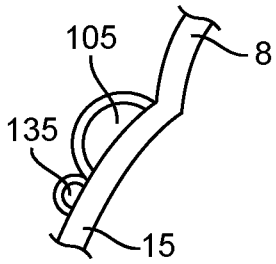


FIG. 1D

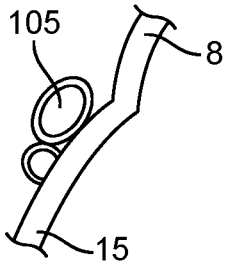
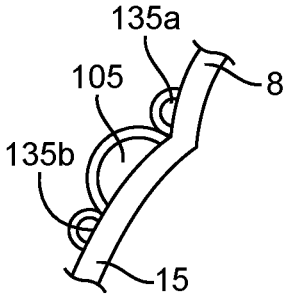


FIG. 1E



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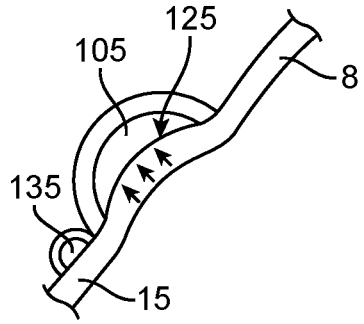

FIG. 1G

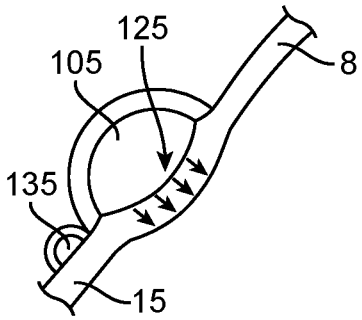

FIG. 1H

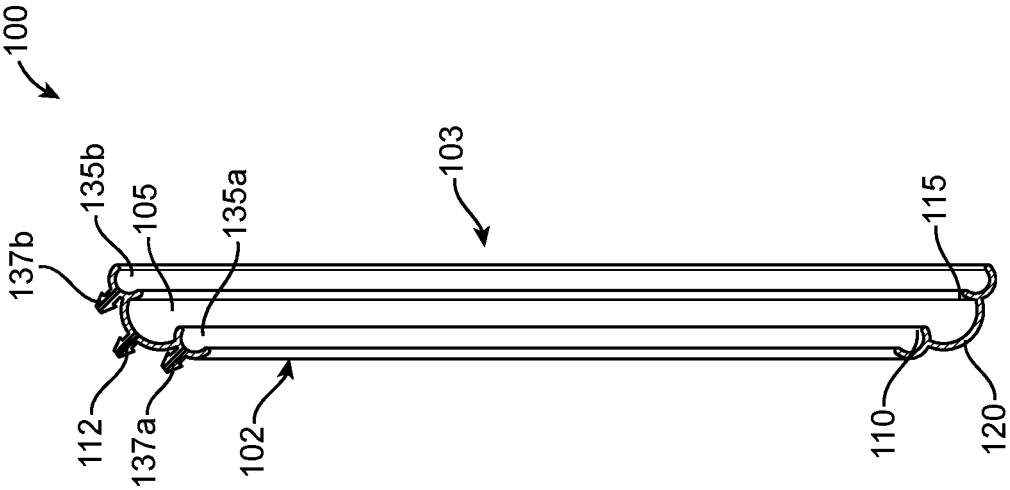
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FIG. 2B

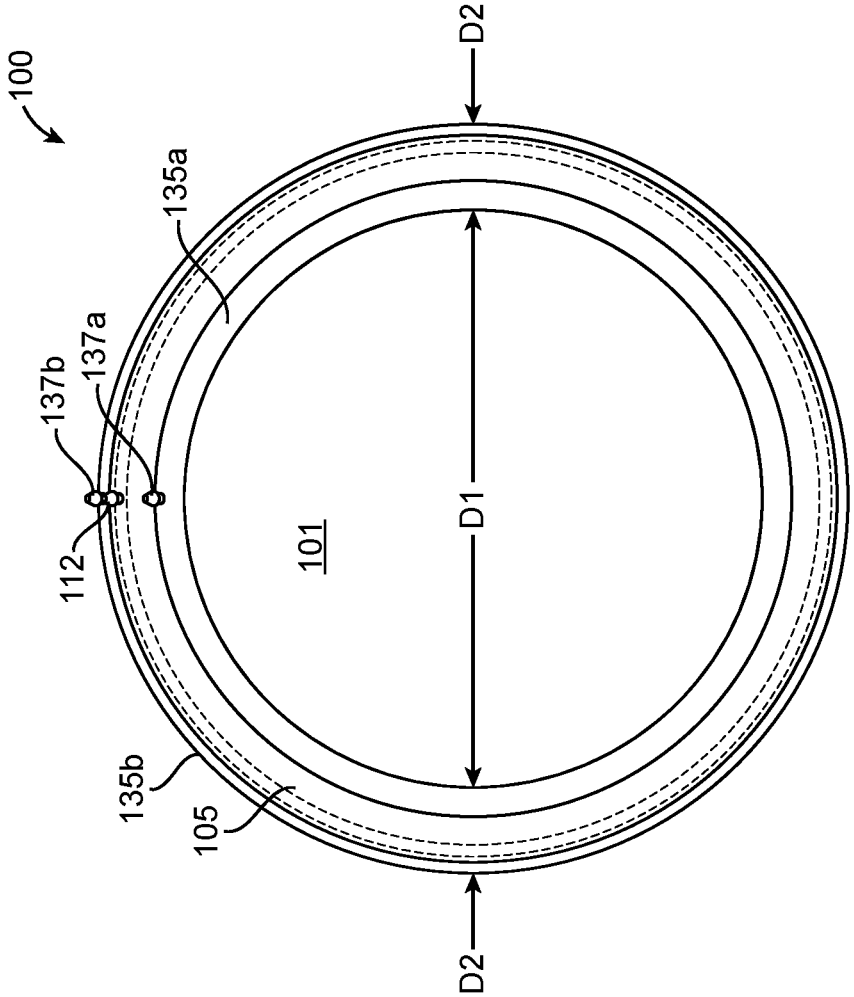
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FIG. 2A

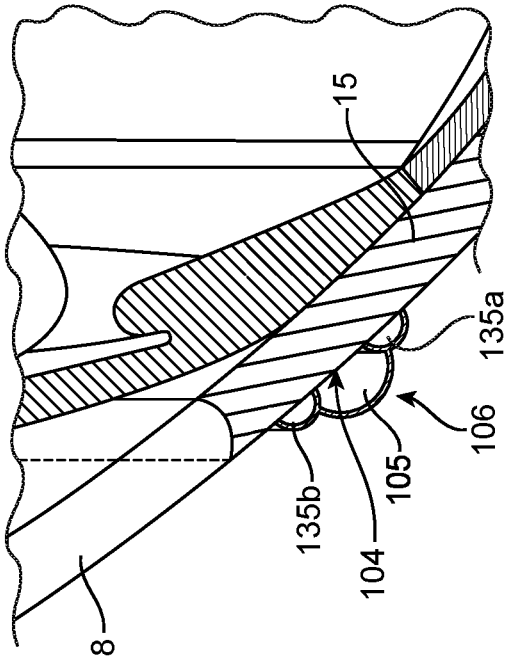

FIG. 2D

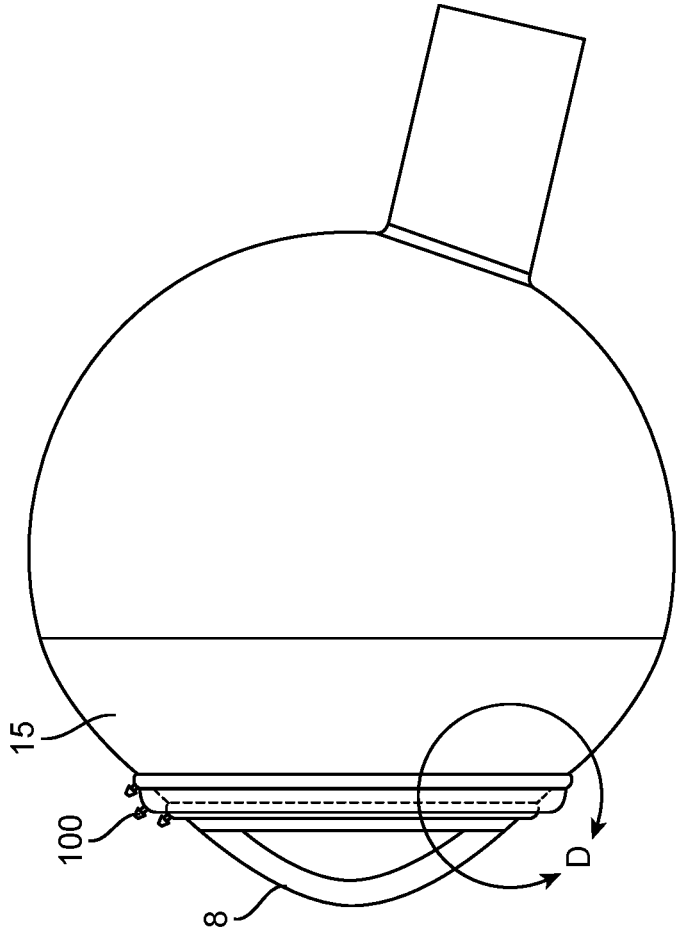

FIG. 2C

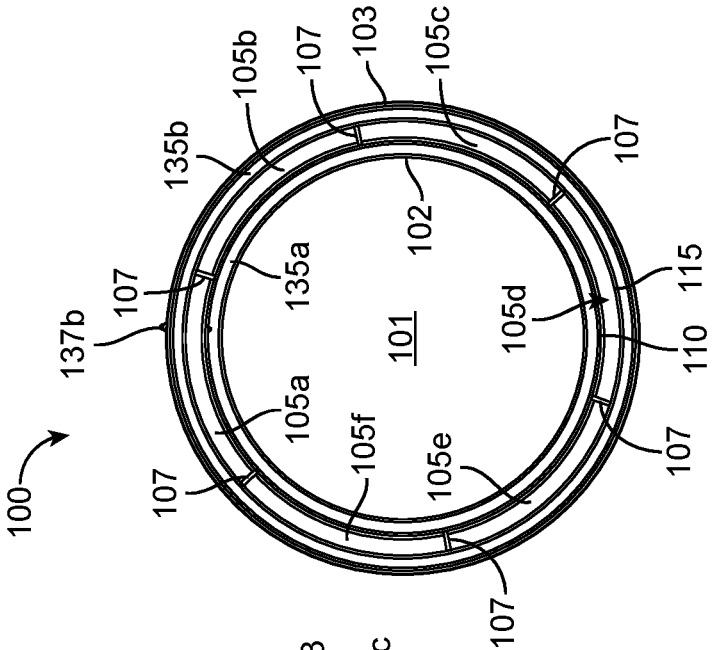

FIG. 3C

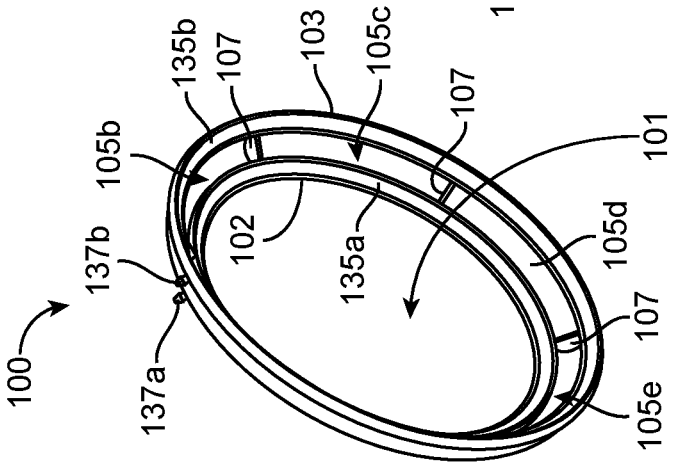

FIG. 3B

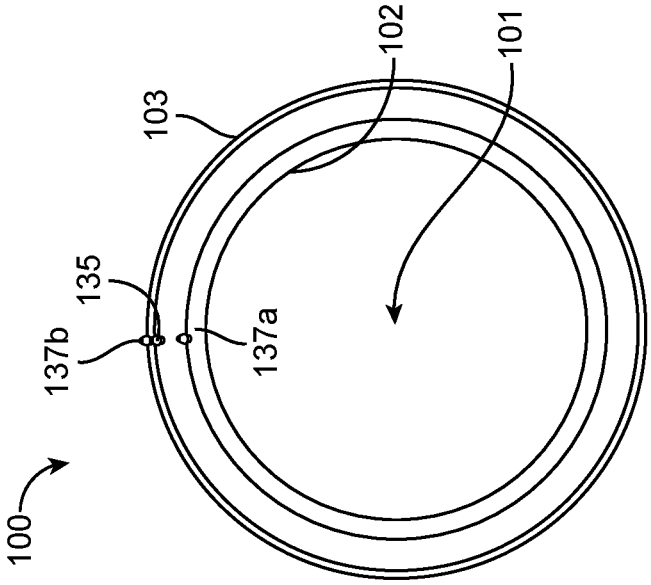

FIG. 3A

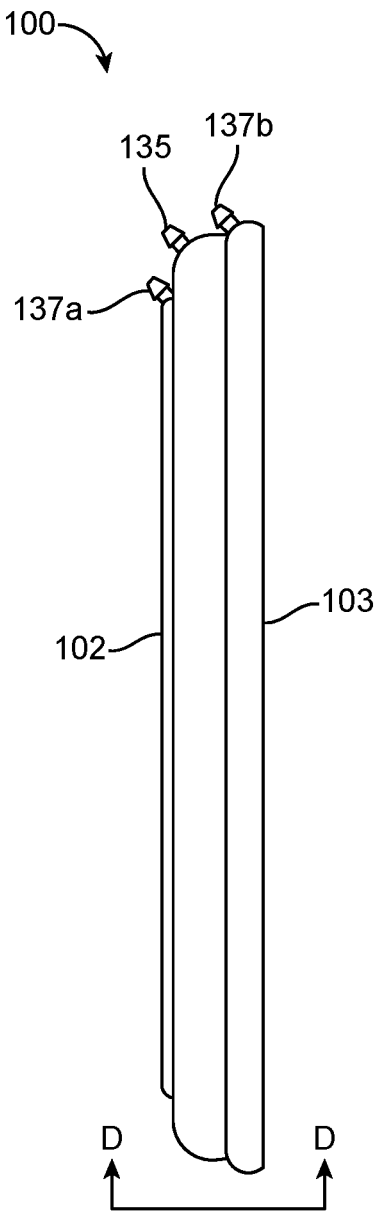
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FIG. 3D

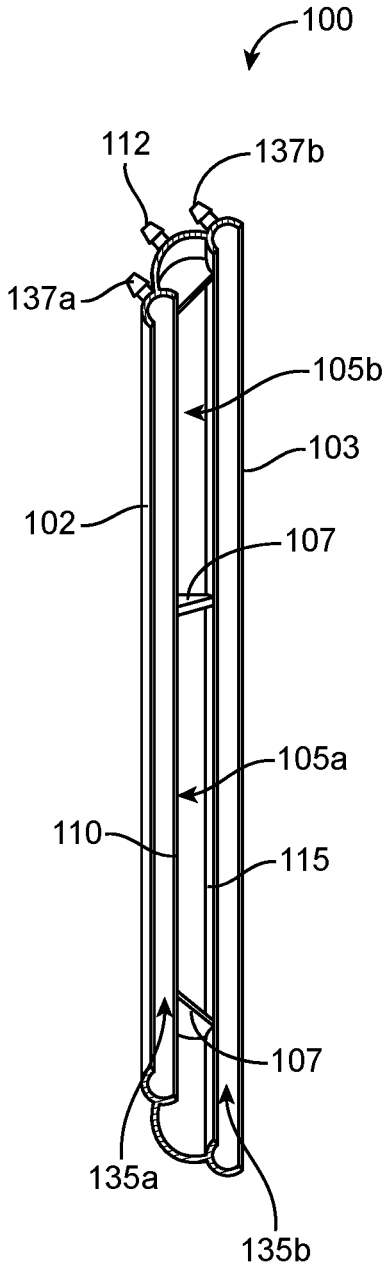
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FIG. 3E

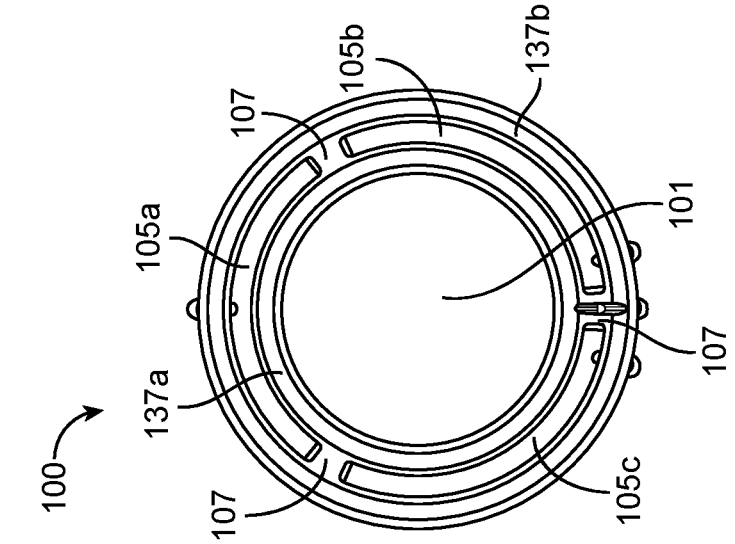
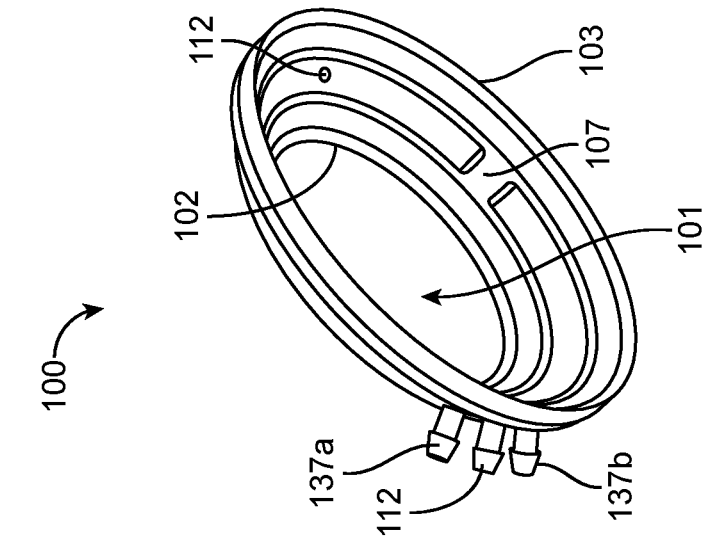


FIG. 4C



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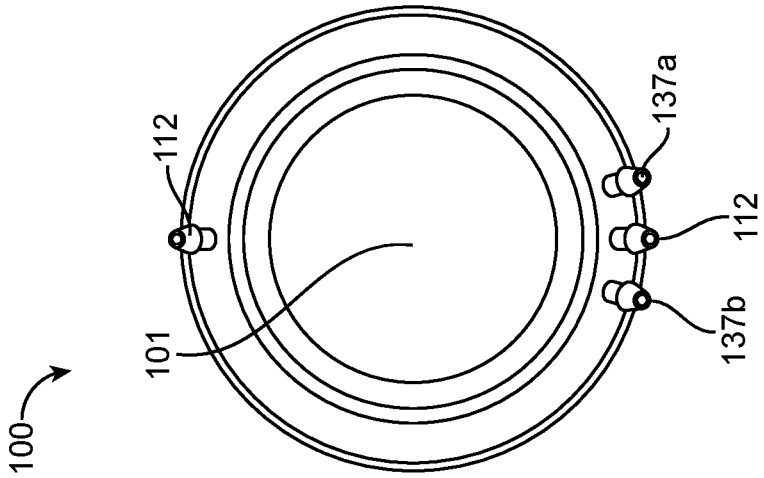

FIG. 4A

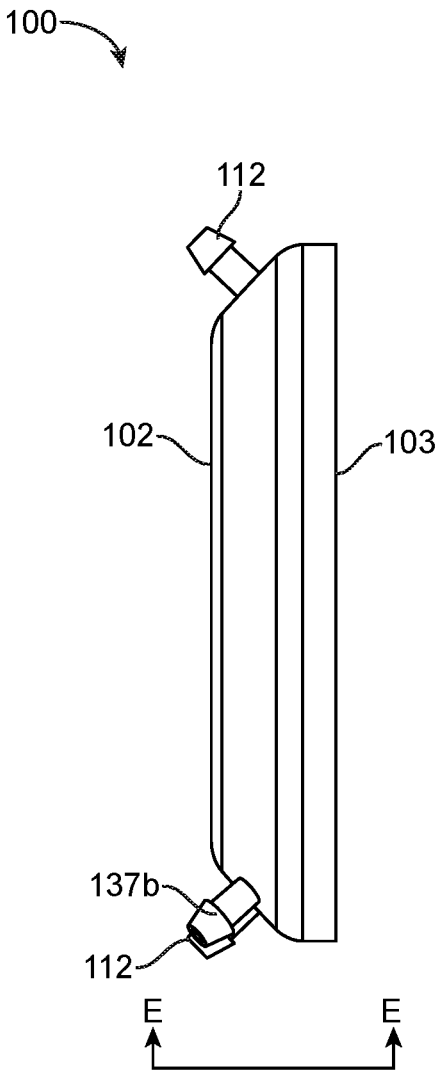
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FIG. 4D

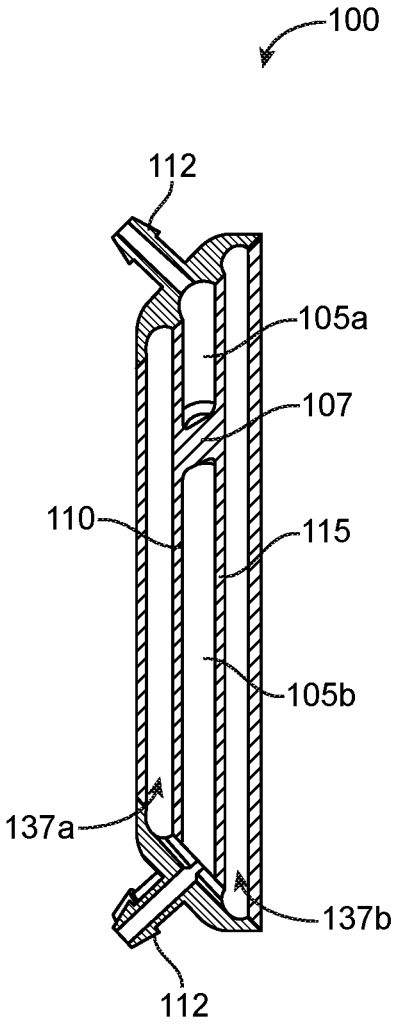
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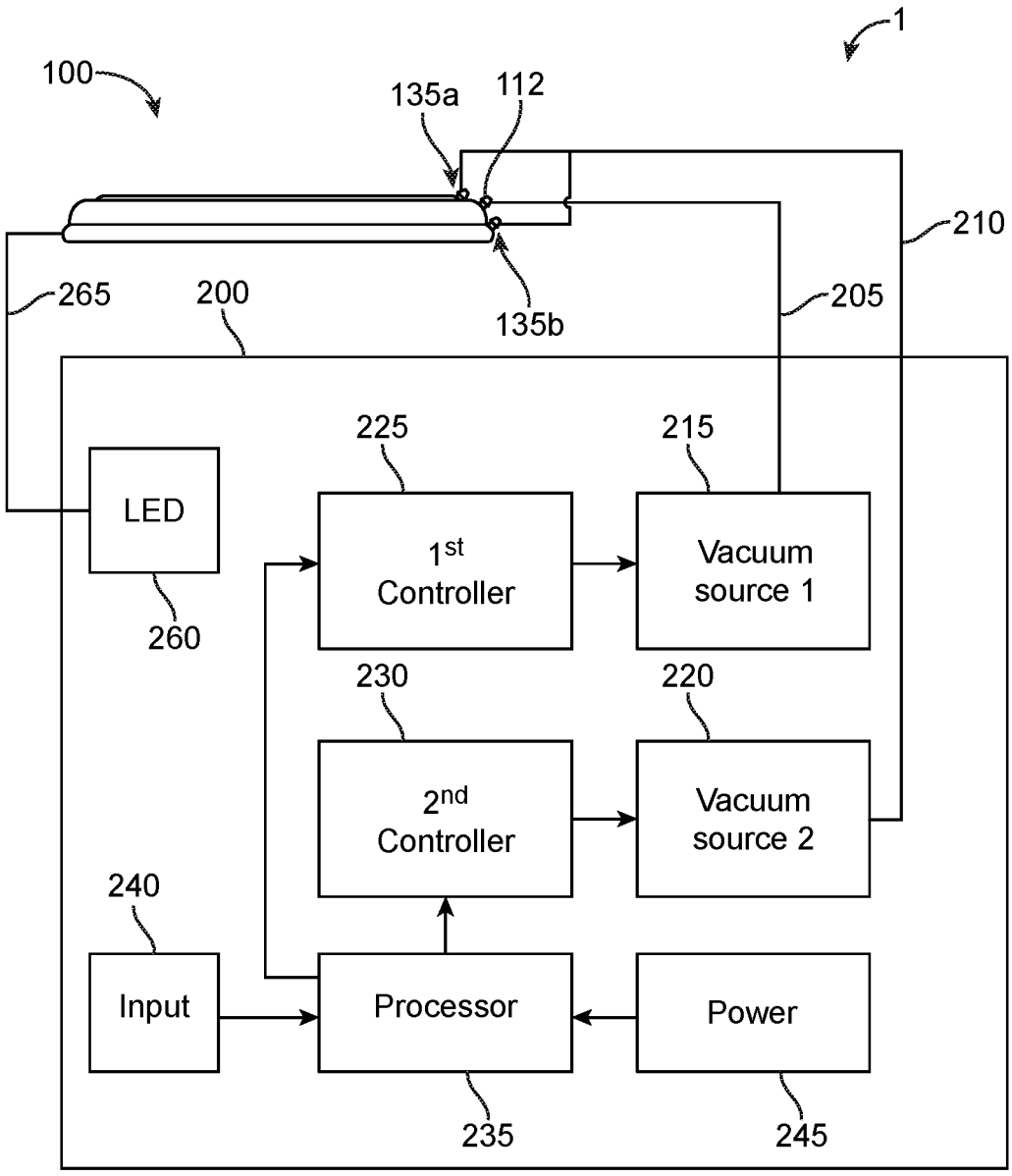
FIG. 4E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2nd Controller
Vacuum source 2
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Input
Processor
Power
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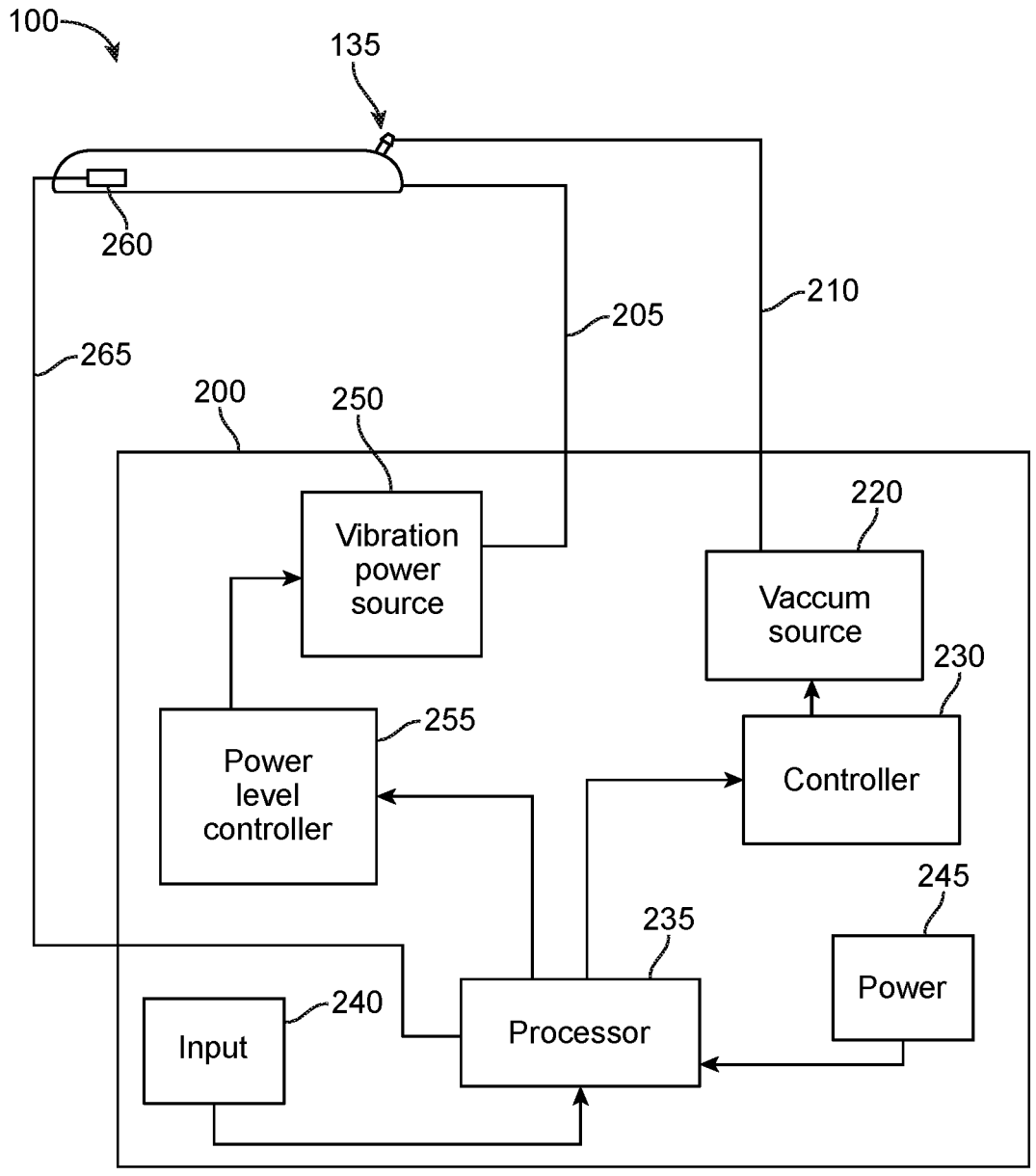
245

FIG. 5A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Vibration power source
220
Vaccum source
230
255
Power level controller
Controller
245
235
Power
240
Input
Processor

FIG. 5B

PULSATILE SUCTION RING FOR VISUALIZING AND TREATING DRAINAGE PATHWAYS OF THE EYE AND METHODS OF USE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority under 35 U.S.C. § 119(e) to co-pending U.S. Provisional Patent Application Ser. No. 63/388,143, filed Jul. 11, 2022. The disclosure of the application is incorporated by reference in its entirety.

BACKGROUND

[0002] Glaucoma is a complicated disease in which damage to the optic nerve leads to progressive vision loss and is the leading cause of irreversible blindness. Aqueous humor is the fluid that fills the anterior chamber in front of the iris and the posterior chamber of the eye behind the iris. Vitreous humor or vitreous body is a gel-like material found in the posterior segment of the eye posterior of the capsular bag. FIG. **1** is a diagram of the front portion of an eye **5** showing the lens **7**, cornea **8**, iris **9**, ciliary body **6** including ciliary processes **4**, trabecular meshwork **10**, and Schlemm's canal **12**. The aqueous humor is a fluid produced by the ciliary body **6** that lies behind the iris **9** adjacent to the lens **7**. This aqueous humor washes over the lens **7** and iris **9** and flows to the drainage system located in the angle of the anterior chamber. The angle of the anterior chamber, which extends circumferentially around the eye, contains structures that allow the aqueous humor to drain.

[0003] Some of the aqueous humor is absorbed through the trabecular meshwork **10** into Schlemm's canal **12** into collector channels and passing through the sclera **15** into the episcleral venous circulation. The trabecular meshwork **10** extends circumferentially around the anterior chamber **16** in the angle. The trabecular meshwork **10** limits the outflow of aqueous humor. Schlemm's canal **12** is located beyond the trabecular meshwork **10**. The two arrows in the anterior chamber **16** of FIG. **1** show the flow of aqueous humor from the ciliary body **6**, over the lens **7**, over the iris **9**, through the trabecular meshwork **10**, and into Schlemm's canal **12** and its collector channels.

[0004] In some cases glaucoma is caused by blockage of aqueous humor outflow such as by sclerosis of the trabecular meshwork, pigment or membrane in the angle. In other cases, blockage is due to a closure of the angle between the iris and the cornea. This angle type of glaucoma is referred to as "angle-closure glaucoma". In the majority of glaucoma cases, however, called "open angle glaucoma", the cause is unknown.

[0005] Treatments of glaucoma attempt to lower intraocular pressure (TOP) pharmacologically or by surgical intervention that enhance outflow of aqueous humor through the outflow pathways. Ab externo trabeculectomy is a type of glaucoma surgery that creates a new path as a "controlled" leak for fluid inside the eye to drain out. Conventionally, a partial thickness scleral flap is formed followed by the creation of a small hole into the anterior chamber. Aqueous humor can flow into the subconjunctival space creating a filtering bleb. The scleral flap is raised up and a blade used to enter the anterior chamber. During the operation a hole is created under the scleral flap that is fluidically connected to the anterior chamber creating an opening. The opening is partially covered with the scleral flap. A small conjunctival "bleb" or bubble appears over the scleral flap, often near the junction of the cornea and the sclera (limbus).

[0006] Minimally-invasive surgical procedures provide TOP lowering by enhancing the natural drainage pathways of the eye with minimal tissue disruption. Minimally-invasive glaucoma surgery (MIGS) uses microscopic-sized equipment and tiny incisions. MIGS offers an alternative to conventional glaucoma surgeries with the potential benefit of reducing a patient's dependence on topical glaucoma medication. Trabeculectomies and trabeculotomies can each be performed ab interno, or from inside the anterior chamber. Ab interno approaches aim to decrease TOP by increasing aqueous humor outflow through a direct opening in the trabecular meshwork from within the anterior chamber so that there is direct communication between the anterior chamber and the outer wall of Schlemm's canal. Ab interno approaches include the TRABECTOME (MST/NeoMedix Corp.) electrosurgical instrument that ablates and removes trabecular meshwork, the Kahook Dual Blade (New World Medical) for excisional goniotomy removing a strip of trabecular meshwork, gonioscopy assisted transluminal trabeculotomy (GATT) involving cutting through the trabecular meshwork, cannulating Schlemm's canal, and Omni (Sight Sciences) for performing viscoplasty or trabeculotomy through an ab interno approach for cannulating Schlemm's canal. Other ab interno methods include the iStent (Glaukos) to create pathway through the trabecular meshwork for improved outflow of aqueous humor through Schlemm's canal.

[0007] During these MIGS procedures it is advantageous to be able to visualize the drainage pathways of the eye (e.g., collector channel network). Vital dyes, such as trypan blue, is injected into the Schlemm's Canal and assists in visualization of the fluid flow through the eye when a surgeon at the time of surgery palpates the sclera. The depression of the sclera followed by release causes fluid to be pushed out and refilled. During refilling of the portion of the sclera palpated, trypan blue flows into the drainage pathways, which can be visualized through the sclera. Absence of the color would indicate where a blockage is.

[0008] In view of the foregoing, there is a need for improved devices and methods related to ophthalmic surgery for the treatment of glaucoma.

SUMMARY

[0009] In an aspect, described is an ophthalmic device for use on an anterior surface of an eye. The device includes a treatment chamber defined at least in part by an anterior ring, a posterior ring, and an upper surface connecting the anterior ring and the posterior ring. The treatment chamber is configured to transmit a force against the anterior surface of the eye. The device includes a fixation chamber configured to be in fluid communication with a vacuum source and in fluid communication with the anterior surface of the eye.

[0010] The vacuum source can be configured to generate a negative pressure within the fixation chamber to maintain the device against the anterior surface of the eye during transmitting the force via the treatment chamber. The treatment chamber can include one or more dividers creating a plurality of treatment chambers. The one or more dividers can extend radially relative to a center of the device or circumferentially around the center of the device. The device

can further include a light source. The light source can be a separate accessory configured to couple to the device or embedded within a region of the device. The light source can be configured to illuminate a region of the eye via the device. The light source can be configured for photobiomodulation of a region of the eye via the device. The light source can be a red, green, or blue light source. The device can further incorporate a tonometer configured to measure intraocular pressure during a procedure in real-time.

[0011] The force transmitted against the anterior surface of the eye by the treatment chamber can be configured to maximize an effect of a therapy. The treatment chamber can be coupled to a vacuum source configured to generate a negative pressure and/or a positive pressure within the treatment chamber so as to transmit the force against the anterior surface of the eye. The treatment chamber can be coupled to a source of vibration configured to generate a vibration within the treatment chamber so as to transmit the force against the anterior surface of the eye. The source of vibration can be a vibrating element embedded within a region of the device. The vibrating element can be a haptic engine, a voice coil/speaker, a piezo actuator, a ribbon vibrator. The device can further include an exciter or transducer configured to vibrate the eye in addition to transmitting the force by the treatment chamber. The treatment chamber may have no lower surface so as to transmit the force by means of a fluid interface. The fluid interface can be a gas interface or a liquid interface. The treatment chamber can have a lower surface so as to transmit the force by means of a mechanical interface. The mechanical interface can include a ribbon transducer forming the lower surface of the treatment chamber.

[0012] The device can further include an anterior enclosure extending anteriorly relative to the treatment chamber and the fixation chamber and sized to fully enclose the cornea of the eye upon positioning the treatment chamber against the anterior surface of the eye. The anterior enclosure can be in a form of an eye cup. At least the posterior ring of the treatment chamber can form a seal with the anterior surface of the eye to contain a liquid within the anterior enclosure. The anterior surface of the eye can be the sclera of the eye with eyelids open or the outside surface of the eyelid with eyelids closed.

[0013] The force transmitted against the anterior surface of the eye can include vibration provided by a vibration power source. The vibration power source can use monotonic frequencies, harmonic frequencies, random frequencies, white noise, pink noise, blue noise, or brown noise. The vibration power source can use an additive set of integer order harmonics or a superimposed set of non-harmonic frequencies. The vibration power source can use any noise characterized by a power spectral density per unit of bandwidth proportional to 1/f^n, wherein f is a frequency of a signal and n is a real valued number. The vibration power source can be tuned to avoid resonant frequencies of the eye or other frequencies that cause unintended damage to the eye. At least the upper surface of the treatment chamber can be transparent or translucent allowing for visualization of the eye through the treatment chamber.

[0014] In an interrelated aspect, provided is a method of visualizing fluid channels of an eye during an intraocular procedure. The method includes injecting an amount of a dye so the dye flows into a region of an eye; positioning an annular device on an anterior surface of the eye so as to encircle the cornea. At least a portion of the annular device is transparent or translucent in order to visualize at least a portion of the anterior surface under the annular device. The method includes transmitting a positive pressure through at least a region of the annular device to create an inwardly compressive force against the anterior surface of the eye, the inwardly compressive force sufficient to prevent dye from entering a region of the eye near the anterior surface of the eye; and visualizing through the transparent or translucent portion of the annular device a return of the dye into the region of the eye.

[0015] In an interrelated aspect, provided is a method of treating glaucoma of an eye having a cornea and an anterior surface surrounding the cornea including positioning an annular device on the anterior surface of the eye so as to encircle the cornea. The annular device includes a treatment chamber and a fixation chamber transmitting a force to at least a portion of the anterior surface of the eye through the treatment chamber of the annular device, the force sufficient to cause a deformation of the anterior surface of the eye in an inwardly direction, an outwardly direction, or a combination of the inwardly and outwardly directions. The method includes fixing the annular device to the anterior surface of the eye by transmitting a negative pressure through the fixation chamber drawing the fixation chamber against the anterior surface of the eye.

[0016] In an interrelated aspect, provided is a method of treating glaucoma of an eye having a cornea and an anterior surface surrounding the cornea including positioning an annular device on the anterior surface of the eye so as to encircle the cornea. The annular device includes a treatment chamber and a fixation chamber. The method further includes transmitting a vibration to at least a portion of the anterior surface with the treatment chamber; and fixing the annular device to the anterior surface of the eye by transmitting a negative pressure through the fixation chamber drawing the fixation chamber against the anterior surface of the eye.

[0017] In some variations, one or more of the following can optionally be included in any feasible combination in the above methods, apparatus, devices, and systems. More details are set forth in the accompanying drawings and the description below. Other features and advantages will be apparent from the description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] These and other aspects will now be described in detail with reference to the following drawings. Generally, the figures are not to scale in absolute terms or comparatively, but are intended to be illustrative. Also, relative placement of features and elements may be modified for the purpose of illustrative clarity.

[0019] FIG. **1**A is a diagram of the anterior portion of the eye in cross-section;

[0020] FIG. **1**B is a diagram of the anterior portion of the eye in cross-section having an implementation of a device positioned over it;

[0021] FIG. **1**C is a schematic of a single chamber device for treatment and fixation;

[0022] FIG. **1**D is a schematic of a dual chamber device having a partially tubular treatment chamber and a partially tubular fixation chamber;

[0023] FIG. **1**E is a schematic of a dual chamber device having a fully tubular treatment chamber and a partially tubular fixation chamber;

[0024] FIG. **1**F is a schematic of a three-chamber device having partially tubular treatment chamber and two partially tubular fixation chambers;

[0025] FIG. **1**G is a schematic of the device of FIG. **1**D outwardly distending the limbus by application of negative pressure through the treatment chamber;

[0026] FIG. **1**H is a schematic of the device of FIG. **1**D inwardly compressing the limbus by application of positive pressure through the treatment chamber;

[0027] FIG. **2**A is an anterior view of an implementation of a treatment device;

[0028] FIG. **2**B is a side cross-sectional view of the device of FIG. **2**A;

[0029] FIG. **2**C is a side view of the device of FIG. **2**A positioned on an anterior surface of an eye in cross-section;

[0030] FIG. **2**D is a detail cross-sectional view of the device in FIG. **2**C taken at circle D;

[0031] FIG. **3**A is an anterior view of another implementation of a treatment device;

[0032] FIG. **3**B is a perspective view of the device of FIG. **3**A;

[0033] FIG. **3**C is a posterior view of the device of FIG. **3**A;

[0034] FIG. **3**D is a side view of the device of FIG. **3**A;

[0035] FIG. **3**E is a cross-sectional view of the device of FIG. **3**D taken along line D-D;

[0036] FIG. **4**A is an anterior view of another implementation of a device;

[0037] FIG. **4**B is a perspective view of the device of FIG. **4**A;

[0038] FIG. **4**C is a posterior view of the device of FIG. **4**A;

[0039] FIG. **4**D is a side view of the device of FIG. **4**A;

[0040] FIG. **4**E is a cross-sectional view of the device of FIG. **4**D taken along line E-E;

[0041] FIG. **5**A is a box diagram of an implementation of a treatment system incorporating a control unit having first and second vacuum sources fluidly connected to an annular-shaped device;

[0042] FIG. **5**B is a box diagram of another implementation of a treatment system incorporating a control unit electrically connected and fluidly connected to an annular-shaped device.

[0043] It should be appreciated that the drawings are for example only and are not meant to be to scale. It is to be understood that devices described herein may include features not necessarily depicted in each figure.

DETAILED DESCRIPTION

[0044] Described herein are devices configured to be placed on the anterior surface of the eye, for example during MIGS procedures, to apply a force against the anterior surface of the eye. In some implementations, the device is configured to apply a force to emulate the manual palpation a surgeon might perform on the anterior surface of the eye to aid in visualizing fluid flow through the active and functional collector channels or other fluid flow pathways from the anterior chamber prior to, during, and/or after surgical procedures in the eye, such as trabeculotomy or other MIGS procedures in which tracking fluid flow in the eye is desired. The forces can include inwardly deforming or compressive forces such as by the application of a positive pressure against the surface of the eye. The forces can alternatively or additionally include outwardly deforming or distending forces such as by the application of negative pressure against the surface of the eye. In still other implementations, the force can include vibration of tissues. The forces can be applied directly by a mechanical element contacting the surface of the eye or can be applied hydraulically or pneumatically.

[0045] The forces applied to the eye by the devices described herein are sufficient to distend and/or compress the underlying tissue of the eye without significantly increasing intraocular pressure (TOP) in the process. The inwardly and/or outwardly deforming forces can have a therapeutic effect on IOP, such as by remobilizing and stretching tissue of the collection channel network, Schlemm's canal, and/or trabecular meshwork thereby improving outflow of aqueous from the eye and reducing IOP. Without limiting this disclosure to any particular theory or mode of operation of the treatment being provided by the systems described herein, open angle glaucoma is believed to be brought on, at least in part, by the trabecular meshwork collapsing or clogging or otherwise reducing the outflow of aqueous fluid from the anterior chamber through Schlemm's canal. The forces applied by the devices and systems described herein are useful in the treatment of glaucoma by unclogging or reversing the collapse of the trabecular meshwork allowing more aqueous to flow out from the anterior chamber. The forces applied by the devices and systems described herein are also useful in the treatment of glaucoma such as by increasing the permeability of the trabecular meshwork, Schlemm's canal, and/or collector channels and collector channel ostia. The spaces within these outflow pathways can be opened up and flow improved by manually altering their shape and/or by vibrating the tissues to improve and aid in the efficiency of drainage by removing small particles within the trabecular spaces such as pigments, cell debris, fibrin, etc.

[0046] FIGS. **2**A-**2**D illustrate an implementation of the device **100**. FIG. **2**A is an anterior view, FIG. **2**B is a side cross-sectional view, FIG. **2**C is a side view of the device positioned on an anterior surface of an eye, and FIG. **2**D is a detail view of the device in FIG. **2**C taken at circle D. The device **100** can be in the shape of an annulus or a frustum so as to be applied to a treatment region **125** of the eye that can be in the shape of a circumferential band of the globe of an eye. The device **100** can include a central aperture **101** having a first opening at an anterior end **102** of the device **100** and a second opening at a posterior end **103** of the device **100**. The first opening has a first inner diameter D1 and the second opening has a second, larger inner diameter D2. The larger inner diameter D2 allows for the posterior end **103** of the device **100** to sit further posterior on the globe of the eye compared to the smaller inner diameter D1 at the anterior end **102** of the device **100**, which is configured to sit closer to the cornea **8**. The smaller inner diameter D1 can be sized to encircle the cornea **8**. The smaller inner diameter D1 may also be sized to sit on the cornea at least in part. D1 can be about 12 mm to about 16 mm and D2 can be about 16 mm to about 20 mm.

[0047] FIG. **2**D shows an external surface **106** of the device **100**, which can be substantially smooth and/or rounded in cross-sectional shape to form a smooth atraumatic surface. The overall shape formed by the internal

surface **104** of the device **100** can substantially match and/or conform to a radius of curvature of the anterior surface of the eye so as to be received on the surface of the eye as shown in FIGS. **2**C-**2**D with the treatment region **125** under and/or in contact with the internal surface **104** the device. The treatment region **125** of the eye is preferably near or over a location of the trabecular meshwork, Schlemm's canal, and/or collector channels from the canal. The cross-sectional height of the device **100** from internal surface **104** to external surface **106** can be in a range of about 1 mm to about 10 mm. The width of the device **100** can be at least as wide as the limbal region of the eye, or at least about 1.5 mm-2.5 mm wide, so that upon placement against the eye, at least a center region of the band of the annulus overlays the limbus **8**. The contact width can be at least 1.5 mm up to about 5 mm.

[0048] Again with respect to FIGS. **2**A-**2**D, the device **100** includes or forms a treatment chamber **105** configured to transmit a force against the treatment region **125** of the eye by applying a positive pressure and/or a negative pressure, vibration, and the like. In some implementations, the treatment chamber **105** can be formed, in part, by an anterior ring **110**, a posterior ring **115** spaced a distance away from the anterior ring **110**, and an upper surface **120** that spans between the anterior and posterior rings **110**, **115** (see FIG. **2**B). The upper surface **120** forms an upper surface to the treatment chamber **105** and the anterior and posterior rings **110**, **115** form side surfaces to the treatment chamber **105**. The treatment chamber **105** can, but need not have a lower surface against the eye. Meaning, that in some implementations, the treatment chamber **105** is defined by a fully tubular structure (see FIG. **1**E) and in others the treatment chamber **105** is defined by a partially tubular structure, for example, so that the treatment chamber **105** is semi-circular or c-shaped as in FIG. **2**B and also FIGS. **1**C, **1**D, **1**F, **1**G, **1**H. The partially tubular treatment chamber **105** can become completely enclosed upon application of the device **100** to the anterior surface of the eye so that the anterior surface of the eye forms the lower surface of the treatment chamber **105** such as illustrated in FIG. **2**D and also FIGS. **1**C, **1**D, **1**F, **1**G, and **1**H.

[0049] The anterior ring **110** can extend 360 degrees around the device **100** and have an inner diameter that is at least 10 mm so as to substantially encircle the cornea **8**. In some implementations, the inner diameter of the device is sufficient to avoid contact with the cornea **8**, such as at least about 12 mm. The inner diameter of the anterior ring **110** is preferably no greater than about 13 mm so that the device **100** upon positioning on the sclera ensures the treatment chamber **105** is capable of overlaying at least a portion of the limbus **18**. The posterior ring **115** also extends 360 degrees around the device and is spaced away from the inner ring **110** by a distance of about 4 mm to about 8 mm for a device **100** in which D1 is about 12-16 mm and D2 is about 16-20 mm. As such, the posterior ring **115** has an inner diameter that is at least about 14 mm and preferably no greater than about 20 mm. The anterior ring **110** can define the inner diameter at the anterior end of the device and the posterior ring **115** can define the inner diameter at the posterior end of the device. Alternatively, the device **100** incorporates one or more additional rings other than the rings **110**, **115** that define the treatment chamber **105**. The additional rings can define other chambers of the device **100**, such as one or more fixation chambers **135**, which will be described in more detail below.

[0050] In the implementation of a partially tubular treatment chamber **105**, the lower surfaces of the anterior ring **110** and the posterior ring **115** make contact with corresponding surfaces of the eye so as to enclose a treatment region **125** under the treatment chamber **105** (see FIGS. **1**B, **1**G, **1**H). In the implementation of a fully tubular treatment chamber **105**, the lower surface of the chamber **105** makes contact with corresponding surface of the eye so as to cover the treatment region **125** under the treatment chamber **105** (see FIG. **1**E). The treatment region **125** can include the Schlemm's canal and trabecular meshwork. The treatment region **125** preferably includes the limbus **18** of the eye, which is the band around the eye that forms the border between the transparent cornea **8** and the opaque sclera **15**. Underlying tissues within the eye, such as Schlemm's canal and the trabecular meshwork, under the area of the limbus are also incorporated by the treatment region **125** (see FIG. **1**A).

[0051] The devices are described herein as having a ring shape and configured to encircle the cornea **8**. It should be appreciated that the device need not avoid making contact with the cornea. For example, the fixation chamber can be sufficiently low durometer and atraumatic such that the device **100** can contact the cornea **8**. In this implementation, the inner diameter D1 of the device can be less than 10 mm such that the device lies on at least some part of the cornea. The device **100** also need not be in the shape of a ring (D1=0 mm) so as to cover the cornea entirely, such as like a contact lens. In other implementations, the device **100** has an overall configuration and shape of an eye cup. The eye cup-shaped device **100** can incorporate a posterior end having annular-shaped treatment section as described above and an anterior enclosure sized to extend anterior to the cornea **8** to fully enclose the cornea **8**. The eye cup-shaped device has no central aperture **101** that extends through the full thickness of the device **100** (i.e., no opening on the anterior end **102**). The anterior enclosure can create a fluid interface for the surface of the eye with the eyelids open (i.e., the sclera and cornea combined) or the outside surface of the eyelid with the eyelids closed. The eye cup-shaped device can be configured contain a fluid within the enclosure. At least a portion of the annular-shaped device **100** applied to the anterior surface of the eye at a location posterior to the treatment region **125** can seal with the eye so as to prevent the fluid within the cup from seeping out. In some implementations, a negative pressure applied through the treatment chamber **105** or another annular chamber of the device can form the seal between the eye and the device **100** to allow for the liquid within the eye cup (e.g., balanced saline solution) from leaking. The liquid within the eye cup can provide cooling, if necessary, as well as moisture to the cornea during treatment of the eye. Any of a variety of aqueous media can be used within the eye cup as known in the art.

[0052] The device **100** can be formed of one or more thermoplastic elastomers, such as silicone elastomers. The material of the device **100** forming the fixation chamber(s) **115** can be Shore A-90 Shore A durometer. The material of the device **100** forming the treatment chamber(s) **105** can be 30 Shore A-90 Shore D durometer. The material is selected so as to maintain a desired shape even when the treatment

chamber **105** is placed under negative or positive pressure. A limiting factor of the amount of pressure applied through the chambers of the device is the eye and amount of distension achieved without causing an increase in TOP. Preferably, the pressure applied through the treatment and fixation chambers is −5 mmHg to about −50 mm Hg. The upper surface **120** is preferably able to maintain its shape through the treatment chamber **105** without collapsing upon transmission of a negative pressure to the treatment chamber **105** or ballooning outward upon transmission of a positive pressure to the treatment chamber **105**. The material and/or cross-sectional thickness of the upper surface **120** can be selected to prevent distortion and/or collapse of the treatment chamber during application of a force. In some implementations, the device **100** can incorporate one or more reinforcements within the material to improve retention of its shape during application of a treatment through the treatment chamber **105**. For example, the device **100** can be formed of a first material such as silicone elastomer and reinforced in one or more locations with a more rigid material, such as a metal or a more rigid plastic, to provide hoop strength or resistance to the first material. The device **100** can be injection molded or otherwise molded into a selected shape to form the various chambers and rings of the device.

[0053] At least some portion of the device **100** can be transparent or translucent to aid in the visualization of the underlying treatment region **125**. For example, the upper surface **120** forming the upper surface of the treatment chamber **105** (and the lower surface of the treatment chamber **105**, if fully tubular) can be a translucent or transparent material, such as polycarbonate, polyvinyl chloride (PVC), ethylene vinyl acetate (EVA), and the like, allowing the user to see the treatment region **125** underneath the treatment chamber **105**, for example, to visualize flow paths of the eye and the eye structures infused by trypan blue or another vital dye. The dye will highlight flow paths until application of a compressive force against the treatment region **125**. The compressive force on the eye prevents the dye from flowing through the flow paths and disappears from view. Upon release of the compressive force, the dye returns to the area once again highlighting those paths. The transparent material of the device **100** allows for a user to see the dye return through the flow paths after a period of force is applied by the treatment chamber against the treatment region **125**.

[0054] In the above implementation, the force applied by the device **100** is an inwardly deforming or compressive force and can be achieved by delivering a positive pressure through the treatment chamber **105**. The upper surface **120** can be sufficiently rigid that when a positive pressure is delivered through the treatment chamber **105**, the upper surface **120** avoids deforming outward and instead the pressure is urged against the surface of the eye under the treatment chamber **105** to compress the tissue downward (i.e., inward relative to the globe of the eye). The force applied via the treatment chamber **105** can also include an inwardly deforming force and can be achieved by delivering a negative fluid pressure through the treatment chamber **105**. The upper surface **120** can be sufficiently rigid that when a negative pressure is delivered through the treatment chamber **105**, the upper surface **120** avoids collapse inward towards the eye and instead the pressure urges the surface of the eye under the treatment chamber **105** to outwardly deform the tissue (i.e., outward relative to the globe of the eye). The force applied via the treatment chamber **105** can also include alternative inwardly and outwardly deforming forces via alternating negative and positive fluid pressure through the treatment chamber **105**.

[0055] The force applied against the treatment region **125** can also include direct contact of a material against the treatment region **125** as opposed to changes in hydraulic or pneumatic pressure. The force can be applied by the internal surface **104** of the device **100**. For example, instead of a fluid interface formed by the treatment chamber **105** that applies the force against the treatment region **125**, the treatment chamber **105** can be fully tubular such that an internal surface **104** of the device can be a solid component that interfaces with the treatment region **125** of the eye (i.e., either directly on the sclera or indirectly on the sclera through the eyelid) to apply the force against the eye. In some implementations, the interface to apply the force against the eye is a solid interface such as a ribbon transducer. In other implementations, the mechanical force is applied by a vibration element, which will be described in more detail below.

[0056] Again with respect to FIGS. **2**A-**2**D, the device **100** can incorporate one or more fixation chambers **135** configured to affix the device **100** to the anterior surface of the eye via negative pressure delivered through the fixation chamber **135**. The fixation chamber(s) **135** can extend a full circumference of the device anterior to and/or posterior to the treatment chamber **105**. The fixation chamber(s) **135** may also extend only a limited portion around the circumference of the device. FIGS. **2**A-**2**D and also FIGS. **3**A-**3**E, and FIGS. **4**A-**4**E illustrate three-chamber versions of the device **100** having a primary treatment chamber **105** encircled by a first fixation chamber **135***a* on an anterior end **102** and a second fixation chamber **135***b* on a posterior end **103** of the treatment chamber **105**. FIG. **1**F also illustrates a two fixation chambers **135** in addition to the treatment chamber (s) **105**. FIGS. **1**B, **1**D, **1**E, **1**G, **1**H each illustrate implementations of a device with a single fixation chamber **135**. In still further implementations, no separate fixation chamber **135** is incorporated and vacuum is applied through the primary treatment chamber **105** sufficient to fix the device to the eye (see FIG. **1**C, for example).

[0057] The fixation chambers **135** can be partially tubular in cross-sectional shape so that negative pressure applied to the fixation chambers **135** results in the device **100** being sucked down onto the anterior surface of the eye for fixation of the device **100** to the eye. FIG. **2**B illustrates the first and second fixation chambers **135***a*, **135***b* encircling both sides of the treatment chamber **105** a full circumference of the device **100**. Each of the fixation chambers **135***a*, **135***b* as well as the treatment chamber **105** is partially tubular and has a c-shape cross-section. The anterior ring **110** of the treatment chamber **105** can be shared with and form a posterior wall for the fixation chamber **135***a*. Similarly, the posterior ring **115** of the treatment chamber **105** can be shared with and form an anterior wall for the fixation chamber **135***b*.

[0058] Each of the fixation chambers **135** and also the treatment chamber **105** of the device **100** can incorporate a corresponding fitting designed to communicate negative and/or positive pressure from one or more pressure sources. The treatment chamber **105** can include a barb fitting **112** and each of the fixation chambers **135** can incorporate a corresponding fitting **137**. FIGS. **2**A-**2**B shows a first fitting

137*a* that communicates with a first fixation chamber **135***a* and a second fitting **137***b* that communicates with a second fixation chamber **137***b*. The fittings **112**, **137** can be barb fittings designed to mate with a segment tubing that connects to a negative or positive pressure source, which will be described in more detail below.

[0059] The treatment chamber **105** of the device **100** can extend a full circumference of the device as shown in FIGS. **2**A-**2**D, such that the corresponding treatment region **125** extends a full circumference of a band of the eye. Alternatively, the treatment chamber **105** can be divided into two or more treatment chambers **105** by radially extending dividers **107** (see FIGS. **3**A-**3**E, and FIGS. **4**A-**4**E). The radially extending dividers **107** create multiple treatment chambers **105** each extending less than a circumference of the device **100** so that the treatment region **125** also extends less than a full circumference of a band of the eye. For example, the device **100** can incorporate two radially extending dividers **107** creating two treatment chambers **105** that extend about 180 degrees each around the circumference of the device. The device **100** can incorporate three radially extending dividers **107** creating three treatment chambers **105** that extend about 120 degrees each around the circumference of the device **100**. With each additionally divider **107**, more treatment chambers **105** can be created that extend shorter distances around the circumference of the device **100**. FIG. **3**C shows an implementation of a device **100** including six radially extending dividers **107** that create a corresponding number of treatment chambers **105***a*, **105***b*, **105***c*, **105***d*, **105***e*, and **105***f* that each extend about 60 degrees around the circumference of the device **100**. FIG. **4**C shows an implementation of a device **100** including 3 radially extending devices **107** that create a corresponding number of treatment chambers **105***a*, **105***b*, and **105***c*. The dividers **107** can extend circumferentially around the device so as to create more than one concentric treatment chambers **105** that each extend a full circumference of the device **100**. In this implementation, the dividers **107** are ring shaped and each of the multiple treatment chambers **105** extend 360 degrees around the device **100**. Each treatment chamber **105**, whether created by radially extending dividers **107** or circumferentially extending dividers **107**, can incorporate a corresponding fitting **112** so as to connect the separate treatment chambers **105** to a pressure source. The treatment region **125** treated by the treatment chamber(s) **105** of the device **100** can be annular or semi-annular or another shape. The multiple treatment chambers **105**, whether fully annular in shape or extending only along a limited arc of the device **100**, can be used independently to apply pressure/vacuum at specific locations around the perimeter of the limbus **18**. The pressure within each treatment chamber **105** can be changed independently to create higher and lower pressure chambers. For example, the treatment chambers **105** can be activated according to a particular sequence (e.g., inward, outward, random) to apply a massaging force against the anterior surface of the eye. As an example, the treatment chambers **105** are in a concentric arrangement. The outer concentric treatment chamber **105** can be first activated to apply a force against the eye. The outer concentric treatment chamber **105** can then be deactivated and the first inner concentric treatment chamber **105** activated to apply a force. The first inner concentric treatment chamber **105** can be deactivated and the next inner concentric treatment chamber **105** can be activated to apply a force, and so on. Once each of the treatment chambers is activated in turn, the sequence can begin again with the outer treatment chamber or can begin a sequence back out towards the outer chamber sequentially activating each concentric chamber in particular order. The treatment chambers **105** can be filled with a liquid and act as a hydraulic treatment chamber or can be air-filled and act as a pneumatic treatment chamber. The pneumatic/hydraulic treatment frequency range can be about 1 Hz up to about 5000 Hz.

[0060] The treatment chamber **105** need not be connected to a pressure source. In an implementation, the device **100** can incorporate an exciter or transducer designed to vibrate the eye alone or in addition to the pressure source designed to apply a force via the primary treatment chamber **105**. The vibration can be applied by the device **100** via a vibrating element embedded within the polymer, such as a haptic engine, voice coil/speaker, piezo actuator, ribbon vibrator, plastic muscle (electrically deformable plastic) or other element that is designed to create a vibration within the device **100**. Where the treatment chamber **105** is configured to apply vibration force, the chamber **105** can be coupled to a line configured to generate vibration by the vibrating element. The line can electronically couple the vibrating element within the device **100** to a control unit **200** configured to energize the vibrating element electronically to vibrate (see FIG. **5**B), which will be described in more detail below.

[0061] FIG. **5**A illustrates an implementation of a system **1** for treatment of an eye including a device **100** for positioning onto and applying a treatment to a region of the eye and a control unit **200**. The device **100** is configured to be fluidly coupled to the control unit **200** configured to generate a force within the treatment chamber **105** via treatment line **205**. The treatment line **205** fluidly connects the treatment chamber **105** of the device **100** to a first vacuum source **215**, which can be a treatment pump configured to be actively operated to apply a particular treatment regimen, within the control unit **200**. The vacuum source **215** can also be a passive source of negative pressure, such as a syringe, that is then actively controlled to achieve a particular treatment regimen, such as by valving or other mechanism to affect the application of the vacuum provided by the syringe. The first vacuum source **215** can be controlled by the control unit **200** to generate a force within the treatment chamber **105**. The control unit **200** can include a fast-switching valve that operates within a desired range to achieve the massaging force, such as in a range of 1 Hz-5000 Hz, 100 Hz-2500 Hz, or about 1000 Hz.

[0062] The system **1** is also configured to affix the device **100** to the eye via fixation line **210**, which fluidly connects the fixation chamber(s) **135** of the device **100** to a second vacuum source **220**, which can be a fixation pump, within the control unit **200**. The force transmitted by the treatment chamber **105** can be an outwardly deforming or distending force provided by a negative pressure (i.e., less than atmospheric pressure) generated by the first vacuum source **215** and transmitted through the treatment line **205** to the treatment chamber **105**. The force transmitted by the treatment chamber **105** can be an inwardly deforming or compressive force provided by a positive pressure (i.e., greater than atmospheric pressure) generated by the first vacuum source **215** and transmitted through the treatment line **205** to the treatment chamber **105**. The force transmitted within the treatment chamber **105** can be a combination of an inwardly

or outwardly deforming force provided by alternating negative and positive pressures within the treatment chamber **105**. The force transmitted within the treatment chamber **105** can be a combination of an outwardly deforming force and release of the outwardly deforming force provided by alternating a negative pressure with a release of the negative pressure back towards atmospheric. The force transmitted within the treatment chamber **105** can be a combination of an inwardly deforming or compressive force and release of the inwardly deforming or compressive force provided by alternating a positive pressure with a release of the positive pressure back towards atmospheric pressure. Any of a variety of combinations of pressures can be applied to the treatment chamber **105** as well as be described in more detail below. The pressures generated by the first vacuum source **215** can vary including about −5 mmHg down to about −50 mmHg so long as that pressure applied avoids increasing TOP, preferably in the range of about −10 to about −30 mmHg. The second vacuum source **220** transmits negative pressure through the fixation line **210** to the fixation chamber(s) **135**. The negative pressure generated by the second vacuum source **220** can vary as well, but like the pressures generated for the first vacuum source **215** is preferably in the range of about −10 down to about −30 mmHg.

[0063] Still with regard to FIG. **5**A, the pressures applied to the treatment chamber **105** can be generated by the first vacuum source **215** and transmitted through the treatment line **205**. The treatment line **205** can be a section of tubing configured to attach to an appropriate coupling on the control unit **200** and the corresponding barb fitting **112** on the device **100**. The pressures applied to the fixation chamber(s) **135** can be generated by the second vacuum source **220** and transmitted through the fixation line **210**. The fixation line **210** can be a section of tubing configured to attach to a coupling on the control unit **200** and the corresponding barb fitting **137** on the device **100**.

[0064] The control unit **200** can include a first controller **225** in communication with the first vacuum source **215** and a second controller **230** in communication with the second vacuum source **220**. Alternatively, a single controller **225**/**230** of the control unit **200** can be in communication with both the first vacuum source **215** and the second vacuum source **220**. The controller(s) **225**/**230** can be controlled by a processor **235** configured to receive input from an operator on an input device **240**. The input device **240** can vary as is known in the art including one or more keypads, buttons, sliders, dials, touchscreens, and the like that are configured to adjust one or more functions of the control unit **200**. The control unit **200** can additionally incorporate one or more outputs such as a display, one or more lights, audio speakers, and the like. The control unit **200** can be powered by a power source **245**, which can supply power to the vacuum sources via the processor **235** and controller(s) **225**/**230**.

[0065] FIG. **5**B illustrates another implementation of a system **1** for treatment of an eye including a device **100** for positioning onto and applying a treatment to a region of the eye. The device **100** is configured to be electronically coupled to the control unit **200** via treatment line **205** and fluidly coupled via fixation line **210**. The fixation line **210** connects the fixation chamber **135** of the device **100** to a vacuum source **220** within the control unit **200**. In some implementations, the device **100** includes more than a single fixation chamber **135** with each chamber **135** incorporating a corresponding barb fitting **137**. The fixation line **210** can have a Y-connector configured to split the line **210** into corresponding tube segments that are configured to connect to the barb fittings **137** so as to transmit negative pressure to each of the fixation chambers **135**. The vacuum source **220** can be controlled by the control unit **200** to generate a negative pressure within the fixation chamber **135**. The negative pressure transmitted through the fixation chamber **135** can be sufficient to affix the device onto the eye via suction force so that the device **100** remains in place during application of force (e.g., negative pressure, positive pressure, vibration, etc.) through the treatment chamber **105**. The vacuum source **220** can include a controller **230** that is controlled by processor **235** that is configured to receive input from an operator on input device **240**. The control unit **200** is powered by a power source **245**, which supplies power to the vacuum source **220** via the processor **235** and controller **230**.

[0066] Still with respect to FIG. **5**B, the device **100** can incorporate a vibrating element embedded within a region of the device to apply vibration to the eye via the treatment chamber **105**. The vibration element is connected to the control unit via treatment line **205**, which electronically couples the vibration element to a vibration power source **250**. The processor **235** provides control outputs to the power level controller **255**, which provides a signal to the vibration power source **250**. The signal and power delivered depends upon the type of vibrating element within the device **100**.

[0067] The vibration power source **250** can use monotonic frequencies or harmonic frequencies. The vibration power source **250** can use random frequencies, white noise, or other sonic hues (i.e. pink, blue, brown, etc.). The noise can be any noise characterized by a power spectral density per unit of bandwith proportional to 1/f^n, where f is the frequency of the signal and n is a real valued number. The vibration power source **250** can use an additive set of integer order harmonics or a superimposed set of non-harmonic (e.g., non-integer multiple frequencies). The frequency can be impedance-matched to effectively transmit the pressure, suction, and/or vibration to the target tissues of the eye (e.g., trabecular meshwork and associated fluid channels) while minimizing reflection of the pressure, suction, or vibration. In order to impedance match the acoustic properties of the acoustic transmitter with the target tissue, a specific membrane, fluid, or gel may be used. The interface has an appropriate density and speed of sound such that acoustic energy is more efficiently coupled with the target tissue with less of the acoustic energy being reflected. This same principle may be used when acoustic impedance matching gel is applied during ultrasound examination. The gel reduces acoustic reflection and facilitates more efficient transmission of ultrasonic energy into the tissue. The vibration power source **250** is preferably tuned to avoid resonant frequencies of the eye or other frequencies that may cause damage to eye structures.

[0068] Ultrasound is known to break calcification and stenosis. In some implementations, the device **100** can incorporate low frequency pulsing with the addition of trans-scleral ultrasound to aid in breaking up stenosis such as in Schlemm's canal, trabecular meshwork, and the ostia of collector channels. In this implementation the vibration power source **250** is an ultrasound power source that is configured to transmit higher frequencies in the ultrasound range (e.g., greater than 20 kHz, up to about 2-18 megahertz)

to the vibrating element embedded within the device. The vibrating element (e.g., piezoelectric crystal) can be embedded within a region of the device **100** and coupled electrically via line **205** to the vibration power source **250** to transmit high frequencies to the eye. The energy, whether ultrasound or other vibration frequency, is applied in an annular treatment area **125** of the eye. The power source **250** can be a sine-wave signal generator at a determined frequency between about 1 kHz and 18 MHz. The power source can also combine various frequencies in the range of 1 KHz to 18 MHz to create a plurality of combinations as described above. The vibration power source **250** can use random frequencies, white noise, or other sonic hues as described herein. The noise can be any noise characterized by a power spectral density per unit of bandwidth proportional to 1/f^n, wherein f is the frequency of the signal and n is a real valued number. The vibration power source **250** can use an additive set of integer order harmonics or a superimposed set of non-harmonic (e.g., non-integer multiple frequencies).

[0069] The system **1** can incorporate one or more light sources **260** to illuminate structures of the eye while in use. In one implementation, the light source **260** is an LED within the control unit **200** that is transmitted to a region of the device **100** via a fiber optic, light pipe or other sort of linkage **265** (see FIG. **5**A). In another implementation, the light source **260** is an LED embedded within a region of the device **100** that is powered via an electrical connection **265** from the control unit **200** (see FIG. **5**B). In still further implementations, the light source **260** can be a separate accessory that is used in combination with the device **100** and the control unit **200** such as a light accessory that is placed over a region of the device **100** to transmit light towards a region of the eye. The light source **260** can be used in conjunction with the pressurization or application of vacuum to the surface of the eye to aid in the visualization of the fluid flow during the procedure.

[0070] The one or more lights sources **260** can be configured for visualization and/or photobiomodulation. For example, one or more light sources **260** can be LEDs or laser diodes and corresponding fiber optics incorporated within the device or the control unit **200** to perform photobiomodulation including red (600-700 nm), near-infrared (770-1200 nm), white, blue, green, ultraviolet or near ultraviolet, or other colors.

[0071] The system **1** or the device **100** can incorporate a tonometer configured to measure intraocular pressure (TOP) during a procedure in real-time. In an implementation, the device **100** can incorporate a bridge or other feature extending inward from an anterior end **102** of the device **100** within the inner diameter of the central aperture **101** to position a sensor near or against the cornea **8** when the device **100** is positioned against the sclera **15**. The sensor can take readings periodically throughout the treatment period and communicate the data to the control unit **200** via an electrical linkage. The tonometer can be a non-contact tonometer configured to apply air pressure against the cornea with a brief puff of air. The tonometer can also be a contact sensor that comes in direct contact with the front of the eye.

[0072] The device **100** can be positioned on a surface of the eyeball directly as illustrated (i.e., the sclera with the eyelids open) or can be a surface of the eyelid with the eyelid closed over the sclera **15**. In some implementations, the device **100** can be coupled to or used in combination with an eye speculum configured to hold open the eyelids during use. For example, an outer perimeter of the device **100** can incorporate one or more clips biased to spring outward to urge the upper and lower eyelids away from one another.

Methods of Use

[0073] The devices described herein can be used to aid in visualizing fluid channels of an eye, for example, during an intraocular procedure. The devices described herein can be used for palpating the eye along a full circumferential band so as to visualize flow of vital dyes such as Trypan blue for assessing outflow during a procedure. The devices described herein can be used during glaucoma treatment by fixating to the eye using suction and performing a treatment on the treatment region, such as by applying suction, positive pressure, a combination of suction and positive pressure, vibration, and the like according to a treatment frequency while the device is affixed to a region of the eye by suction.

[0074] In an implementation, the device is used for visualizing fluid channels of an eye during an intraocular procedure. An amount of a dye, such as Trypan blue, is injected locally so that the dye enters into a region of an eye. The device is positioned on an anterior surface of the eye. At least a portion of the device is transparent or translucent so as to visualize at least a portion of the anterior surface of the eye underlying the annular device. A positive pressure is transmitted through at least a region of the annular device to create an inwardly compressive force against the anterior surface of the eye. The inwardly compressive force is sufficient to prevent the dye from entering a region of the eye near the anterior surface of the eye. A surgeon visualizes through the transparent or translucent portion of the device a return of the eye into a region of the eye upon release of the positive pressure. The device can be an annular device sized to encircle at least a portion of the cornea. The inwardly compressive force to prevent the dye from enter the region of the eye can vary, but is preferably sufficient to substantially prevent fluid flow through the channels in the region being compressed similar to how a surgeon may palpate an eye with a finger during a procedure. The force can be applied to a circumferential band of an eye or along one or more distinct regions of an eye as described elsewhere herein. The device can additionally incorporate a chamber configured to affix the device to the eye during use. The fixation suction can be about −5 mmHg, preferably about −10 mmHg. The fixation suction can be no greater than about −50 mmHg, preferably no greater than about −30 mmHg.

[0075] In another implementation, the device is used as a method of treating glaucoma of an eye. The device is positioned on the anterior surface of the eye so as to encircle at least a portion of the cornea. The device includes a treatment chamber and a fixation chamber. A force is transmitted to at least a portion of the anterior surface of the eye through the treatment chamber of the device. The force is sufficient to cause a deformation of the anterior surface of the eye in an inwardly direction, an outwardly direction, or a combination of the inwardly and outwardly directions. The device is fixed to the anterior surface of the eye by transmitting a negative pressure through the fixation chamber drawing the fixation chamber against the anterior surface of the eye. The device can be an annular device sized to encircle at least a portion of the cornea. The pneumatic/hydraulic treatment frequency range can be about 1 Hz-5000 Hz. The fixation suction can be about −5 mmHg, preferably

about −10 mmHg. The fixation suction can be no greater than about −50 mmHg, preferably no greater than about −30 mmHg.

[0076] In another implementation, the device is used as a method of treating glaucoma of an eye. The device is positioned on the anterior surface of the eye and includes a treatment chamber and a fixation chamber. The device transmits a vibration with the treatment chamber to at least a portion of the anterior surface of the eye. The device is fixed to the anterior surface of the eye by transmitting a negative pressure through the fixation chamber drawing the fixation chamber against the anterior surface of the eye. The device can be an annular device sized to encircle at least a portion of the cornea. The piezo or other electrical treatment frequency range can be about 1 kHz-18 MHz. The fixation suction can be about −5 mmHg, preferably about −10 mmHg. The fixation suction can be no greater than about −50 mmHg, preferably no greater than about −30 mmHg.

[0077] The system can include a control unit, power source, microprocessor computer, and the like. Aspects of the subject matter described herein may be realized in digital electronic circuitry, integrated circuitry, specially designed ASICs (application specific integrated circuits), computer hardware, firmware, software, and/or combinations thereof. These various implementations may include an implementation in one or more computer programs that are executable and/or interpretable on a programmable system including at least one programmable processor, which may be special or general purpose, coupled to receive signals, data and instructions from, and to transmit signals, data, and instructions to, a storage system, at least one input device, and at least one output device.

[0078] These computer programs (also known as programs, software, software applications, or code) include machine instructions for a programmable processor, and may be implemented in a high-level procedural and/or object-oriented programming language, and/or in assembly/machine language. As used herein, the term "machine-readable medium" refers to any computer program product, apparatus, and/or device (e.g., magnetic discs, optical disks, memory, Programmable Logic Devices (PLDs)) used to provide machine instructions and/or data to a programmable processor, including a machine-readable medium that receives machine instructions as a machine-readable signal. The term "machine-readable signal" refers to any signal used to provide machine instructions and/or data to a programmable processor.

[0079] In various implementations, description is made with reference to the figures. However, certain implementations may be practiced without one or more of these specific details, or in combination with other known methods and configurations. In the description, numerous specific details are set forth, such as specific configurations, dimensions, and processes, in order to provide a thorough understanding of the implementations. In other instances, well-known processes and manufacturing techniques have not been described in particular detail in order to not unnecessarily obscure the description. Reference throughout this specification to "one embodiment," "an embodiment," "one implementation, "an implementation," or the like, means that a particular feature, structure, configuration, or characteristic described is included in at least one embodiment or implementation. Thus, the appearance of the phrase "one embodiment," "an embodiment," "one implementation, "an implementation," or the like, in various places throughout this specification are not necessarily referring to the same embodiment or implementation. Furthermore, the particular features, structures, configurations, or characteristics may be combined in any suitable manner in one or more implementations.

[0080] The use of relative terms throughout the description may denote a relative position or direction. For example, "distal" may indicate a first direction away from a reference point. Similarly, "proximal" may indicate a location in a second direction opposite to the first direction. The reference point used herein may be the operator such that the terms "proximal" and "distal" are in reference to an operator using the device. A region of the device that is closer to an operator may be described herein as "proximal" and a region of the device that is further away from an operator may be described herein as "distal". Similarly, the terms "proximal" and "distal" may also be used herein to refer to anatomical locations of a patient from the perspective of an operator or from the perspective of an entry point or along a path of insertion from the entry point of the system. A region of the device that is designed to be arranged on an eye in an anterior direction or towards a front part of the eye may be described herein as "anterior" and a region of the device that is further away from the front part of the eye towards the back of the eye may be described herein as "posterior". As such, a location that is proximal may mean a location in the patient that is closer to an entry point of the device along a path of insertion towards a target and a location that is distal may mean a location in a patient that is further away from an entry point of the device along a path of insertion towards the target location. However, such terms are provided to establish relative frames of reference, and are not intended to limit the use or orientation of the devices to a specific configuration described in the various implementations.

[0081] As used herein, the term "about" means a range of values including the specified value, which a person of ordinary skill in the art would consider reasonably similar to the specified value. In aspects, about means within a standard deviation using measurements generally acceptable in the art. In aspects, about means a range extending to +/−10% of the specified value. In aspects, about includes the specified value.

[0082] While this specification contains many specifics, these should not be construed as limitations on the scope of what is claimed or of what may be claimed, but rather as descriptions of features specific to particular embodiments. Certain features that are described in this specification in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable sub-combination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a sub-combination or a variation of a sub-combination. Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Only a few examples and imple-

mentations are disclosed. Variations, modifications and enhancements to the described examples and implementations and other implementations may be made based on what is disclosed.

[0083] In the descriptions above and in the claims, phrases such as "at least one of" or "one or more of" may occur followed by a conjunctive list of elements or features. The term "and/or" may also occur in a list of two or more elements or features. Unless otherwise implicitly or explicitly contradicted by the context in which it is used, such a phrase is intended to mean any of the listed elements or features individually or any of the recited elements or features in combination with any of the other recited elements or features. For example, the phrases "at least one of A and B;" "one or more of A and B;" and "A and/or B" are each intended to mean "A alone, B alone, or A and B together." A similar interpretation is also intended for lists including three or more items. For example, the phrases "at least one of A, B, and C;" "one or more of A, B, and C;" and "A, B, and/or C" are each intended to mean "A alone, B alone, C alone, A and B together, A and C together, B and C together, or A and B and C together."

[0084] Use of the term "based on," above and in the claims is intended to mean, "based at least in part on," such that an unrecited feature or element is also permissible.

[0085] The systems disclosed herein may be packaged together in a single package. The finished package would be sterilized using sterilization methods such as Ethylene oxide or radiation and labeled and boxed. Instructions for use may also be provided in-box or through an internet link printed on the label.

[0086] All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein is intended merely to better illuminate the invention and does not pose a limitation on the scope of any claims. No language in the specification should be construed as indicating any non-claimed element essential to the practice of the invention.

P Embodiments

[0087] P Embodiment 1. An ophthalmic device comprising: A ring with one or multiple open lumens with the ability to be placed against the surface of the eye; A suction source coupled to the ring to keep the ring on the eye; A pressure, suction, or vibration source coupled to the primary lumen of the device; A primary lumen that is transparent allowing for visualization of the surface of the eye through the lumen.

[0088] P Embodiment 2. The ophthalmic device of P Embodiment 1 containing dividers (radial or circumferential) that allow for variable pressures within the primary lumen of the device.

[0089] P Embodiment 3. The ophthalmic device of P Embodiment 1 containing a light source that allows for illumination of the structures of the eye.

[0090] P Embodiment 4. The light source of P Embodiment 3 that is a separate accessory to the device.

[0091] P Embodiment 5. The light source of P Embodiment 3 that is built into the pulsatile suction ring.

[0092] P Embodiment 6. The ophthalmic device of P Embodiment 1 containing a light source for photobiomodulation using red, green, or blue light.

What is claimed is:

1. An ophthalmic device for use on an anterior surface of an eye, the device comprising:

a treatment chamber defined at least in part by an anterior ring, a posterior ring, and an upper surface connecting the anterior ring and the posterior ring, the treatment chamber configured to transmit a force against the anterior surface of the eye; and

a fixation chamber configured to be in fluid communication with a vacuum source and in fluid communication with the anterior surface of the eye.

2. The ophthalmic device of claim **1**, wherein the vacuum source is configured to generate a negative pressure within the fixation chamber to maintain the device against the anterior surface of the eye during transmitting the force via the treatment chamber.

3. The ophthalmic device of claim **1**, wherein the treatment chamber comprises one or more dividers creating a plurality of treatment chambers.

4. The ophthalmic device of claim **3**, wherein the one or more dividers extend radially relative to a center of the device or circumferentially around the center of the device.

5. The ophthalmic device of claim **1**, further comprising a light source.

6. The ophthalmic device of claim **5**, wherein the light source is a separate accessory configured to couple to the device.

7. The ophthalmic device of claim **5**, wherein the light source is embedded within a region of the device.

8. The ophthalmic device of claim **5**, wherein the light source is configured to illuminate a region of the eye via the device.

9. The ophthalmic device of claim **5**, wherein the light source is configured for photobiomodulation of a region of the eye via the device.

10. The ophthalmic device of claim **9**, wherein the light source is a red, green, or blue light source.

11. The ophthalmic device of claim **1**, further comprising a tonometer configured to measure intraocular pressure during a procedure in real-time.

12. The ophthalmic device of claim **1**, wherein the force transmitted against the anterior surface of the eye by the treatment chamber is configured to maximize an effect of a therapy.

13. The ophthalmic device of claim **1**, wherein the treatment chamber is coupled to a vacuum source configured to generate a negative pressure and/or a positive pressure within the treatment chamber so as to transmit the force against the anterior surface of the eye.

14. The ophthalmic device of claim **1**, wherein the treatment chamber is coupled to a source of vibration configured to generate a vibration within the treatment chamber so as to transmit the force against the anterior surface of the eye.

15. The ophthalmic device of claim **14**, wherein the source of vibration is a vibrating element embedded within a region of the device.

16. The ophthalmic device of claim **15**, wherein the vibrating element is a haptic engine, a voice coil/speaker, a piezo actuator, a ribbon vibrator.

17. The ophthalmic device of claim **1**, further comprising an exciter or transducer configured to vibrate the eye in addition to transmitting the force by the treatment chamber.

18. The ophthalmic device of claim **1**, wherein the treatment chamber has no lower surface so as to transmit the force by means of a fluid interface.

19. The ophthalmic device of claim **18**, wherein the fluid interface is a gas interface or a liquid interface.

20. The ophthalmic device of claim **1**, where the treatment chamber has a lower surface so as to transmit the force by means of a mechanical interface.

21. The ophthalmic device of claim **20**, wherein the mechanical interface comprises a ribbon transducer forming the lower surface of the treatment chamber.

22. The ophthalmic device of claim **1**, further comprising an anterior enclosure extending anteriorly relative to the treatment chamber and the fixation chamber and sized to fully enclose the cornea of the eye upon positioning the treatment chamber against the anterior surface of the eye.

23. The ophthalmic device of claim **22**, wherein the anterior enclosure is in a form of an eye cup, wherein at least the posterior ring of the treatment chamber forms a seal with the anterior surface of the eye to contain a liquid within the anterior enclosure.

24. The ophthalmic device of claim **23**, wherein the anterior surface of the eye is the sclera of the eye with eyelids open or the outside surface of the eyelid with eyelids closed.

25. The ophthalmic device of claim **1**, wherein the force transmitted against the anterior surface of the eye comprises vibration provided by a vibration power source.

26. The ophthalmic device of claim **25**, wherein the vibration power source uses monotonic frequencies, harmonic frequencies, random frequencies, white noise, pink noise, blue noise, or brown noise.

27. The ophthalmic device of claim **25**, wherein the vibration power source uses an additive set of integer order harmonics or a superimposed set of non-harmonic frequencies.

28. The ophthalmic device of claim **25**, wherein the vibration power source uses any noise characterized by a power spectral density per unit of bandwidth proportional to 1/f^n, wherein f is a frequency of a signal and n is a real valued number.

29. The ophthalmic device of claim **25**, wherein the vibration power source is tuned to avoid resonant frequencies of the eye or other frequencies that cause unintended damage to the eye.

30. The ophthalmic device of claim **1**, wherein at least the upper surface of the treatment chamber is transparent or translucent allowing for visualization of the eye through the treatment chamber.

31. A method of visualizing fluid channels of an eye during an intraocular procedure, the method comprising:

injecting an amount of a dye so the dye flows into a region of an eye;

positioning an annular device on an anterior surface of the eye so as to encircle the cornea, wherein at least a portion of the annular device is transparent or translucent in order to visualize at least a portion of the anterior surface under the annular device;

transmitting a positive pressure through at least a region of the annular device to create an inwardly compressive force against the anterior surface of the eye, the inwardly compressive force sufficient to prevent dye from entering a region of the eye near the anterior surface of the eye; and

visualizing through the transparent or translucent portion of the annular device a return of the dye into the region of the eye.

32. A method of treating glaucoma of an eye comprising a cornea and an anterior surface surrounding the cornea, the method comprising:

positioning an annular device on the anterior surface of the eye so as to encircle the cornea, wherein the annular device comprises a treatment chamber and a fixation chamber;

transmitting a force to at least a portion of the anterior surface of the eye through the treatment chamber of the annular device, the force sufficient to cause a deformation of the anterior surface of the eye in an inwardly direction, an outwardly direction, or a combination of the inwardly and outwardly directions; and

fixing the annular device to the anterior surface of the eye by transmitting a negative pressure through the fixation chamber drawing the fixation chamber against the anterior surface of the eye.

33. A method of treating glaucoma of an eye comprising a cornea and an anterior surface surrounding the cornea, the method comprising:

positioning an annular device on the anterior surface of the eye so as to encircle the cornea, wherein the annular device comprises a treatment chamber and a fixation chamber;

transmitting a vibration to at least a portion of the anterior surface with the treatment chamber; and

fixing the annular device to the anterior surface of the eye by transmitting a negative pressure through the fixation chamber drawing the fixation chamber against the anterior surface of the eye.

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