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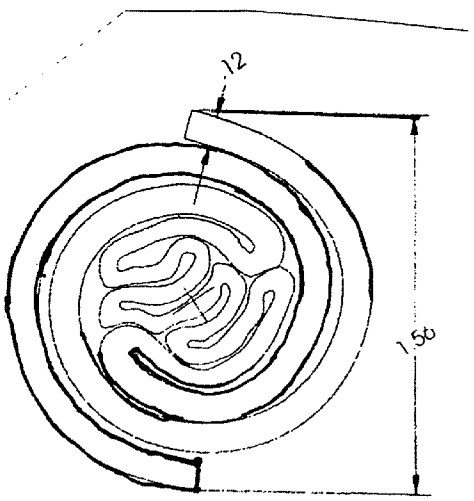
(54) Title: BIODEGRADABLE MEDICAL DEVICES INCLUDING BIODEGRADABLE PATENT FORAMEN OVALE (PFO) CLOSURE DEVICES



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(57) Abstract: Devices, methods, systems and kits are provided, the devices including biodegradable material which is configured to completely degrade over time after placement within a patient's body. Medical devices made with completely biodegradable materials provide the therapeutic benefit of the device before a substantial amount of erosion occurs, effective to provide therapeutic benefit that enables natural repair mechanisms to repair the defect, and which then provide the further and additional therapeutic benefit of dreading away so that no foreign object remains in the region which has been repaired. Devices disclosed herein may be configured to repair a structural defect, such as a congenital or other defect (e.g., a patent foramen ovale) of a patient in need of such repair. The medical devices, elements, systems, and methods disclosed herein may be configured to be introduced through a catheter via a single entry point or via multiple entry points.

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BIODEGRADABLE MEDICAL DEVICES including BIODEGRADABLE PATENT FORAMEN OVALE (PFO) CLOSURE DEVICES

BACKGROUND

[0001] Medical devices are useful for a wide variety of clinical applications, including repairing damaged, diseased, deformed, or ineffective or poorly functioning tissues. For example, although normally the heart and blood vessels are configured to pump and transport blood throughout the body, in some cases, including cases of congenital disease, an opening, or other alternative pathway may exist through which blood may flow inappropriately or which may lead to or contribute to turbulence and may increase the risk of clots or other blood problems which can lead to migraine, transient ischemic attack, or stroke. Thus, situations and conditions which may require medical treatment to close a shunt include patent foramen ovale (PFO), patent ductus arteriosus (PDA), atrial septal defect (ASD), ventricular septal defect (VSD), aneurysm, varix and so on.

[0002] In the cases of PFO, PDA, ASD and VSD, the defects may be closed by a surgical operation (a thoracotomy) that was generally performed in the past, and in which the ductus arteriosus is ligated or cut. Drawbacks of this operation include, for example, the danger of the operation, and the functional effects of remaining scar tissue. Further treatments may include reducing the blood pressure to avoid the risk that an aneurysm or a varix may cause the bursting of the defective blood vessel.

[0003] For example, a relatively common condition called "patent foramen ovale" occurs when the foramen ovale, an opening between the left and right atria of the heart, normally found in fetuses and sometimes in newborn infants, fails to fully close, leaving an open or "patent" foramen ovale which may then serve as a shunt pathway between the two atria that can reduce heart function and is believed to be implicated in such disorders as migraine, transient ischemic attacks (TIAs) and stroke.

[0004] Similarly, a patent ductus arteriosus (an opening in the septum of the heart which may provide a shunt pathway between the two ventricles) and other diseases and conditions related to inappropriate pathways for bloodflow may cause

medical problems in the people having these diseases or conditions, and are suitable conditions for treatment by medical devices configured to provide a solution to these problems. Thus, closure of the patent foramen ovale, or patent ductus arteriosa, or reduction in the size of the opening of a patent foramen ovale or patent ductus arteriosa, is believed to reduce the risk of stroke, migraine, TIA, or other condition, in the patient.

[0005] For example, U.S. Patents 3,874,388 to King and Mills, and 4,007,743 to Blake disclose devices for closing a shunt between the left atrium and the right atrium of the human heart. U.S. Patents 5,634,936 to Linden *et al.*, and 5,192,301 to Kamiya *et al.*, disclose further medical devices useful for closing an opening in a body cavity. Further medical devices include, for example, those discussed in U.S. Patents 5,853,422; 6,024,756; 6,312,446; which discuss septal closure devices which may be covered with biodegradable or non-biodegradable covering materials; U.S. Patent 5,634,936 discusses placement of a plug by a balloon which may be made with a biodegradable, biocompatible polymer; and U.S. Patent 6,932,833, which discusses closure of a rent in a membranous tissue by forming a biocompatible and biodegradable barrier at the site of the rent (which is said to be in the dura mater surrounding the brain).

[0006] Medical devices useful for medical procedures typically must be introduced into the body of a patient; typically, a common goal of such introduction is to do so in a minimally invasive manner. A typical procedure for introduction of a medical device may follow hemodynamic measurements, angiography, transesophogeal echocardiography, local anesthesia, admininstration of anticoagulants, antibiotics, and other drugs, or other procedure. For example, a device may be introduced into the heart to correct a defect in the tissue separating the atria, or the ventricles, or to correct a defect in a heart valve. For example, as an exemplary procedure, a device may be introduced into a patient's heart to correct a defect that allows inappropriate blood flow between the atria in the heart (e.g., closure of a patent foramen ovale (PFO)). Such an exemplary procedure may follow or include some or all of the following procedures: a valved introducer sheath is placed in the femoral vein to gain functional access to that vein. A guidewire or guide catheter is used to find the defect in the heart, and often-times balloon sizing (e.g., using fluoroscopy or echocardiography) is necessary to determine the proper treatment for the individual patient. Atrial location, size and relation to other structures

of the heart is measured and compared for exclusion criteria for the intra-atrium closure. The sizing balloon can be placed across the defect showing a waist that can be measured for tunnel width. The properly sized device is loaded in a loader and then in the delivery sheath. The device is delivered, via the delivery sheath, into the femoral artery, and then advanced (tracked) to the particular desired location over a guidewire or within a sheath. The delivery catheter is retracted and the device is allowed to expand. The device position is documented for residual shunt and checked for any compromise of cardiac structure, typically by ultrasonic examination using dye or bubbles (which may be, e.g., introduced through the catheter). Post-procedural anticoagulants are given for some period of time and several examinations are used to check for patency of the defect (reduced patency, or complete closure, being the desired outcome of the procedure). Often the closure rate increases over time as endothelial overgrowth proceeds.

[0007] However, medical devices may be difficult to position securely in place, or may be complicated to use, are foreign to the body, and may cause inflammation, thrombosis, electrical disturbances (e.g., atrial fibrillation), may move or detach and thereby possibly cause damage, may interfere with subsequent procedures, and may have other drawbacks. Thus, improved devices and treatments are required.

SUMMARY OF THE INVENTION

[0008] Devices, methods, and kits providing medical devices made with biodegradable material, which are configured to completely degrade over time, are provided herein. Medical devices made with completely biodegradable (also termed bioresorbable and bioerodeable) materials provide the therapeutic benefit of the device before a substantial amount of erosion occurs, effective to provide therapeutic benefit that enables natural repair mechanisms to repair the defect, and which then provide the further and additional therapeutic benefit of degrading away so that no foreign object remains in the region which has been repaired.

[0009] Devices may be configured, for example, to repair a structural defect, such as a congenital or other defect (e.g., a patent foramen ovale) of a patient in need of such repair. Such repair may include, for example, occluding a defect (e.g., a patent foramen ovale), or causing tissue, such as tissue leaflets, near a defect such as a

patent foramen ovale to join together to close the defect, or to adhere to each other effective to substantially prevent inappropriate blood flow through the defect. For example, where the defect is a patent foramen ovale (PFO), any blood flow through the defect is inappropriate blood flow through the defect, and successful repair or treatment of a PFO reduces, or substantially reduces, or preferably substantially stops, blood flow through the PFO. In particularly preferred embodiments, successful repair or treatment of a PFO completely prevents blood flow through the PFO.

[0010] The medical devices, elements, systems, and methods disclosed herein are configured to be introduced through a catheter via a single entry point or via multiple entry points. For example, in embodiments, devices, elements, or systems disclosed herein may assume a first configuration and a second configuration, where a second configuration may be an expanded or enlarged configuration as compared with the first configuration. A device, element, or system disclosed herein may be placed in an opening or passage within a patient's body when in a smaller or first configuration, and may subsequently assume, and may be caused to assume, an expanded or second configuration when adjacent tissue or when within a passage or opening in a patient's body. For example, an inappropriate passage or opening within a patient's body may need treatment or repair. An example of an inappropriate passage or opening within a patient's body that may need treatment or repair is a patent foramen ovale (PFO). For example, prior to placement in the PFO, or other opening or passage within a patient's body, such devices, elements, and systems may be in the smaller or first configuration, e.g., may be extended and stretched to present only a very small cross-section, suitable for placement within a delivery catheter, for example, or other delivery device or mechanism, and suitable for placement into and within a passage or opening in a patient's body. Such devices, elements, and systems, when in place in a passage or opening within a patient's body (e.g., within a PFO), may be used to occlude a passage or opening and so to treat or repair the condition presented by an inappropriate passage or opening (e.g, the condition presented by a PFO).

[0011] It will be understood that designs, elements, and components suitable for use in the practice of the invention, and suitable for positioning and placement within a patient's body, including within a passage or opening within a patient's body, typically

have surfaces that are compatible and safe for such positioning and placement, and thus do not have sharp or jagged edges on surfaces that are not designed or configured to puncture or attach to tissues. Thus surfaces may be smoothed, or covered with soft or atraumatic coverings or layers, and/or may be made with materials that have smooth and/or atraumatic surfaces. In embodiments, barbs, hooks, spurs, adhesives, suction elements or other elements may be included to anchor devices in a desired location. Thus, while in general a smooth, or soft, or compliant surface is advantageous to reduce perforation or other trauma to body tissue, designs, elements, and components suitable for use in the practice of the invention may include anchoring elements, such as barbs, hooks, spurs, adhesives, suction elements or other elements, and may include positioning elements and retrieval elements (such as loops, hooks, mesh, netting, tabs, or other elements) which may aid in holding a device during delivery and/or placement, or which may aid in retrieving a device following delivery and/or placement at a desired location within a patient's body.

[0012] In particular embodiments, the devices, systems and methods are configured for, and may be used to, close or reduce the open aperture of a patent foramen ovale (PFO). In particular embodiments, the devices, systems and methods are configured for, and may be used to, close or reduce the open aperture of a patent ductus arteriosus (PDA). In other embodiments, the devices, systems and methods are configured for, and may be used to, close or reduce the open aperture of other body openings, including, for example, openings of an atrial septal defect (ASD), a ventricular septal defect (VSD), an aneurysm, a varix, or other opening. The devices, systems and methods disclosed herein are suitable for use in treating any of the above, and are suitable for treating other dysfunctional openings, whether congenital, or whether developed by disease or by trauma. In the following, the application to, and treatment of, PFO will be used to describe and to exemplify the design, use, and otherwise to describe embodiments of the devices, systems and methods having features of the invention. PFO devices, systems and methods will be used as examples of all the possible uses and applications of the devices, systems and methods disclosed herein. Thus, it will be understood that where, in the following, the use and design of devices, systems and methods having features of the invention are described in terms of PFO applications, such descriptions are

also intended to apply to the use and design of devices, systems and methods having features of the invention for PDA applications, for ASD applications, for VSD applications, for aneurysm applications, for varix applications, and for any other application.

[0013] Medical devices, systems, and methods disclosed herein include the two exemplary design categories of Stabilizer Designs and Plug Designs, and combinations of the two. These designs, and all designs disclosed herein, are suitable for construction using biodegradable (alternatively termed "bioerodeable" or "bioresorbable") materials, including preferably biodegradable shape memory polymers. Thus, the devices and systems are suitable to be made with, or made in substantial part with, a material or materials that will biodegrade or be broken down either completely or partially degraded and removed from the location by natural processes over time. It will be understood that while the device itself may be completely degraded and absent after a period of time, evidence of the device, in the form of an enduring repair or treatment, and possibly including scar tissue or other tissue growth in the region may remain.

[0014] For example, a device or system having features of the invention may be a device for treating, closing or repairing a PFO, PDA, ASD, VSD, or other defect or condition, that is made using a biodegradable shape memory polymer (biodegradable SMP). In embodiments suitable for use in treating, closing or repairing a PFO, for example, a device may be introduced into the heart in a first, small configuration, and after placement in a location suitable for treating, closing, or repairing a PFO, the device is induced to assume a second configuration by action of a triggering step, which may include application of a chemical, alteration of chemical concentration, alteration of pH, application or the action of heat, light, magnetic field, electric field, electrical current, ultrasound, or other energy effective to allow or cause the device to assume its second configuration. In some embodiments, the second configuration may be an initial configuration where the first, small configuration is imposed after the device is manufactured or initially shaped in its initial configuration. In other embodiments, the second configuration may be a subsequent configuration where the first, small configuration is an initial configuration of the device, which is a configuration in which the device is manufactured or initially shaped. The second configuration, assumed after a

triggering step upon placement of the device in its target location, may be a permanent configuration. There may be two, three, or more transitions where shape memory is activated and therefore there may be as many or more corresponding configurations (see, e.g., U.S. 6,388,043 for description related to shape memory transitions, including shape memory materials and elements having more than one shape memory configuration; this patent is hereby incorporated by reference herein in its entirety for all its disclosure, including but not limited to its disclosure regarding shape memory transitions).

[0015] A device may be configured to undergo a shape memory transition within a patent foramen ovale, or may be configured to undergo more than one shape memory transitions within a patent foramen ovale (PFO). A device may be configured to undergo a shape memory transition within a patent ductus arteriosus, or may be configured to undergo more than one shape memory transitions within a patent ductus arteriosus (PDA). A device may be configured to undergo a shape memory transition within an atrial septal defect, or may be configured to undergo more than one shape memory transitions within an atrial septal defect (ASD). A device may be configured to undergo a shape memory transition within a ventricular septal defect, or may be configured to undergo more than one shape memory transitions within a ventricular septal defect (VSD). A device may be configured to undergo a shape memory transition, or to undergo multiple shape memory transitions, within an aneurysm, or within a varix, or within any other opening.

[0016] In addition, devices, systems, methods, and components having features of the invention may include one or more stabilization features and/or one or more plug features. Plug and/or stabilization features may be used alone or in conjunction with other features and elements, including, for example, clip elements or features.

[0017] In embodiments of the elements, devices, systems, and methods disclosed herein, an occlusive or closure device may be manufactured from, or include, a suitable material that may be a polymer, a plastic, a metal, a mesh, a fabric, or other material. In embodiments, a suitable starting material may be a biodegradable material, such as a biodegradable polymer, a biodegradable plastic, or other biodegradable material or composite. In embodiments, a suitable material may be a shape memory material, such

as a shape memory metal or a shape memory plastic or a shape memory polymer, or shape memory composite. In embodiments, a suitable material may be a biodegradable shape memory material, such as a biodegradable shape memory polymer, a biodegradable shape memory plastic, or other biodegradable shape memory material or composite.

[0018] In addition, these designs, and all designs disclosed herein, are suitable for construction using shape memory materials, including shape memory metals, shape memory plastics, shape memory polymers, and other shape memory materials. In embodiments of the devices, systems, and methods disclosed herein, suitable shape memory materials include biodegradable shape memory materials, including preferably biodegradable shape memory polymers. Thus, the devices and systems are suitable to be made with, or made in substantial part with, a material or materials that have "shape memory" and that will biodegrade or be broken down and removed from the location by natural processes over time. It will be understood that while the device itself may be completely degraded and absent after a period of time, evidence of the device, in the form of an enduring repair or treatment, and possibly including scar tissue or other tissue growth in the region may remain.

[0019] Suitable polymers include thermosetting polymers and or thermoplastics, thermosetting shape memory polymers categorically, polymer networks, semi-interpenetrating networks, interpenetrating networks, and mixed interpenetrating networks. Thermoplastic polymers can be a blend of one or more homo- or co-polymer with one or more diblock-, triblock-, tetrablock, or multiblock copolymers, branch or graft polymers. Suitable polymers include copolymers, block copolymers, homopolymers, crystalline polymers, semi-crystalline polymers, amorphous polymers, including, for example, polylactide polymers, polyglycolide polymers, polycaprolactone polymers, polylactide-poly glycolide copolymers, polylactide-polycaprolactone copolymers, polyglycolide-polycaprolactone copolymers, polylactide-polyglycolide-polycaprolactone copolymers, and other polymers and copolymers, including block copolymers. Particularly suitable polymers include biodegradable polymers.

[0020] Particularly preferred biodegradable polymers include biodegradable shape memory polymers, and include polymers and copolymers based on, for example:

caprolactone and glycolide; polycaprolactone; lactide, glycolide, and caprolactone. Such biodegradable polymers include polymers and copolymers are produced, for example, by mNemoscience (mNemoscience GmbH, Carlstrasse 50, 52531 Ubach-Palenberg, Germany). Such biodegradable polymers and biodegradable shape memory polymers are described, for example, in U.S. Patent 7,217,744; U.S. Patent 6,852,825; U.S. Patent 6,720,402; U.S. Patent 6,388,043; and U.S. Patent 6,160,084. The contents of these patents, and all other patents and patent applications cited herein, both *supra* and *infra*, are hereby incorporated by reference in their entireties.

[0021] For example, polymers suitable for use in devices and systems having features of the invention include polyester urethanes, including polyester urethanes having a component of polypentadecalactone. As discussed in U.S. Patent 6,852,825, regarding the use of polypentadecalactone segments in polyester urethanes, the polypentadecalactone segments may be the only polyester segments in the polyester urethan or further segments, different from polypentadecalactone may be present. In a preferred embodiment the polypentadecalactone segments are employed as hard segments in the polyester urethane, which, in addition to the polypentadecalactone segments, do comprise further polyester segments, preferably polycaprolactone segments, as soft segments. These further segments may be selected among a broad variety of chemically different components which are suitable as soft segment. Specific examples which may be named comprise partially crystalline segments, comprising polyester segments, polyether ester segments and polyether segments, such as polycaprolactone segments (PCL), polycaprolactone-co-polytetrahydrofurane segments (PCL-co-pTHF), tetrahydrofurane segments (pTHF), polypropyleneglycol segments (PPG) and polyethyleneglycol segments (PEG), as well as glassy segments, comprising polyester and copolyester, such as poly-L-lactid-co-glycolide (ran) (PLGA) and poly-DL-lactide (P-DL-LA). In particular a combination of polypentadecalactone segments and polyethyleneglycole segments enables intriguing properties of the resulting material due to the combination of hydrophobic and hydrophilic segments.

[0022] Occlusion or closure devices having features of the invention, as disclosed herein, may be manufactured from a single sheet of starting material. Such manufacturing provides greater strength and improved reliability and safety of use as

compared to alternative methods of manufacture, and avoids methods which include the possibility of failure and separation of component parts. Such possibility of failure and separation of component parts, were such to occur when a device was in place within a passage or opening in a patient's body, such as a PFO could have extremely serious consequences to the health and well-being of the patient. Thus, manufacture of occlusion or closure devices from a single sheet of starting material as disclosed herein provides significant advantages over other methods and designs.

[0023] Category One, Stabilizer Designs:

[0024] "Stabilizer Designs" include designs having an Anchor Plate with a joining tie, spring, suture, and/or shape memory polymer effective to provide recovery of an initial or previous shape or configuration. An Anchor Plate can be concave or convex in shape. An Anchor Plate can be porous (e.g., made with membrane material or materials or with textile material or materials) or may be nonporous (e.g., molded sheet). Such devices can be made from single or multiple materials molded or woven in layers or beam members for strength.

[0025] Category Two, Plug designs:

[0026] A Plug can be made from multiple materials such as foam; foam with soft flexible covering; balloon with liquid filling such as viscous fluid, polymer fluid, heparin fluid, saline; hydrogel or membrane covered hydrogel; solid soft ball; long string or coil filling; expanding mandrel.

[0027] Design One, Clip Designs:

[0028] In embodiments of the devices, systems and methods having features of the invention, clips may be made with, and used with a plug mechanism. In other embodiments of the devices, systems and methods having features of the invention, clips may be made without, or used without, a plug mechanism. Clips may include an arm or multiple arms configured to engage (e.g., to hook, or pierce, or grab, or otherwise adhere to) to a septum wall effective to stabilize the device and to provide a pinching force effective to close PFO. A clip can be single or may have multiple members, which may be, e.g., in coil configurations, in loop configurations, or in combinations of coil and loop

configurations. A clip can feature a rotation upon actuation or may have a simple member that may bend, and upon bending, is disposed in a closed configuration which may be used to effect the closure of a PFO.

[0029] Design Two: Broom Bundle

[0030] A medical device, or component thereof, having features of the invention may be made from a polymer sheet cut in thin strips on the ends and rolled up and tied in the center. Upon actuation, the stretched material recovers forcing the distal and proximal edges outward forming an hourglass shape. Actuation may be by change in temperature (e.g., heating, such as by exposure to radiation (light, infra-red, ultraviolet, microwave, ultrasound, radiofrequency, or other radiation) or by exposure to ambient temperature that is higher than a critical temperature or temperature range), by chemical means, by electrical means, or by any other suitable means.

[0031] Design Three: Grommet:

[0032] A medical device, or component thereof, having features of the invention may be made from a polymer occluder or plug shaped like a "grommet" or, equivalently, shaped like the letter "H". The central region of the device or component can swell to plug the defect and the device flange opens to occlude the defect. The device may encompass just the occluder or both the plug feature and the occluder.

[0033] Other designs, devices, systems, and methods of using them are taught herein, as shown in the figures and as described herein. Such designs and systems include devices, or components thereof a first configuration (suitable for placement of the device or component thereof) and a second configuration (suitable for occlusion of a body opening).

[0034] Methods for using such devices include placement of such devices (or a component or components thereof) into a body opening or pathway (such as, e.g., into a PFO) with the device in a first configuration; and causing or allowing the device to take on a second configuration effective to substantially occlude or substantially close the opening. For example, in embodiments, a device or component thereof may be placed into a first configuration by mechanical means, by rolling, stretching, folding or

unfolding, or other means. For example, in embodiments, a device or component thereof may take on a second configuration under the influence of a change in temperature (e.g., heating, such as by exposure to radiation (light, infra-red, ultraviolet, microwave, ultrasound, radiofrequency or other radiation) or by exposure to ambient temperature that is higher than a critical temperature or temperature range), by chemical means, by electrical means, or by any other suitable means. For example, in embodiments, a device or component thereof may be manufactured in a first configuration (as defined above), so that effort or energy is required to place the device or component into a second configuration; however, in embodiments, a device or component thereof may be manufactured in a second configuration, as defined above, so that effort or energy is required to place the device or component into a first configuration.

[0035] It will be understood that devices and components thereof may take additional configurations, in addition to the first configuration (suitable for placement of the device or component thereof) and to the second configuration (suitable for occlusion of a body opening).

[0036] The devices and components thereof are made with biodegradable materials, preferably biodegradable polymers. Such biodegradable polymers may include polylactide, polyglycolide, polycaprolactone, and other polymers, and copolymers of two or more of these polymers.

[0037] In preferred embodiments, the devices and components thereof are made with biodegradable shape-memory polymers. Such biodegradable shape-memory polymers may include polylactide, polyglycolide, polycaprolactone, and other polymers, and copolymers of two or more of these polymers. In embodiments, the biodegradable shape-memory polymers are set using ultraviolet light to produce the "memory" configuration, and then the biodegradable shape-memory polymers may be deformed (e.g., by mechanical means, with heat, or other means or a combination of means).

[0038] Biodegradable polymers and biodegradable shape memory polymers, as discussed above, are particularly suited for the practice of the invention. For example, biodegradable polymers and biodegradable shape memory polymers including monomers and polymers of caprolactone and/or polycaprolactone, glycolide

and/or polyglycolide, lactide and/or polylactide, ethylene glycol and/or polyethylene glycol may be used.

[0039] As is known in the art, shape memory materials, such as shape memory polymers, may typically have or assume more than one, and often more than two, configurations related to the shape and recovery of the material having shape memory. Transitions between the forms and shapes of these different configurations typically follow a hysteresis curve; that is, the shape of a first configuration may be retained at a temperature at which the shape of a second configuration would be expected, under proper conditions; and the transition from that first to second configuration may be triggered by an alteration in conditions (e.g. by heating, or exposure to light or other electromagnetic radiation, or to a magnetic field, or to electrical current flow, or other trigger). For example, a component or an entire device made of shape memory polymer may have a first configuration: e.g., the manufactured or initial configuration. Energy is imparted to the shape memory polymer component or device in its first configuration at or above either the glass transition temperature (Tg) or the melt temperature (Tm) depending on material structure. The shape memory polymer component or device is then stretched, bent, folded, compressed, expanded, or otherwise manipulated effective to change its shape to the second configuration. The shape memory polymer component or device, in its second configuration, is then cooled below Tg or Tm and held in the second configuration. The second configuration may be, for example, designed to be useful for introduction of the component or device made with the shape memory material to a site of treatment. In use, once the component or device is in proximity to the location of the treatment site, energy is applied again and the component or device recovers to the first configuration, or to some similarly shaped third configuration, typically effective to provide a function or improve the operation of the device or component.

[0040] Such devices, and components thereof, made with biodegradable shape-memory polymers degrade so as to eventually leave substantially no residue of the device or component at a time after placement of the device in a body opening (although the device may, for example, induce scar tissue formation, endothelialization, or remodeling of heart tissue which may have long-lasting or permanent effects which remain after the

device or components have disappeared from the location). The amount of time after placement of the device or component is a sufficient amount of time effective to allow the substantial closure or substantial occlusion of the body opening to have a therapeutic effect. In embodiments, amount of time after placement of the device or component is a sufficient amount of time effective to allow tissue near or adjacent to the body opening to effect a partial or complete repair of the opening, e.g., to grow new or additional tissue to cover the opening, or to connect two or more parts of adjacent tissue effective to close or occlude the opening, or otherwise to provide lasting therapeutic benefit after the complete or substantially complete degradation or erosion of the device or component thereof. For example, where the body opening is a PFO, after placement of the device or component thereof effective to substantially occlude or substantially close the PFO, and after a sufficient time so that the device or component thereof has substantially degraded away, tissue flaps adjacent the original PFO will have grown together by growth of additional tissue, such as, e.g., epithelial tissue, or e.g., scar tissue, effective to connect the tissue flaps and substantially prevent blood flow between the atria of the heart. In embodiments, tissue flaps adjacent the original PFO may become connected by fibers or strands of tissue, or may become connected by overgrowth of tissue, such as epithelial tissue or scar tissue, to create membranes, sheets, or other tissue structures connecting tissue across the previously open PFO.

[0041] The devices, components thereof, systems, and methods having features of the present invention provide advantages of ease of use, including ease of insertion in a first configuration, with effective occlusion of a body opening in a second configuration, and provide the further advantage of being biodegradable so that, over time, the entire device degrades so as to leave no foreign component in the body, thus reducing the risk of damage or injury if the device moves or is dislodged long after its placement, and reducing the risk of inflammation and of scar tissue build-up.

BRIEF DESCRIPTION OF THE FIGURES

[0042] Figure 1A shows an expanding coil placed between two flaps of a PFO.

[0043] Figure 1B shows a grommet-shaped plug placed between two flaps of a PFO.

[0044] Figure 1C shows an expanding foam placed between two flaps of a PFO.

[0045] Figure 1D shows a frame occluder placed between two flaps of a PFO. The frame occluder includes two sheets and structural members, and may include a middle tie connecting the two sheets.

[0046] Figure 2A shows an expandable balloon having arms suitable for use in occluding a PFO.

[0047] Figure 2B shows the expandable balloon having arms of Figure 2A in an actuated configuration with the arms extended.

[0048] Figure 2C shows the expandable balloon having arms of Figures 2A and 2B in an actuated configuration with the arms extended, and with the balloon filled, and suitable for use in occluding a PFO.

[0049] Figures 3A, 3B, 3C, 3D, and 3E show different embodiments of fixation elements suitable for use in occluding or closing an opening, and may be made with self-expanding polymeric materials. Figure 3A shows a hook fixation element.

[0050] Figure 3B shows a braid fixation element.

[0051] Figure 3C shows a coil fixation element.

[0052] Figure 3D shows a clock spring coil fixation element.

[0053] Figure 3E shows a clip fixation element.

[0054] Figure 4A shows an embodiment of an occlusion element having features of the invention which may actuate and twist effective to increase the diameter, suitable for occlusion of a body opening.

[0055] Figure 4B provides further views of a device as shown in Figure 4A, connected to flanges, and schematically indicates a change in configuration upon actuation.

[0056] Figure 4C shows a further embodiment of an occlusion element having flanges and a connecting element having features of the invention, and schematically indicates a change in the connecting element to a coiled configuration upon actuation.

[0057] Figure 5 shows an embodiment of an occlusion device having features of the invention and having a core element and arm elements.

[0058] Figure 6A shows an embodiment of an occlusion device having features of the invention and having a coil element, illustrated in place occluding a PFO.

[0059] Figure 6B shows the occlusion device having a coil element of Figure 6A, illustrated before its final manufacture from a single sheet of material, showing the single sheet of material and a spiral-shaped cut which provides the coil element.

[0060] Figure 6C provides a further illustration of a single sheet of material having a spiral-shaped shape cut into the material which provides the coil element which has a first, extended configuration when stretched and elongated in a form suitable for placement into a PFO and a second, coiled configuration (as illustrated in Figure 6A) as well as an original configuration as illustrated in Figure 6C.

[0061] Figure 6D shows a further embodiment of an occlusion device made from a single sheet of material, and having two plate portions linked by a connecting portion. As illustrated in Figure 6D, the plate portions may be of different sizes; however, in embodiments, the plate portions are each the same size.

[0062] Figure 7A shows an occlusion or closure device having two plate portions linked by a ribbed connecting portion effective that at least a tip portion of the ribbed connecting portion may pass through (as shown in Figure 7A) or over a retaining portion of at least one of the plate portions, effective to bring the plate portions closer together and to prevent their separation after having been brought closer together.

[0063] Figure 7B shows the occlusion or closure device having two plate portions linked by a connecting portion that may be stretched into an extended configuration, and then can be activated (e.g., by heat, light (including infra red, visible, ultraviolet, and other light) ultrasound, microwaves, chemical means, radiofrequency means, or by other means) to return to a non-extended configuration, effective to bring the plate portions closer together.

[0064] Figure 7C shows a further embodiment of an occlusion or closure device having a plurality of flaps disposed at both ends of a connecting element.

[0065] Figure 8A illustrates further embodiments of occlusion or closure devices having features of the invention.

[0066] Figure 8B illustrates still further embodiments of occlusion or closure devices having features of the invention, suitable for manufacture from a single sheet or block of material.

[0067] Figure 8C illustrates still further embodiments of occlusion or closure devices having features of the invention, having coiled or kinked configurations.

[0068] Figure 9 illustrates an embodiment of an occlusion device having features of the invention which has a plug element and an anchor member in which a plug is disposed within a tunnel and occluders pinch together so that they are almost touching.

[0069] Figure 10A shows a spiral-shaped occlusion device made from a single sheet of material having a folded central portion connecting two outer portions.

[0070] Figure 10B shows a further embodiment of a spiral-shaped occlusion device made from a single sheet of material having a central portion with a multitude of rounded folds.

[0071] Figure 10C shows a further embodiment of a spiral-shaped occlusion device made from a single sheet of material, having a central portion that is thinner than the outer portions.

[0072] Figure 10D shows a further embodiment of a spiral-shaped occlusion device made from a single sheet of material, having an irregularly shaped central portion connecting the two outer portions.

[0073] Figure 10E shows a further embodiment of a spiral-shaped occlusion device made from a single sheet of material, having further design for the central portion connecting the two outer portions.

[0074] Figure 11A shows an embodiment of an occlusion device having end portions connected by a central portion, shown in perspective view.

[0075] Figure 11B shows the embodiment of an occlusion device of Figure 11A, shown in side view.

[0076] Figure 12 shows an embodiment of an occlusion device having a smaller and a larger configuration, schematically illustrating a transformation from the smaller to the larger configuration upon application of heparin or other antithrombogenic material.

[0077] Figure 13A shows an embodiment of an occlusion device having end portions connected by a central portion, shown in side view.

[0078] Figure 13B shows the occlusion device of Figure 13A shown in perspective view.

[0079] Figure 13C shows the occlusion device of Figure 13A and Figure 13B shown in perspective view in place within a PFO.

[0080] Figure 14 shows an occlusion device having features of the invention, comprising a clip element and a plug element, shown in perspective view in place within a PFO.

[0081] Figure 15A shows an embodiment of an occlusion device having curved end portions connected by a central portion, shown in side view.

[0082] Figure 15B shows the occlusion device of Figure 15A having curved end portions connected by a central portion, shown in end view.

[0083] Figure 15C shows the occlusion device of Figure 15A and Figure 15 B having curved end portions connected by a central portion, shown in side view, with the central portion in an expanded configuration and the end portions in expanded configurations.

[0084] Figure 16A shows an embodiment of an occlusion device made from a single sheet of material, shown flat as cut by a laser or other means.

[0085] Figure 16B shows the occlusion device of Figure 16A, shown in top view.

[0086] Figure 16C shows the occlusion device of Figure 16A and Figure 16B disposed in a rolled-up configuration, shown in side view.

[0087] Figure 16D shows the occlusion device of Figure 16C in a rolled-up configuration, shown in top view.

[0088] Figure 16E shows the flat sheet from which a device having features as shown in Figures 16A-D may be made.

[0089] Figure 17 shows an embodiment of a clip-shaped occlusion device having features of the invention, shown in perspective view.

[0090] Figure 18A shows another embodiment of a clip-shaped occlusion device having features of the invention, and having lateral expansions on a connecting portion of the device, shown in perspective view.

[0091] Figure 18B shows the clip-shaped occlusion device of Figure 18A, shown in isometric view.

[0092] Figure 19A shows an embodiment of an occlusion device having features of the invention as deployed within a PFO.

[0093] Figure 19B shows the occlusion device of Figure 19A, shown during activation of the device, part way through a change in configuration from a first configuration (suitable for deployment) to a second configuration (effective to occlude or constrain a PFO).

[0094] Figure 19C shows the occlusion device of Figure 19A and Figure 19B disposed in its second configuration, and effecting closure of the PFO.

[0095] Figure 19D shows the occlusion device of Figure 19C in its second, closed configuration, shown in side view.

[0096] Figure 20A shows an embodiment of an occlusion device having features of the invention, shown in an initial configuration as set following an initial manufacture step.

[0097] Figure 20B shows the occlusion device of Figure 20A, shown in a subsequent configuration.

[0098] Figure 20C shows the occlusion device of Figure 20B disposed in another subsequent configuration.

[0099] Figure 20D shows the occlusion device of Figure 20C further stretched for deployment.

[0100] Figure 21A shows another embodiment of a clip-shaped occlusion device having features of the invention, and having an expanded connecting portion of the device, shown in perspective view.

[0101] Figure 21B shows the clip-shaped occlusion device of Figure 21A, shown in isometric view.

[0102] Figure 22A shows another embodiment of a clip-shaped occlusion device having features of the invention, having a non-planar shape, shown in perspective view.

[0103] Figure 22B shows the clip-shaped occlusion device of Figure 22A, shown in right view.

[0104] Figure 22C shows the clip-shaped occlusion device of Figure 22A, shown in top view.

[0105] Figure 23A shows an "S"-shaped occlusion device having features of the invention.

[0106] Figure 23B shows the "S"-shaped occlusion device of Figure 23A after the ends have been rolled and the device has been stretched.

[0107] Figure 23C shows the "S"-shaped occlusion device of Figure 23A and Figure 23B, after the ends have been rolled and the device has been stretched, inserted into a tube indicative of a PFO.

[0108] Figure 23D shows the "S"-shaped occlusion device of Figures 23A, 23B and 23C, within the tube indicative of a PFO, after being submerged in 46° C bath effective to trigger a shape-memory transformation of shape.

[0109] Figure 24A shows a further embodiment of an occlusion device having features of the invention.

[0110] Figure 24B shows the occlusion device of Figure 24A after the ends have been rolled and the device has been stretched.

[0111] Figure 24C shows the occlusion device of Figure 24A and Figure 23B, after the ends have been rolled and the device has been stretched, inserted into a tube indicative of a PFO.

[0112] Figure 24D shows the occlusion device of Figures 24A, 24B and 24C, within the tube indicative of a PFO, after being deployed and after having been submerged in 46° C bath effective to trigger a shape-memory transformation of shape.

[0113] Figure 25A shows a further embodiment of an "S"-shaped occlusion device having features of the invention, after the ends having been rolled and the connecting portion stretched.

[0114] Figure 25B shows the occlusion device of Figure 25A after having been deployed across a passage through a thin and flat material, indicative of a PFO.

[0115] Figure 26A shows a side view of a non-planar "S"-shaped clip device having features of the invention.

[0116] Figure 26B shows a top view of a non-planar "S"-shaped clip device having features of the invention, showing also an aperture into the lumen of the device.

[0117] Figure 26C shows an end view of a non-planar "S"-shaped clip device having features of the invention, showing part of an aperture into the lumen of the device.

[0118] Figure 26D shows a perspective view of a non-planar "S"-shaped clip device having features of the invention, showing an aperture into the lumen of the device.

[0119] Figure 27A shows a side view of a further embodiment of a non-planar clip device having features of the invention.

[0120] Figure 27B shows a top view of the further embodiment of a non-planar clip device having features of the invention of Figure 27A.

[0121] Figure 27C shows an end view of the further embodiment of a non-planar clip device having features of the invention of Figure 27A.

[0122] Figure 27D shows a perspective view of the further embodiment of a non-planar clip device having features of the invention of Figure 27A.

[0123] Figure 28A shows a side view of a further embodiment of a non-planar clip device having features of the invention.

[0124] Figure 28B shows a top view of the further embodiment of a non-planar clip device having features of the invention of Figure 28A.

[0125] Figure 28C shows an end view of the further embodiment of a non-planar clip device having features of the invention of Figure 28A.

[0126] Figure 28D shows a perspective view of the further embodiment of the non-planar clip device having features of the invention of Figure 28A.

[0127] Figure 29A shows a side view of a further embodiment of a non-planar clip device having features of the invention.

[0128] Figure 29B shows a top view of the further embodiment of a non-planar clip device having features of the invention of Figure 29A.

[0129] Figure 29C shows an end view of the further embodiment of a non-planar clip device having features of the invention of Figure 29A.

[0130] Figure 29D shows a perspective view of the further embodiment of the non-planar clip device having features of the invention of Figure 29A.

[0131] Figure 30A shows a side view of a further embodiment of a non-planar clip device having features of the invention, having an expanded central portion.

[0132] Figure 30B shows a top view of the further embodiment of a non-planar clip device having features of the invention of Figure 30A.

[0133] Figure 30C shows an end view of the further embodiment of a non-planar clip device having features of the invention of Figure 30A.

[0134] Figure 30D shows a perspective view of the further embodiment of the non-planar clip device having features of the invention of Figure 30A.

[0135] Figures 31A-31C shows aspects of an embodiment of a fixation device.

DETAILED DESCRIPTION

[0136] Devices, methods, and kits are provided herein which are suitable for use in treating conditions related to inappropriate body openings, and for repairing, closing or occluding, at least partially, and preferably substantially closing or occluding, most preferably substantially completely closing or occluding an inappropriate body opening, where the inappropriate body opening is in need or closing, occluding, or other repair. An inappropriate body opening may be an opening in an organ, or a tissue, or other part

of the body, and typically may allow passage of fluid (e.g., blood) through the opening to a location at which, or to which, such passage of fluid is inappropriate. In some cases, such passage of fluid may be harmful or damaging. An inappropriate body opening may be, for example, an opening between the two atria in the heart, or may be an opening between the two ventricles in the heart. An inappropriate body opening may be a virtual opening, or a potential opening, for example, one that allows fluid or blood flow through the opening only potentially, or only rarely, or only under certain conditions, but still presents a problem in need of treatment or for which treatment is indicated or desirable. An inappropriate body opening may be present, for example, due to a congenital condition or may be due to a disease process, or due to damage or trauma, or may be related to aging. An inappropriate body opening may be, for example, a patent foramen ovale (PFO), a patent ductus arteriosus (PDA), an atrial septal defect (ASD), a ventricular septal defect (VSD), an aneurysm, a varix, or other inappropriate opening in a body.

[0137] A body opening, whether appropriate or inappropriate, is bounded by body tissue or by more than one body tissue (e.g., epithelial tissue, muscle tissue, bone tissue, or other tissue). Such a tissue boundary may be in a roughly circular form, or may be in a roughly linear form (e.g., a gash or tear) or may be in an irregular form. Typically, such a tissue boundary will include one or more portions (e.g., a flap or leaf) which may be connected to other tissue in order to close or occlude the opening. For example, a PFO may often have two or more tissue flaps in sufficiently close proximity to the opening as to enable closure or occlusion of the PFO by suturing, gluing, clipping or otherwise joining the tissue together. In addition, placement of occlusive devices within the opening of, e.g., a PFO, allows occlusion of the PFO. A device, method, or element that effect closure of tissue so as to treat or repair an inappropriate body opening may be termed a closure device or closure element or closure method. Occlusive devices may be attached to tissue adjacent the opening. A device or element or method that occludes an inappropriate opening may be termed an occlusion device or an occlusion element or an occlusion method. In embodiments of the devices and methods having features of the invention, occlusive devices, elements and methods, and closure devices, elements and methods are disclosed. In embodiments of the devices and methods having features of the invention, devices, elements and methods are disclosed which are, or have attributes

of, and so combine the attributes of both occlusive and closure devices, elements and methods.

[0138] In embodiments of the devices, elements, systems, and methods having features of the invention, an occlusive element or device, and/or a closure element or device, may be made with biodegradable material, including biodegradable shape memory material. In preferred embodiments, an occlusive element or device, and/or a closure element or device is primarily or completely made with biodegradable material. In preferred embodiments, an occlusive element or device, and/or a closure element or device is primarily or completely made with biodegradable shape memory material.

[0139] It will be understood that an element, device, or system disclosed herein, and described as an "occlusion device" may also be termed and considered a "closure device." It will further be understood that an element, device, or system disclosed herein, and described as a "closure device" may also be termed and considered an "occlusion device."

[0140] In embodiments of the devices, elements, systems, and methods disclosed herein, the tissue surrounding an inappropriate body opening, such as tissue flaps adjacent a PFO, may be brought together by the devices, elements, systems, and methods having features of the invention. Such a bringing together of the tissue provides close apposition of tissue that was formerly separated by the opening. Upon such close apposition of the tissue, such as tissue flaps of the PFO, over time, the tissue (e.g., the flaps) may adhere, and may grow together, so that even in the absence of the device, the opening (e.g., a PFO) may remain closed. For example, where a devices, elements, or system disclosed herein has degraded following placement within an opening or a passage, so as to be substantially absent from the opening or passage, the opening or passage may remain closed or occluded even in that absence. Such closure or occlusion may persist in the absence of the devices, elements, or systems for example, due to growth of tissue, formation of scar tissue, adhesion of tissues to each other, or for other reasons or combinations of reasons.

[0141] It will be understood that the properties and elements of the devices, elements, systems, and methods disclosed herein, as discussed above, apply to, and

concern and may describe, all the embodiments disclosed herein, including, but not limited to, the exemplary embodiments shown in the figures and as discussed below.

[0142] As illustrated in Figure 1, methods and devices having features of the invention may be placed within a passage, such as a PFO, and adjacent to tissue, such as the tissue flaps of a PFO shown in the figures. Figure 1A shows an expanding coil placed between two flaps of a PFO, effective to occlude the passage and treat the PFO.. In embodiments of the devices illustrated in Figure 1A, an end cap, or two end caps may be attached to the coil, with an end cap disposed outside the passage between the flaps. In embodiments of the devices, elements, systems, and methods having features of the invention, an expanding coil may be made with biodegradable material, including biodegradable shape memory material. In preferred embodiments, an expanding coil is primarily or completely made with biodegradable material, which may be or include biodegradable shape memory material. It will be understood that these materials, and such properties, may be used for, and apply to, all embodiments disclosed herein, including embodiments discussed below, even if not explicitly repeated with respect to those embodiments.

[0143] Figure 1B shows a grommet-shaped plug placed in a passage between two flaps of a PFO, effective to occlude the passage and treat the PFO. A grommet-shaped plug may expand after its initial placement in the passage to more effectively occlude the passage. Note that the plug may include end portions which aid in anchoring the plug in the passage and which aid in compressing the tissue flaps together, further effecting closure of the passage.

[0144] Figure 1C shows an expanding foam placed between two flaps of a PFO, effective to occlude the passage and treat the PFO. An expanding foam may have an initial small configuration, suitable for placement of the foam into a passage or opening, and may have an alternative expanded configuration, effective that the foam may expand after its initial placement in the passage to more effectively occlude the passage. Note that the expanded configuration (shown in Fig. 1C) of the foam may include end portions or protrusions which aid in anchoring the plug in the passage and which aid in compressing the tissue flaps together, further effecting closure of the passage.

[0145] Figure 1D shows a frame occluder placed between two flaps of a PFO. The frame occluder includes two sheets and structural members, and may include a middle tie connecting the two sheets. Such a device or element may be termed an "actuated umbrella" and may unfold from a compressed configuration. A compressed configuration, in which the sheets may be apposed, or may be folded together, or may be wrapped or rolled together, around the middle tie portion, or may have other orientation or configuration when compressed, is suitable for delivery of a frame occluder to a location where it may serve to occlude or close an opening or passage in a patient's body. During placement, or after placement, the frame occluder may assume an expanded or deployed configuration, as shown in Figure 1D. Subsequently, the middle tie may shorten, or be caused to shorten, effective to bring the two sheet portions closer together and effecting closure of the PFO or other tissue around a body opening or passage. For example, where the body opening is a PFO, the frame occluder may bring PFO flaps together. Upon such apposition of the flaps of the PFO, over time, the flaps may adhere, and may grow together, so that even in the absence of the device, the PFO may remain closed. For example, where the frame occluder or other device or element disclosed herein has degraded so as to be substantially absent from the PFO, the PFO may remain closed or occluded even in that absence.

[0146] Figure 2A shows an expandable balloon having arms suitable for use in occluding a PFO. A balloon may be used to introduce fixation elements into a passage or opening, for example, into a right atrium or into a left atrium, or into a passage between a right atrium and a left atrium, where the body opening to be treated is a PFO. A balloon may be filled with a gel, and/or a coil (e.g., of string or filament), and/or a foam, and/or another material. In embodiments utilizing an expandable balloon, fixation elements may be disposed in a right atrium, or in a left atrium, or in both a right and a left atrium. A balloon having features of the invention, and a material or fixation element introduced along with, or by, a balloon, may be made with, either partially or completely, a biodegradable material. Such a biodegradable material may be, or may include, for example, a shape memory biodegradable material.

[0147] In embodiments, a balloon as illustrated in Figure 2A may be about 4 mm to about 6 mm long, and may have on outer diameter of about 0.1 inches (about 2.5 mm)

in a relaxed configuration, and may have an outer diameter of about 0.4 inches (about 10 mm) minimum in an expanded configuration. In further embodiments, a balloon may be about 7 mm, or about 8 mm, or about 9 mm, or about 10 mm long; and may have on outer diameter of about 0.2 inches (about 5 mm), or of about 0.3 inches (about 7.5 mm), or of about 0.4 inches (about 10 mm), or of about 0.5 inches (about 12.5 mm) in a relaxed configuration; and may have an outer diameter in an expanded configuration of up to about 20mm, or about 30 mm, or about 40 mm, or about 50 mm. Such a balloon in a relaxed configuration is suitable for introduction into a body opening or passage.

[0148] Figure 2B illustrates an expandable balloon having arms and in an actuated configuration with the arms extended and with the balloon in a relaxed configuration. Typically, such a balloon may have more than one arm. In embodiments, such an expandable balloon may have, for example, two, three or four arms. In preferred embodiments, such an expandable balloon may have, for example, three or four arms. When activated, such arms are effective to hold tissue in place and to hold a device introduced into an opening or passage adjacent such tissue in place.

[0149] Figure 2C shows the expandable balloon having arms of Figures 2A and 2B in an actuated configuration with the arms extended, and with the balloon filled, and suitable for use in occluding a PFO.

[0150] Figures 3A, 3B, 3C, 3D, and 3E show different embodiments of fixation elements suitable for use in occluding or closing an opening or a passage, and may be made with self-expanding polymeric materials. Figure 3A shows a hook fixation element. Such self-expanding elements may be similar to a balloon as illustrated in Figure 2, and provide a further capability of being self-expanding. Such elements may have a smaller configuration (e.g., having a diameter or other dimension of about 0.08 inches (about 2 mm)) or smaller, and may have a larger configuration (e.g., having a diameter or other dimension of about 0.3 inches (about 7.5 mm)) or larger. A change in configuration may be triggered, for example, by application of energy, including, for example, heat energy, electromagnetic energy, sonic energy, electrical energy, or other energy. For example, the applied energy may induce a change in diameter of about 500%, or of about 600%, or

of about 700%, or of about 800%, or of about 900%, or of about 1000 %, or more. Suitable materials include soft polymer materials or foam.

[0151] As illustrated in Figure 3 (Figures 3A through 3E), such self-expanding fixation elements may include hooks, braids, coils, clock spring coils, and clips. Such elements, and others (e.g., plates, prongs, balls, beads, and other shapes), are suitable for use as fixation elements in the devices, systems and methods having features of the invention.

[0152] As illustrated in Figure 4 (Figures 4A through 4C), an occlusive or a closure device having features of the invention may an element that may shorten, or twist, or shorten and twist (see, e.g., Figure 4A) and may increase in diameter upon such shortening, twisting, or shortening and twisting, effective to provide improved occlusion of a passage or opening. Figure 4A shows an embodiment of an occlusion element which may serve as a connecting element between flanges having features of the invention which may actuate and twist effective to increase the diameter, suitable for occlusion of a body opening while bringing flanges closer together effective to effect closure of an opening. Figure 4B illustrates an element as shown in Figure 4A, connected to flanges, and provides further illustration of a device having features as shown in Figure 4A. Figure 4B schematically indicates a change in configuration upon actuation of the connecting element, effective to bring flanges closer together. Figure 4C shows a further embodiment of an occlusion element having flanges and a coiled connecting element having features of the invention, and schematically indicates a change in the connecting element from an elongated, substantially linear configuration to a shortened, coiled configuration upon actuation. In a coiled configuration as shown in Figure 4C, the flanges are brought closer together, effective to bring tissue closer together and to close or hold tissue together to effect closure or occlusion of a body opening. As indicated in Figures 4B and 4C, flange members may be smooth, so that torsion of the flanges occurs easily. It will be understood that one or both of the flanges illustrated in Figures 4B and 4C may move (e.g., slide or rotate) easily against tissue; in embodiments, one or both flange elements may include rough, sharp, or projecting elements effective to anchor the flange or flanges to tissue. In embodiments, one or both flange elements may include screw-like features or elements effective to anchor the flange or flanges to tissue.

[0153] Figure 5 shows an embodiment of an occlusion device having features of the invention and having a core element (main body) and arm elements (stabilization arms). Such devices or elements may have a radial orientation, may include hinge elements effective to allow movement of stabilization arms shown in the figure. One suitable position for a hinge element is indicated by an arrow in the figure (labeled "hinge here"). Other positions are also suitable for a hinge or hinges. For example, a stabilization arm may fold up (e.g., following a path indicated by the curved, upwardly pointing arrow shown on the right side of the illustration) allowing a stabilization arm to fold up and inwardly, forming a configuration suitable for placement of the occlusion device shown in Figure 5 into a passage or opening in a patient's body. In embodiments, there is a gap between a stabilization arm and main body, as shown in the figure. The stabilization arms are shown in a closed position; upon activation, stabilization arms may assume an open configuration, effective to grab or be positioned near to tissue adjacent an opening or passage in a patient's body. A core element (main body) of an element, device, or system having features as shown in Figure 5 may assume a collapsed configuration and may assume an expanded configuration. Thus, a core element (main body) of an element, device, or system having features as shown in Figure 5 may be or include a balloon, a tube, foam, an expanding polymer, or other material or element.

[0154] An expanding polymer may be, for example, a hydrogel. A hydrogel is capable of expanding a significant amount: for example, a hydrogel may expand up to about 10 times or more in size; or a hydrogel may expand up to about 100 times or more in size; or a hydrogel may expand up to about 1000 times or more in size. An expanding polymer may be another polymer form or material including a foam, or a mesh, or a network, or a composite. Such materials may also be capable of expanding a significant amount: for example, such materials may also be capable of expanding up to about 10 times or more, or up to about 100 times or more, or up to about 1000 times or more in size. The expanding material may be covered by a membrane, a fabric, a mesh, a balloon, or other covering, to contain the gel, foam, or other expanding material.

[0155] In embodiments of the elements, devices, systems, and methods disclosed herein, an occlusive or closure device may include an element or a device that is manufactured from a single sheet or block of starting material; such a starting material

may be a polymer, a plastic, a metal, a mesh, a fabric, a foam, or other material. In embodiments, a starting material may be a biodegradable material, such as a biodegradable polymer or biodegradable plastic. In embodiments, a starting material may be a shape memory material, such as a shape memory metal or a shape memory plastic or a shape memory polymer. In embodiments, a starting material may be a biodegradable shape memory material, such as a biodegradable shape memory polymer. It will be understood that a starting material may be a composite starting material, including a mixture of components, that are combined together to form a continuous or substantially continuous, or a connected, sheet or block from which an element or device may be shaped, cut, drawn, formed, or otherwise manufactured.

[0156] For example, elements and devices may be manufactured from a single sheet or block of starting material by cutting a desired shape in the starting material. For example, a laser cutter may be used to cut out a desired shape (e.g., a carbon dioxide (CO_2) laser), or a photomask process may be used to cut or form a desired shape from a starting material, or a punch, or other means may be used to provide a desired shape from a single sheet of block of starting material.

[0157] For example, as illustrated in Figure 6, coil shapes may be provided from a single sheet or block of a starting material. Figure 6A shows an embodiment of an occlusion device having features of the invention and having a coil element. Such coils may be effective to form a plug effective to occlude an opening or passage in a patient's body. As shown in Figure 6A, such a coil, when in place in a PFO, may be used to occlude a PFO and so to treat or repair the PFO. Prior to placement in the PFO, or other opening or passage, such a coil may be extended and stretched to present only a very small cross-section, suitable for placement within a delivery catheter, for example, or other delivery device or mechanism, and suitable for placement into and within a passage or opening in a patient's body.

[0158] As illustrated in Figures 6B and 6C, an occlusion device having a coil element, may be cut from a single sheet of material, the figure showing the single sheet of material and a spiral-shaped cut which provides the coil element. When extended, such a coil element is able to fit into a very small delivery device, such as a catheter, and is able

to fit into and within a passage or opening within a patient's body. Such a coil element or device may serve as an occlusion device or as an element of an occlusion device without an additional plug element. In embodiments, such a coil element or device may also be used in combination with a plug element, and together these elements may serve as an occlusion device or as elements of an occlusion device.

[0159] Figure 6D shows a further embodiment of an occlusion device made from a single sheet of material, and having two plate portions linked by a connecting portion. In embodiments, the plate portions are larger in size than the connecting portions. For example, a connecting portion may be a thin, elongated shape (and may be a thin, coiled shape capable of being stretched or unwound into a thin, elongated shape) and a plate portion may be an extended, substantially planar shape. As illustrated in Figure 6D, the plate portions may be of different sizes; however, in embodiments, the plate portions are each the same size. Manufacture of such occlusion or closure devices from a single sheet of starting material as disclosed herein provides greater strength and improved reliability and safety of use as compared to alternative methods of manufacture. For example, manufacture of such occlusion or closure devices from a single sheet of starting material avoids the need for the use of glues, welding, annealing, stitching, clipping, stapling, pinning, or other attachment means and methods, all of which include the possibility of failure and separation of component parts. Such possibility of failure and separation of component parts, were such to occur when a device was in place within a passage or opening in a patient's body, such as a PFO could have extremely serious consequences to the health and well-being of the patient. Thus, manufacture of occlusion or closure devices from a single sheet of starting material as disclosed herein provides significant advantages over other methods and designs.

[0160] Suitable starting materials include, for example, sheets of material having a thickness of about 0.25 mm, and having lateral dimensions of about 60 mm wide and about 60 mm long. It will be understood that other dimensions are also suitable. For example, suitable sheets of material may have a thickness of about 0.25 mm, and having lateral dimensions of about 100 mm wide and about 100 mm long. For example, suitable sheets of material may have a thickness of about 0.25 mm, and having lateral dimensions of about 40 mm wide and about 40 mm long. For example, suitable sheets of material

may have a thickness of about 0.25 mm, and having lateral dimensions of about 200 mm wide and about 200 mm long. It will be further understood that the thickness of a suitable sheet of material may be, for example, a thickness of between about 0.05 mm and about 2 mm; for example, a suitable sheet of material may have a thickness of about 0.1 mm, or about 0.2 mm, or about 0.3 mm, or about 0.4 mm, or about 0.5 mm, or about 0.6 mm, or about 0.7 mm, or about 0.8 mm, or about 0.8 mm, or about 1 mm, or about 1.5 mm, or about 2 mm, or more. Suitable materials include, for example, polymers, plastics, metals, meshes, fabrics, and other materials. In embodiments, a suitable starting material may be a biodegradable material, such as a biodegradable polymer, a biodegradable plastic, or other biodegradable material or composite. In embodiments, a suitable material may be a shape memory material, such as a shape memory metal or a shape memory plastic or a shape memory polymer, or shape memory composite. In embodiments, a suitable material may be a biodegradable shape memory material, such as a biodegradable shape memory polymer, a biodegradable shape memory plastic, or other biodegradable shape memory material or composite.

[0161] Further elements and devices having features of the invention are shown in Figure 7. For example, Figure 7A shows an occlusion or closure device having two plate portions linked by a ribbed connecting portion effective that at least a tip portion of the ribbed connecting portion may pass through (as shown in Figure 7A) or over a retaining portion of at least one of the plate portions, effective to bring the plate portions closer together and to prevent their separation after having been brought closer together. In embodiments of the methods of using such devices and elements, a portion of the connecting element may be cut or removed after cinching the plates together, effective to prevent or avoid having an unwanted loose or projecting element. Figure 7B shows the occlusion device having two plate portions linked by a connecting portion that may be stretched into an extended configuration, and then can be activated (e.g., by heat, light, ultrasound, microwaves, or other means) to return to a non-extended configuration, effective to bring the plate portions closer together. Figure 7C shows a further embodiment of an occlusion device having a plurality of flaps disposed at both ends of a connecting element. Such flaps may serve to occlude an opening or passage, and may

serve to hold tissue, e.g., to hold tissue to effect or to secure apposition of tissue, and so to aid in the closure or occlusion of a passage or opening.

[0162] Figure 8A illustrates further embodiments of occlusion devices having features of the invention. For example, coiled elements are shown which have portions with greater, and portions with lesser, amounts of curvature, and which have portions with greater, and portions with lesser, radii of curvature. Such coiled elements and devices may include a connecting portion connecting curved portions, or connecting plates, or connecting cones, or connecting coils. Such coiled elements and devices may include a connecting portion that is substantially perpendicular to a plane passing through the attached plates, coils, or curves, and may alternatively include a connecting portion that is disposed at an angle to a plane passing through the attached plates, coils, or curves.

[0163] Figure 8B illustrates still further embodiments of occlusion devices having features of the invention, including an illustration showing placement of a device between flaps of a PFO, and noting that dimensions of the device or element may be about 8 mm in length in the embodiment shown, and may also be from about 2 mm to about 16 mm in length.

[0164] Figure 8C illustrates still further embodiments of elements and devices having features of the invention. For example, an occlusion device or element may include a coiled, kinked, or folded connecting portion; such a connecting portion is capable of stretching, unkinking, or uncoiling to provide an extended connection between two end portions, and to provide a connecting or inwardly directed force or impulse holding such end portions together. As illustrated, the end portions may be themselves coiled, kinked, or folded, and will typically have a larger size, or larger lateral extension, than the connecting portion. Placement of such elements or devices into a passage or opening is typically performed with the connecting portion in an extended configuration. Upon placement of such elements or devices into a passage or opening, the connecting portion may relax into a less extended configuration, or may be induced (e.g., by heat, light (including infrared, visible, ultraviolet, and other light), microwaves, radiofrequency energy, electricity, chemical means, or by other means) to assume a less extended

configuration, effective to apply closing force to tissue against which the end portions are placed.

[0165] Figure 9 illustrates an embodiment of an occlusion device having features of the invention which has a plug element and an anchor member in which a plug is disposed within a tunnel and occluders pinch together so that they are almost touching in a coil configuration. A plug may sit within an opening or passage within a patient's body. Such a plug may be any suitable plug, as discussed above, and may be a foam, a gel, a coil, a mesh, a balloon, or any other suitable plug.

[0166] Figure 10A shows a spiral-shaped occlusion device made from a single sheet of material having a folded central portion connecting two outer portions. Such a coiled shape may be made from a single sheet of material by cutting (e.g., laser cutting by, for example, a CO_2 laser), by photomask means, by stamping, by micromachining, or by other techniques and methods. In preferred methods, the material will not come into contact with oils or chemicals, and care should be taken to maintain the temperature of the material at relatively low levels (e.g., below about 35 °C, for example). As indicated in the figure, the width of the coil material may be about 0.12 inches and the total diameter of the coiled element may be about 1.56 inches.

[0167] Figure 10B shows a further embodiment of a spiral-shaped occlusion device made from a single sheet of material having a central portion with a multitude of rounded folds. Note that in this embodiment, the width of the central portion is less than the width of the outer end portions. Increasing the numbers of folds increases the ability of the central portion to tangle and to form an irregularly shaped mass to form a plug feature. Figure 10C shows a further embodiment of a spiral-shaped occlusion device made from a single sheet of material, having a central portion that is thinner than the outer portions. In this embodiment, the coils of the central portion have larger radii of curvature than do the coils of the embodiment shown in Figure 10B. Larger radii of curvature and wider portions of material allow the material to provide more force. The thinner portions, with longer springs, will tend to tangle and "ball-up" and thus to better pack into a defect or passage. Figure 10D shows a further embodiment of a spiral-shaped occlusion device made from a single sheet of material, having an irregularly shaped

central portion connecting the two outer portions. Figure 10E shows a further embodiment of a spiral-shaped occlusion device made from a single sheet of material, having further design for the central portion connecting the two outer portions in which the width of the central portion is less than the width of the outer portions.

[0168] Figure 11A shows an embodiment of an occlusion device having end portions connected by a central portion, shown in perspective view. Figure 11B shows the embodiment of an occlusion device of Figure 11A, shown in side view. Such designs may require two each of the elements shown in Figure 11B, and having a connecting portion or a plug feature similar previously listed (e.g., a cylinder, as shown in Figure 11A) which may be of any suitable shape or configuration, including linear, coiled, irregular, or other configuration.

[0169] Figure 12 shows an embodiment of an occlusion device having a smaller and a larger configuration, schematically illustrating a transformation from the smaller to the larger configuration upon application of heparin or other antithrombogenic material. In the larger configuration, the plug is more effective to occlude or close a passage or opening within a patient's body. A plug as shown in Figure 12 may be a biodegradable plug, and is preferably made with a shape memory biodegradable material or materials. Such a plug may change shape, as indicated in the Figure, upon exposure to a trigger, such as a chemical trigger (e.g., exposure to heparin), or exposure to energy (e.g., heat, light, ultrasound, or other energy as discussed herein), or after the passage of an amount of time, or upon other triggering situation or event.

[0170] Figures 13A, 13B, and 13C shows an embodiment of an occlusion device having end portions connected by a central portion, shown in side view. Such design may be termed an "ear muff design" in which end portions have heart-shaped configurations as shown, connected by a coil or spring which connects the end portions and holds them together against tissue effective to close or occlude a passage or opening within a patient's body. When deployed, the end portions may flatten and conform to tissue, such as to septum when deployed in a PFO, while the central spring portion urges the end portions together to aid in closure or occlusion of the passage or opening within a patient's body.

[0171] Figure 14 shows an occlusion device having features of the invention, comprising a clip element and a plug element, shown in perspective view in place within a PFO. The polymer provides a force effective to urge the tissue together, e.g., urging tissue flaps or leaflets adjacent a PFO, for example, together effective to close or occlude the PFO. The central plug portion may be a ball portion, connecting clip outer portions. In embodiments, the clip elements (and in embodiments, the central plug portion, and/or the entire device) may be made with shape memory materials, so that, upon assuming an altered configuration after initial placement within the opening or passage, the clip portions are effective to urge the adjacent tissue together to aid in closure or occlusion of the passage or opening within a patient's body. In embodiments, the clip elements (and in embodiments, the central plug portion, and/or the entire device) may be made with biodegradable shape memory materials.

[0172] In embodiments, closure and/or occlusive devices and elements may include foam shape memory plugs, including biodegradable foam shape memory plugs; solid ball shape memory plugs, including biodegradable foam shape memory plugs (the solid balls may be soft, and may be able to compress and/or to stretch); may be solid ball halves, in which two halves come together, providing an increase in diameter – e.g., expanding the lateral dimensions of the device or element. In embodiments, a sphere, such as a spherical surface made with a shape memory material, may be cut in a special way so that when the sphere is stretched, e.g., one end of the cut surface is pulled, it forms a coil or some other shape when stretched. When the shape memory material is activated to assume a different configuration, the sphere shape reassembles. For example a sphere may be cut in a coil pattern, effective that it can stretch to form a single filament. Upon activation of the shape memory facility, the stretched material may recover effective to reassemble in the spherical shape. Thus, for example, devices, elements and systems having features of the invention may include balls comprising shape memory material, or spring material, or other material which can re-assume an original shape after deformation. Such balls may be manufactured so as to be able to disassemble for introduction and to reassemble for occlusion or plugging of an opening or passage; and may include a balloon or balloons. The ball or sphere may be a balloon, e.g., as disclosed above regarding embodiments of plug devices.

[0173] Figures 15A and 15B shows an embodiment of an occlusion device having curved end portions connected by a central portion, shown in side view. The occlusion device of Figure 15A and 15B is shown in a relaxed configuration. As indicated, the width of such an end portion may be about 5mm, and the width of a central portion may be about 5 mm near the center and may be about 1 mm at the ends of the central portion near to the jointure with end portion. A central portion may be about 5 mm long. An end portion may have a curvature, and the radius of such curvature may be about 1 mm, while the vertical height of such an end portion may be about 0.25 mm.

[0174] Figure 15C shows the occlusion device of Figure 15A and Figure 15 B in an expanded configuration, and having curved end portions connected by a central portion, shown in side view, with the central portion in an expanded configuration and the end portions in expanded configurations.

[0175] Figures 16A, 16B, 16C, and 16D show an embodiment of an occlusion device made from a single sheet of material, with Figures 16C and 16D showing the element or device in a rolled-up configuration. The lines in Figures 16A and 16C indicate linear elements of the device, which are separated from each other by gaps. Also indicated are flaps of tissue as in a PFO, indicating placement of the element or device within a PFO, as shown in Figure 16C. Such devices or elements may be fabricated form a single sheet of material, e.g., by laser cut, and may be rolled up for insertion into a catheter or other delivery device, and for insertion into a passage or opening within a patient's body. Such an embodiment may be termed a "broom bundle" to indicate that the embodiment includes multiple tines or whiskers, similar to those found on a broom. Figure 16E shows the flat sheet from which a device having features as shown in Figures 16A-D may be made. The width of the gaps between the tines or whiskers may be, for example, about 0.004 inches in width. As shown in Figure 16E, the length of the sheet is about 1.25 inches, and the width of the sheet is about 0.4 inches, with the depth of the cut forming the tines in each half being about 0.08 inches in depth.

[0176] Functionally the flat sheet is first cut in strips as shown in Figure 16 and then stretched by an amount that is a percentage of the original length ranging from about 100% to about 1000%, and is then rolled up. The device, in the rolled-up configuration,

is then constrained in the rolled-up configuration. The device may be constrained by mechanical constraint or by chemical adhesion. For example, the device may be constrained with a tie, a sheath, an adhesive, a clip, or other element that may be placed on or around the rolled-up device effective to maintain it in its rolled-up configuration. Non-limiting of examples of mechanical constraint include, for example, a filament or band tied or wrapped around the bundle; a snap; a hook; a clip; and a slit in the film or sheet. Non-limiting examples of chemical adhesion include, for example, application of adhesive; application of thermal energy to melt or to bond a portion or portions of the device effective to constrain it in a desired configuration; application of solvent to melt or to bond a portion or portions of the device effective to constrain it in a desired configuration; application of laser energy to weld a portion or portions of the device effective to constrain it in a desired configuration; application of radiofrequency energy to melt or to bond a portion or portions of the device effective to constrain it in a desired configuration; and other means and constraints. The stretching provides a smaller profile for introduction and will provide the radial expansion upon actuation. After actuation, the small filaments recover to their original size, e.g., they shorten and increase in width, thus providing the radial expansion. The device can be used with a membrane or balloon cover, or may be used without such a cover. In embodiments, such a device is primarily a plug device, but in embodiments can be used with some stabilization element noted elsewhere in the present disclosure.

[0177] Figure 17 shows an embodiment of a clip-shaped occlusion device having features of the invention, shown in perspective view. Such a device or element may be made with biodegradable material, and may be made with shape memory material, and preferably is made with shape memory biodegradable material.

[0178] Figures 18A and 18B show another embodiment of a clip-shaped occlusion device having features of the invention, and having lateral expansions on a connecting portion of the device, shown in perspective view. The design shown in Figures 18A and 18B is a variation of clip designs discussed above, and has designated region configured for a secondary plug component to reside. A single beam clip design, as shown, may provide maximum pinching force from shape memory polymer material or other polymer or metal or shape memory metal. The plug is not shown in the figure,

but would be located in the center over the cylindrical portion. As shown, this design includes lateral protrusions which may be effective to retain a plug during placement, and which may be effective to engage tissue upon deployment. As shown, the central portion may have a length of about 0.26 inches, and a width or diameter of about 0.08 inches. The width of the end portions may be greater, e.g., about 0.1 inches. The lateral protrusion may extend about 0.2 inches in diameter. The cross section of the end portions need not be circular; as shown the cross section of the end portions may be rectangular or square, and may have a thickness, for example, of about 0.15 inches. Such devices provide the advantages of having a single beam to increase recovery or pinching force; have a small profile to aid insertion into a delivery catheter and into a passage or opening within a patient's body; and provides a stable region (e.g., the central region) suitable for attachment of another element, such as a plug, for delivery to a desired location. Such a device or element may be made with biodegradable material, and may be made with shape memory material, and preferably is made with shape memory biodegradable material.

[0179] Figure 19A shows an embodiment of an occlusion device having features of the invention as deployed within a PFO. Figure 19B shows the occlusion device of Figure 19A, shown during activation of the device, part way through a change in configuration from a first configuration (suitable for deployment) to a second configuration (effective to occlude or constrain a PFO). Figure 19C shows the occlusion device of Figure 19A and Figure 19B disposed in its second configuration, and effecting closure of the PFO. Figure 19D shows the occlusion device of Figure 19C in its second, closed configuration, shown in side view. Such a device or element may be made with biodegradable material, and may be made with shape memory material, and preferably is made with shape memory biodegradable material. A suitable shape memory material may be a shape memory metal, may be a shape memory plastic, and may be a shape memory polymer.

[0180] Figure 20A shows an embodiment of an occlusion device having features of the invention, shown in an initial configuration as set following an initial manufacture step. Figure 20B shows the occlusion device of Figure 20A, in a subsequent configuration. Figure 20C shows the occlusion device of Figure 20B disposed in another

subsequent configuration. Figure 20D shows the occlusion device of Figure 20C further stretched for deployment. These elements and devices may be fabricated from a single piece of starting material, and may be made by cutting or by machining, including micromachining, a single piece of starting material. Such a starting material may be biodegradable, and may be a shape memory material, and preferably is a shape memory biodegradable material. A suitable shape memory material may be a shape memory metal, may be a shape memory plastic, and may be a shape memory polymer.

[0181] Figures 21A and 21B show another embodiment of a clip-shaped occlusion device having features of the invention, and having an expanded connecting portion of the device, shown in perspective view. Exemplary dimensions are indicated in the figure. Such elements and devices are preferably fabricated from a single piece of starting material.

[0182] Figures 22A and22B shows another embodiment of a clip-shaped occlusion device having features of the invention, having a non-planar shape, shown in perspective view. As indicated in the figures, the end portions ("arms") are disposed out of the plane of the central portion. Such a design may provide increased or more favorable pinching pressure on tissue. As shown, shape memory polymer will provide greater pinching force on tissue and will provide greater torsion force providing better closure of an opening or passage, than may be available with prior art designs.

[0183] In addition, as shown in Figure 22C, such a device or element may include an aperture or a through hole. An aperture, which does not extend completely through the material, may be configured to accept a mandrel, or the tip of a guidewire, or a hook or attachment element, and may be configured to aid in the placement, and/or in the replacement or recovery, of the element of device. A through hole, which extends completely through the part, may be configured to accept a guidewire or mandrel, or a hook or attachment element, or other element, and may be configured to aid in the placement, and/or in the replacement or recovery, of the element of device.

[0184] These elements may be made from a single piece of starting material, which may be biodegradable, and may be a shape memory material, and preferably is a shape memory biodegradable material. A suitable shape memory material may be a

shape memory metal, may be a shape memory plastic, and may be a shape memory polymer. Such devices and elements are preferably fabricated from a single piece of starting material.

[0185] Figure 23A shows an "S"-shaped occlusion device having features of the invention. Such a device or elements may be fabricated from a single piece of starting material. For example, a sheet of polymer about 0.01 inches thick, may be used. For example, elements or devices as disclosed herein may be cut form a single piece of material using a scalpel or other cutting implement, or by laser cutting, or by micromachining, or by other means. Further shaping may be accomplished, if desired, using, for example, a soldering iron or other heat source (e.g., to apply a temperature of about 385 °F), and applying pressure, tension, or other force, to shape the material. Once cut and shaped, such an S-shaped, or a spiral shaped, or other shape, may be stretched and extended, as shown in Figure 23B. Figure 23 B shows the "S"-shaped occlusion device of Figure 23A after the ends have been rolled and the device has been stretched. Figure 23C shows the "S"-shaped occlusion device of Figure 23A and Figure 23B, after the ends have been rolled and the device has been stretched, inserted into a tube indicative of a PFO. For example, a stretched and rolled element as shown may be inserted into a tube having an inner diameter of about 6 mm. Providing heat (e.g., ambient temperature of about 46 °C) allows shape memory to occur, and the material returns to its former S-shape, as shown in Figure 23D.

[0186] Figure 24A shows a further embodiment of an occlusion device having features of the invention. A shape as shown in Figure 24A may be obtained by cutting material from a single sheet of material, and by application of heat (e.g., about 386 °F). Figure 24B shows the occlusion device of Figure 24A after the ends have been rolled and the device has been stretched. Figure 24C shows the occlusion device of Figure 24A and Figure 23B, after the ends have been rolled and the device has been stretched, inserted into a tube indicative of a PFO. Figure 24D shows the occlusion device of Figures 24A, 24B and 24C, within the tube indicative of a PFO, after being deployed and after having been submerged in 46° C bath effective to trigger a shape-memory transformation of shape.

[0187] Figure 25A shows a further embodiment of an "S"-shaped occlusion device having features of the invention, after the ends having been rolled and the connecting portion stretched. Figure 25B shows the occlusion device of Figure 25A after having been deployed across a passage through a thin and flat material, indicative of a PFO. As shown in Figure 25B, the ends of the shaped element unfold and press against the walls of the passage through which it is deployed, indicating effective closing force on tissue adjacent a passage or opening in a patient's body. Such arms as shown in this figure may be particularly suitable for fixation of a plug (e.g., foam, gel, hydrogel, or other plug) within a passage or opening.

[0188] Figure 26A shows a side view of a non-planar "S"-shaped clip device having features of the invention. Figures 26B-26D show further views of the clip device, which includes an aperture into the lumen of the device. The lumen may extend partially, or may extend completely through the length of the interior of the device. There may be one, or two apertures, at one or at both ends of the elongated (non-linear) portion of the device. An aperture and a lumen may be configured to receive a positioning element, or a retaining element, or a retrieval element, or other element. Thus, a lumen and/or an aperture may be configured to receive a guidewire, for example, or a mandrel, or a hook, or a clasp, or a locating pin, or other element, device or component. It will be understood that embodiments of a clip device as illustrated in Figures 26A-D may be lack an aperture or lumen.

[0189] As shown in Figures 26A and 26D, the ends of the "S" shapes do not extend around to a position close to or overlapping with the main body (inner portion) of the device, as shown most clearly in Figures 26A and 26D, so that the outermost curves of the "S" shapes form only a part of a circle (as shown in these figures, only about a half-circle for the portion extending from the outer rim back to the portion of the "S" shape where the radius of curvature changes direction (indicated in Fig. 26A by a vertical line across the width of the curved, extended element). In addition, in embodiments of the clip devices having features as illustrated in Figures 26A-D, the outer curved portions may have a substantially constant radius of curvature along their entire length of the outer portion, so that, in such embodiments, the outer curved portion approximates a portion of a circle.

[0190] In embodiments of the clip devices disclosed herein, the outer portions of a clip device may have a non-constant radius of curvature along the length of the outer portion, so that, in such embodiments, the outer curved portion approximates a spiral. Such a spiral may have progressively increasing radius of curvature along the length of the outer portion, with a maximal radius of curvature near the end of the portion (e.g., an "expanding" spiral). Such a spiral may have progressively decreasing radius of curvature along the length of the outer portion, with a minimal radius of curvature near the end of the portion (e.g., a "tightening" spiral). Thus, in embodiments, the radius of curvature of the nearest outer curved portion (shown in the upper portion of the image) has a smaller radius of curvature (a "tighter" curve) in the portions nearest to the central portion of the clip device, and has a larger radius of curvature (a "looser" curve) in the portions farthest from the central portion of the clip device. In embodiments, some clip devices having features of the invention have outer curved portions do not have a constant radius of curvature along their entire length of the outer portion, so that the outer curved portion approximates a portion of a spiral. It will be understood that such embodiments may be provided with any of the designs and embodiments disclosed herein, including, but not limited to, the designs illustrated in Figures 26-30.

[0191] Such curved portions, as illustrated in these and in other Figures, may be effective to capture or retain tissue. For example, such outer curved portions, whether circular or spiral shaped, may engage and retain tissue in a desired position or configuration, and thus aid or effect the desired treatment or repair. The central portions may be disposed across a passage, or within an opening, or between tissue portions, and may serve to connect the two outer portions of the devices illustrated herein (e.g., as illustrated in Figures 26-30, and elsewhere), so that tissue engaged or retained by one outer portion is held in place apposed to tissue engaged or retained by the other outer portion of the device.

[0192] Figure 27A shows a side view of a non-planar clip device having features of the invention, with extended loops. As shown in Figures 27A and 27D, the ends of the "S" shapes extend around to a position closer to, or more closely overlapping with the main body (inner portion) of the device, as compared to the embodiments illustrated in Figures 26A-D. Although no aperture or lumen is shown in Figures 27A-D, it will be

understood that an aperture or lumen may be included in a clip device as illustrated in Figures 27A-D, or that the device may be hollow. As illustrated in Figures 27A-D, the outer curved portions may have a substantially constant radius of curvature along their entire length of the outer portion, so that, in such embodiments, the outer curved portion may approximate a portion of a circle, and may approximate a portion having an angular extent of greater than a half-circle. It will be understood that in other embodiments, the outer curved portions need not have a substantially constant radius of curvature along the entire length of the outer portion.

[0193] Figure 28A shows a side view of a further embodiment of a non-planar clip device having features of the invention with extended loops, the loops having even greater linear extent and covering an even greater angle of curvature than the embodiments of Figures 26A-D or Figures 27A-D. As shown in Figures 28A and 28D, the ends of the "S" shapes extend around to a position closer to, or more closely overlapping with the main body (inner portion) of the device, as compared to the embodiments illustrated in Figures 26A-D and 27A-D. Similar to the embodiments illustrated in Figures 26A-D and 27A-D, the outer curved portions in embodiments of the clip devices as illustrated in Figures 28A-D may have a substantially constant radius of curvature along their entire length of the outer portion, so that, in such embodiments, the outer curved portion approximates a portion of a circle. The outer ends of the curved portions of the device closely approach transverse sections of those element, and may have an angular extent substantially greater than a half-circle, and such curved portions may be effective to capture or retain tissue. It will be understood that in other embodiments, the outer curved portions need not have a substantially constant radius of curvature along the entire length of the outer portion.

[0194] Although no aperture or lumen is shown in Figures 28A-D, it will be understood that an aperture or lumen may be included in a clip device as illustrated in Figures 28A-D, or that the device may be hollow.

[0195] Figures 29A, 29B, 29C, and 29D show a further embodiment of a non-planar clip device having features of the invention. Such devices may have outer curved portions in which the radius of curvature is substantially constant over a region of the

outer curved portion. It will be understood that, in embodiments, the outer curved portions of the clip device may have a shape more closely approximating a portion of a spiral than approximating a portion of a circle. For example, the radius of curvature of the nearest outer curved portion (shown in the upper portion of the image) has a smaller radius of curvature (a "tighter" curve) in the portions nearest to the central portion of the clip device, and has a larger radius of curvature (a "looser" curve) in the portions farthest from the central portion of the clip device. Thus, in embodiments of devices illustrated herein, the outer curved portions need not have a constant radius of curvature along their entire length of the outer portion.

[0196] Figures 30A, 30B, 30C, and 30D illustrate a further embodiment of a non-planar clip device having features of the invention, having an expanded central portion. An expanded central portion as illustrated may be effective to engage, or to be retained within, a passage or opening within a patient's body, and may serve to occlude such a passage or opening. An expanded central portion may further, or alternatively, serve to anchor a clip device having features of the invention in place within a passage or opening, effective to secure it for long-term operation in treating, repairing, and/or closing a defect or condition of a patient.

[0197] Figure 31A illustrates an embodiment of a fixation device 300 and its associated delivery system having features of the invention which may be used, for example, to stabilize a PFO. Device 300 may include a plurality of distal stabilization arms 301 (shown in an expanded state) and a plurality of proximal arms 302 (shown in an expanded state) coupled via a pusher 303 incorporating a push/pull actuator and release mechanism 306 and a locking mechanism 304. Device 300 may be attached to a delivery arm 310 (e.g., via a threaded attachment) and delivered to the PFO in a compressed configuration within a delivery catheter 305 . Device 300 may be preloaded in the compressed configuration in the catheter 305 or may be packaged and loaded with the assist of a heating mechanism and a compression loading tool at the time of the procedure.

[0198] The device 300 may be delivered via catheter 305 from the venous side of the heart and guided across the PFO from the right atrium to the left atrium via a guide

wire (not shown) as is known in the art. The location of device 300 may be tracked using fluoroscopic and or echogenic techniques as described below in greater detail. After crossing the PFO, the delivery catheter 305 may be retracted to unsheathe distal stabilization arms 301. Distal stabilization arms 301 may then be expanded as illustrated in Figure 30A. Expansion may be achieved using shape-memory materials, the application of heat, mechanically assisted expansion or any combination thereof as is known in the art. The pusher may then be withdrawn to pull the distal stabilization arms 301 against the septum. Contact with the septum may be detected by mechanical feedback (e.g., sensing resistance to movement) or by fluoroscopic or echogenic techniques.

[0199] Once the distal stabilization arms 301 are positioned against the septum, the delivery catheter 305 may be further retracted to unsheathe the proximal stabilization arms 302 within the right atrium. Proximal stabilization arms 302 may then be expanded as illustrated in Figure 30A. Expansion may be achieved using shape-memory materials, the application of heat, mechanically assisted expansion or any combination thereof as is known in the art.

[0200] Axial articulation of the distal and proximal stabilization arms may then be used to bring the distal and proximal stabilization arms together to close down the PFO. The axial articulation may be accomplished, for example, via relative rotation of a threaded coupling within the push/pull actuator 306 between the distal and proximal stabilization arms. When the proper spacing between the distal and proximal stabilization arms is achieved, locking mechanism 304 may be operated to maintain the proper configuration. For example, locking mechanism 304 may include a keyway in an outer portion of the pusher 303 and a popup key in an inner portion of the threaded pusher 303. Other locking mechanisms as may be known in the art are also contemplated embodiments of the present invention.

[0201] In one embodiment, device 300 may include a retraction feature that allows the device 300 to be re-sheathed and removed before device 300 is locked in place. For example, as illustrated in figure 31B, device 300 may include threads 307 attached to the ends of the distal stabilization arms 301, which may be used to return the

distal stabilization arms 301 to a configuration that allows delivery catheter 305 to recapture the distal stabilization arms after retracting the proximal stabilization arms 302 (it will be appreciated that the proximal stabilization arms 302 may not require a retraction mechanism by virtue of their orientation with respect to the delivery catheter 305. In one embodiment, as illustrated in figure 31C, retraction of the distal stabilization arms may be achieved with a conformal ring 308, which may be located on the distal end of device 300 and attached to threads 309 which may be used to pull conformal ring 308 over distal stabilization arms 301 until they are in a configuration that may be re-sheathed by delivery catheter 305.

[0202] Once fixation device 300 is properly deployed and locked across the septum, and the PFO is closed, the delivery arm 310 may be disconnected from fixation device 300 (e.g., by unthreading a threaded coupling) and both the delivery arm 310 and the delivery catheter 305 may be withdrawn from the patient's body.

[0203] As discussed above, the designs, devices, components, and systems disclosed herein are suitable for construction using biodegradable (alternatively termed "bioerodeable" or "bioresorbable") materials, including preferably biodegradable shape memory polymers. In embodiments, the device or component made with biodegradable materials may degrade over a time period of days, or of months, or of years. For example, the device or component made with biodegradable materials may degrade over a time period of at least about 30 days, or of at least about two months, or of at least about three months, or of at least about four months, or of at least about five months, or at least about six months. In further embodiments, a device or component having features of the invention, and made with biodegradable materials, may degrade over a time period of at least about one year, or of at least about two years, or of at least about three years, or of at least about four years, or of at least about five years, or of more than about five years. In preferred embodiments, a device or component having features of the invention, and made with biodegradable materials, may degrade over a time period of about three months to about three years. In yet other preferred embodiments, a device or component having features of the invention, and made with biodegradable materials, may degrade over a time period of about six months to about six years. In preferred embodiments, a device or component having features of the invention, and made with

biodegradable materials, may degrade over a time period of about one year to about three years.

[0204] Treatment or repair may include filtration of bodily fluids, e.g., trapping or retaining debris or particles flowing in the blood stream. For example, where a device having features of the invention is disposed in a heart, for repair of a PFO, or PDA, or ASD, or VSD, or other heart condition or defect, it may be desirable to capture emboli, or thromboses, or plaque particles, or other material that may be flowing within the blood stream and which may present a medical problem or threaten injury or damage to the patient. Mesh, netting, fabric, whiskers, or other elements may be included or may be attached to the devices illustrated herein. For example, a mesh or fabric configured to allow substantially unimpeded blood flow may be effective to capture debris or thromboses, or other material, having a dimension larger than the mesh size of the mesh of fabric, effective to reduce or prevent the risk of stroke, heart attack, embolism, or other condition related to or caused by occlusion (partial or complete) of a blood vessel.

[0205] Devices as disclosed herein may be configured to release drugs or therapeutic chemicals. Drugs released (or "eluted") from the devices disclosed herein may promote endothelialization or tissue healing, and may promote the growth or release of endothelial progenitor cells or extracellular matrix proteins such as collagen and laminin. Such drugs may be effective to reduce the risk of platelet aggregation and of thrombosis. For example, heparin, clpidrogrel, albumin-binding coating, thrombolytic agents, eptifibatide, hirudin, prostacyclin analogues such as iloprost, and statins may be suitable for such uses. Drug release may be effective to improve biocompatibility, reduce inflammation, and to modulate tissue proliferation. For example, such drugs as everolimus, biolimus, tacrolimus, paclitaxel, sirolimus, and derivatives and analogues thereof may be useful where reduction of tissue proliferation is desired. In addition, drug release from devices having features of the invention may be effective to deliver small molecule or large molecule drugs to target tissues and regions.

[0206] For example, materials used to make the devices disclosed herein may be impregnated with therapeutic compounds such as, for example: antibiotics; anti-inflammatory agents; anti-arrhythmia agents; agents that aid in regulating heart rate;

agents that aid in reducing or regulating blood pressure; hormones; growth factors; agents that affect endothelial proliferation; and other agents. For example, materials used to make the devices disclosed herein may be covered with coatings or a layer of material including therapeutic compounds as described above. It will be understood that, where the desired therapy is to reduce the ingrowth of cells, such therapeutic compound may be a toxic compound, or a compound that is not considered therapeutic in other circumstances. Devices and elements may include, and may be covered by, material that promotes endothelial tissue overgrowth as well as smooth surface so as not to perforate the endocardium. In embodiments, devices and elements having features of the invention may include features that promote endothelial tissue overgrowth as well as smooth surface so as not to perforate the endocardium.

[0207] Devices as disclosed herein may be made with, or contain, or be covered, at least in part, with radio-opaque materials, or materials that provide good ultrasound images, or materials that are readily discerned under magnetic resonance imaging (MRI) or computer assisted tomography (CAT), Fluoroscopy or X-ray, Intracardiac Echocardiography (ICE), Transesophageal Echocardiography (TEE) or other imaging or visualization system or technique. For example the surfaces of the elements and devices may be textured so as to enhance the visibility of the device by imaging or visualization techniques. For example, a surface may be textured to enhance the ability to view the device under ICE or other visualization technique. A surface texture could comprise a microblasted finish, a surface pattern, or an otherwise ultrasound reflective surface. Metals or dense materials can be used to improve visibility under X-ray, for example: precious or semiprecious metals, such as, for example Platinum, Gold, Tungsten, and Tantalum. Metal Alloys, such as, for example Platinum Iridium, Stainless Steel or Nitinol are also useful for improving visualization under X-ray, ICE or other visualization techniques. Metal oxides, such as, for example, Barium Sulfate, Bismuth Subcarbonate, Bismuth Trioxide, and others, may be included in (e.g. impregnated) or may be coated or placed on a surface of a device or element having features of the invention so as to enhance the visibility of the device by imaging or visualization techniques. Materials or coatings may be included within a lumen or within an aperture of a device having features of the invention, so as to enhance the visibility of the device

by imaging or visualization techniques. Catheter based delivery systems may utilize the techniques listed and/or may utilize other visualization techniques by including features such as textures, metals or metal oxides as discussed above. Additional textures and materials suitable for use in the devices and elements having features of the invention include ribs, bands, stripes, dots, and other elements placed on, or within, the materials used to manufacture the devices and elements described herein. Surface perforations, or depressions, or bumps, or surface roughness may aid in visualization by various techniques. Inclusion of bubbles or voids may aid in visualization by ultrasound techniques. It will be understood that any suitable method or means of enhancing visualization known in the art may be used in the practice of the invention.

[0208] In embodiments, a device having features of the invention is configured to be able to be delivered and recovered, and, in further embodiments, may be configured to be repositioned for better performance of its intended function (e.g., for better closure of a PFO). The device may include features capable of such operations for example one or more of the following: a through hole, male or female screw threads, internal or external loop, or some other method to fasten to the delivery system. The feature can be a permanent part of the device or can be removed or cut following the successful procedure. There may be features that remain on the device that enable future retrieval via a snare, hook, latch, loop, tab, mesh, receptacle, socket, or other device in case of some related problem. For example, a retrieval element may include a threaded feature configured to engage or be captured by a portion of a retrieval tool. For example, a retrieval element may include a latch or tab feature configured to engage a portion of a retrieval tool. For example, a retrieval element may include a hook or loop feature configured to engage or be captured by a portion of a retrieval tool. For example, a retrieval element may include a mesh feature configured to engage or be captured by a portion of a retrieval tool, e.g., by a hook or threaded element. For example, a retrieval element may include a receptacle, or socket feature configured to engage a portion of a retrieval tool, which may fit into such receptacle or socket.

[0209] In embodiments, the delivery system can be catheter-based and capable of delivery, recovery, and or reposition. For example, the delivery system can have a system of catheters with multiple functions and or lumens. One or more of these

catheters or lumens functions can be a method to introduce heat, light, or other forms of energy to the site to activate the shape memory property of the material. Catheter features such as insulation, reflective, optically clear, texture smooth, or other specific to the energy required to activate the device in-situ. The catheters may have some or more of the following mechanical properties: properties that enable inhibit or reduce torque; enable, induce or inhibit compression; enable, induce or inhibit elongation; enable induce or inhibit bending; have soft or a-traumatic tip; contain micromachined features; or other mechanical properties. A catheter having features of the invention can be made of metal, shape memory metal, polymer, shape memory polymer, biodegradable materials, glass, textiles, composites, and/or other materials.

[0210] In embodiments, tether, retrieval, or release properties may be integral to the design of a device and delivery system having features of the invention. The device can be tethered, retrieved or released by many methods for example: catheters or lumens can have torque-able micocatheters cables or lumens can contain wires or filaments used to tether the device or release the device; clamping mechanism loop or hook; screw features; thermal electrical or mechanical switch; lock and key; or other similar methods. Catheters or lumens can consist of guidewire lumens where the device is tracked over a guidewire to the site of the defect and left in place for all or part of the procedure. Catheters or lumens can consist of endoscopic devices, balloons for sizing, saline, air bubbles in saline, or other visualization devices used to view the defect to better understand the defect geometry or the health of the internal structure of the heart. The catheters or lumens can be contained within a single outer catheter or can be multiple independent catheters. The delivery system can be either from a single access point or a multiple access point, such as, for example from the left or the right side of the heart, from the anterior or posterior, from the same access or multiple access points. Catheters may have textures metals or features specific to common visualization techniques such as MRI, CAT, ICE, X-ray, or any other technique. The catheters may have features specific to orientation in plane, rotation, or other necessary function to guide the proper delivery of the device. For example, a specific advantage is provided by delivery system visualization technology that utilizes metals or materials that are only temporarily introduced in the body and after completing the procedure are removed on or near the

delivery system. As disclosed herein, such removal may include physical removal, at orn ear the time of placement; retrieval at a later time; and/or degradation of the material to provide degradation and/or removal of elements of a device, or complete removal of a device, over time without need for the performance of further invasive procedures.

[0211] The shape memory activation temperature can be below, at, or above temperature of the human body. There may be one or more shape memory configurations from one or more materials.

[0212] Further disclosed herein are methods for treating and methods for repairing a defect within a patient's body. In embodiments of the methods, the defects may be defects in the heart. In embodiments, the defects are congenital defects. In embodiments, the defects are the result of disease, or are the result of injury, or are the result of aging.

[0213] For example, a method of delivering a device comprising a biodegradable shape memory material configured for a shape-memory transformation of shape upon activation, comprising rolling an end of the device, and stretching a connecting portion of the device. In embodiments, the method may further comprise inserting the device into a delivery tool. The method may further comprise placement of the device to a desired location within a patient's body. The method may further comprise the step of deploying the device across a passage through a thin and flat tissue within the patient's body. The method may be practiced wherein said thin and flat tissue within a patient's body comprises a defect selected from a patent foramen ovale (PFO), a patent ductus arteriosus (PDA), an atrial septal defect (ASD), a ventricular septal defect (VSD), an aneurysm, and a varix.

[0214] In embodiments, a method of repairing a defect within a patient's body, comprising the steps of delivering a device comprising a biodegradable shape memory material to a desired location within said patient's body adjacent said defect; repairing said defect; and allowing said device comprising a biodegradable shape memory material to degrade, effective that at a sufficient time after said repair, substantially no biodegradable shape memory material remains at said desired location within the patient's body. The method may be practiced wherein said repair comprises activation of

said shape-memory material effective to trigger a transformation of shape of said device. The method may be practiced wherein said repair comprises repair of a defect in the heart. In embodiments of the method, said defect in the heart comprises a defect selected from a patent foramen ovale (PFO), a patent ductus arteriosus (PDA), an atrial septal defect (ASD), a ventricular septal defect (VSD), an aneurysm, and a varix.

[0215] In embodiments, the method may be practiced wherein said repair is effected without perforation of the endocardium. In alternative embodiments, the method may be practiced wherein said repair is effected with perforation of the endocardium to suture the defect closed, or to anchor the device at a desired location.

[0216] Methods disclosed herein may include a step of tying a knot, e.g., using a shape memory self-tying knot. Devices disclosed herein may include elements having a shape memory self-tying knot element. In embodiments, said step of tying a knot may comprise tying a knot such as a half-hitch knot, or other knot. A step of tying a knot may comprise an alteration in the shape of an element made with a shape memory material. In embodiments, the shape memory shape alteration is effective to tie said knot. In embodiments wherein said defect has two sides, the knot may be tied on one side of said defect. In other embodiments wherein said defect has two sides, the knot may be tied on both sides of said defect. The knot may shorten in length while increasing in diameter or may be used with a plug or other stabilization device noted.

[0217] All patents and patent applications referred to herein are hereby incorporated by reference in their entireties.

EXEMPLARY CLAIMS

Examples of the subject matter disclosed herein, written in the form of patent claims, includes:

1. A device for repairing a defect in the body of a patient in need of treatment, the device configured for minimally invasive placement within a patient's body, and having an element effective to repair a defect in said patient's body, the device comprising at least a portion which remains for a time within the patient's body, said at least a portion which remain within the patient's body comprising a biodegradable shape memory material.

2. The device of claim 1, wherein said minimally invasive placement is selected from a minimally invasive procedure utilizing a single access point, and a minimally invasive procedure utilizing multiple access points.

3. The device of claim 1, wherein said defect is selected from patent foramen ovale (PFO), patent ductus arteriosus (PDA), atrial septal defect (ASD), ventricular septal defect (VSD), aneurysm, and varix.

3. The device of claim 1, wherein said device is configured to repair said defect by means comprising one or more of the group of means consisting of: placement of adhesive material effective to provide an adhesive bond between tissue surfaces within the patients body; placement of a plug element adjacent tissue effective to reduce fluid flow through a defect which otherwise could provide inappropriate fluid flow; placement of a clamping element configured to bring tissue within the patient into close apposition effective to reduce fluid flow through a defect which otherwise could provide inappropriate fluid flow; placement of a closure device such effective to engage tissue and to reduce fluid flow through a defect which otherwise could provide inappropriate fluid flow; placement of a balloon effective to reduce fluid flow through a defect which otherwise could provide inappropriate fluid flow; and combinations thereof.

4. The device of claim 3, wherein said clamping element comprises a clip element or a piercing element.

5. The device of claim 3, wherein said balloon is configured to deliver an adhesive element.

6. The device of claim 3, wherein said balloon is configured to act as a plug.

7. The device of claim 3, wherein said occlusion device comprises a clip element or a piercing element.

8. The device of claim 1, comprising an expanding coil.

9. The device of claim 1, comprising a grommet-shaped plug.

10. The device of claim 1, comprising an expanding foam.

11. The device of claim 1, comprising a frame occluder

12. The device of claim 11, wherein said frame occluder comprises two sheets and structural members

13. The device of claim 12, further comprising a middle tie connecting the two sheets.

14. The device of claim 1, comprising an expandable balloon having arms.

15. The device of claim 14, wherein said arms have an actuated configuration with the arms extended.

16. The device of claim 1, comprising fixation elements suitable for use in occluding or closing an opening,

17. The device of claim 16, wherein said fixation elements comprise self-expanding polymeric materials.

18. The device of claim 16, wherein said fixation element is selected from one or more of a hook fixation element; a braid fixation element; a coil fixation element; a clock spring coil fixation element; and a clip fixation element.

19. The device of claim 1, comprising an occlusion element configured to actuate and twist effective to increase the diameter, suitable for occlusion of a body opening.

20. The device of claim 19, comprising flanges and a connecting element.

21. The device of claim 20, wherein said connecting element is initially in a first configuration, and is configured to adopt a second configuration upon actuation, wherein said second configuration is selected from a coiled configuration, an expanded configuration, and a coiled and expanded configuration.

22. The device of claim 1, comprising a core element and arm elements.

23. The device of claim 1, comprising a coil element configured for placement within a defect in the body of a patient.

24. The device of claim 23, comprising a coil element manufactured from a single sheet of material.

25. The device of claim 24, wherein said coil element comprises a spiral-shaped cut from a single sheet of material.

26. The device of claim 25, wherein said spiral-shaped coil element has a first, extended configuration when stretched and elongated in a form suitable for placement into a PFO and a second, coiled configuration.

27. The device of claim 1, comprising an occlusion device made from a single sheet of material, and having two plate portions linked by a connecting portion.

28. The device of claim 27, wherein the plate portions are of different sizes.

29. The device of claim 27, wherein the plate portions are each the same size.

30. The device of claim 1, comprising two plate portions linked by a ribbed connecting portion configured to engage a retaining portion of a plate portion, effective to prevent the separation of said plate portions after such engagement.

31. The device of claim 1, comprising two plate portions linked by a connecting portion, wherein said connecting portion is configured to be stretched into an extended configuration.

32. The device of claim 31, wherein said connecting portion is configured to be activated and to return to a non-extended configuration

33. The device of claim 32, wherein said activation is effective to bring the plate portions closer together.

34. The device of claim 1, comprising a plurality of flaps disposed at both ends of a connecting element.

35. The device of claim 1, comprising a device manufactured from a single piece of material, having a coiled or a kinked configuration.

36. The device of claim 1, comprising a device manufactured from a single piece of material, having a central portion connecting the two outer portions, said central portion selected from a central portion having a multitude of rounded folds; a central portion that is thinner than the outer portions; and an irregularly shaped central portion.

37. The device of claim 1, comprising a spiral-shaped occlusion device made from a single sheet of material having a folded central portion connecting two outer portions.

38. The device of claim 1, comprising a plug element and an anchor member.

39. The device of claim 1, comprising an occlusion device having a smaller and a larger configuration, wherein the transformation from said smaller to said larger configuration occurs upon application of heparin or other antithrombogenic material.

40. The device of claim 1, comprising a clip element and a plug element, configured for placement within a patent foramen ovale (PFO).

41. The device of claim 1, comprising curved end portions connected by a central portion, configured for placement within a patent foramen ovale (PFO).

42. The device of claim 41, wherein said central portion is configured to have an expanded configuration and an unexpanded configuration.

43. The device of claim 1, wherein said device is cut by a laser from a single sheet of material.

44. The device of claim 1, comprising a rolled-up configuration.

45. The device of claim 1, comprising a clip-shaped occlusion device made with biodegradable shape memory material.

46. The device of claim 45, having lateral expansions on a connecting portion of the device.

47. The device of claim 1, having a relaxed and having a stretched configuration, wherein said stretched configuration is configured for deployment of said device within a defect within a patient's body, wherein said device is configured to assume a shape effective to repair a defect upon activation of said biodegradable shape memory material.

48. The device of claim 1, comprising a clip-shaped occlusion device having a non-planar shape.

49. The device of claim 1, comprising a "S"-shaped occlusion device having a non-planar shape.

50. The device of claim 48 or 49, having a relaxed and having a stretched configuration, wherein said stretched configuration is configured for deployment of said device within a defect within a patient's body, wherein said device is configured to assume a shape effective to repair a defect upon activation of said biodegradable shape memory material.

51. The device of claim 47, 48, or 49, wherein said device is configured to fit within a delivery device in said stretched configuration.

52. The device of claim 51, wherein said delivery device is a tubular delivery device.

53. The device of claim 51, wherein said delivery device is selected from a catheter and a sheath.

54. The device of claim 51, wherein said delivery device is configured for use with a guidewire.

55. The device of claim 1, wherein said biodegradable shape memory material is configured for a shape-memory transformation of shape upon activation by a triggering action.

56. The device of claim 55, wherein said biodegradable shape memory material is configured for a shape-memory transformation of shape upon activation by one or more of the group consisting of application of a chemical, alteration of chemical concentration, alteration of pH, application or the action of heat, light, magnetic field, electric field, electrical current, ultrasound, or other energy.

57. The device of claim 55, wherein said triggering action comprises submersion in a bath having a temperature of between about 30° C and about 70° C effective to trigger a shape-memory transformation of shape.

58. The device of claim 1, further comprising a lumen within said device.

59. The device of claim 1, having a surface, and further comprising an aperture or depression in said surface of said device.

60. The device of claim 58 or 59, comprising an aperture into a lumen of the device.

61. A method of delivering a device comprising a biodegradable shape memory material configured for a shape-memory transformation of shape upon activation, comprising rolling an end of the device, and stretching a connecting portion of the device.

62. The method of claim 60, further comprising inserting the device into a delivery tool.

63. The method of claim 62, further comprising placement of the device to a desired location within a patient's body.

64. The method of claim 63, further comprising the step of deploying the device across a passage through a thin and flat tissue within the patient's body.

65. The method of claim 64, wherein said thin and flat tissue within a patient's body comprises tissue adjacent a defect selected from a patent foramen ovale (PFO), a patent ductus arteriosus (PDA), an atrial septal defect (ASD), a ventricular septal defect (VSD), an aneurysm, and a varix.

66. A method of repairing a defect within a patient's body, comprising delivering a device comprising a biodegradable shape memory material to a desired location within said patient's body adjacent said defect;

repairing said defect;

and allowing said device comprising a biodegradable shape memory material to degrade, effective that at a sufficient time after said repair, substantially no biodegradable shape memory material remains at said desired location within the patient's body.

67. The method of claim 66, wherein said repair comprises activation of said shape-memory material effective to trigger a transformation of shape of said device.

68. The method of claim 66, wherein said repair comprises repair of a defect in the heart.

69. The method of claim 68, wherein said defect in the heart is selected from a patent foramen ovale (PFO), a patent ductus arteriosus (PDA), an atrial septal defect (ASD), a ventricular septal defect (VSD), an aneurysm, and a varix.

70. The method of claim 68, wherein said repair is effected without perforation of the endocardium.

71. The method of claim 68, wherein said repair is effected with perforation of the endocardium to suture the defect closed, or to anchor the device at a desired location.

72. The method of claim 68, comprising a step of tying a knot.

73. The method of claim 72, wherein said step of tying a knot comprises tying a half hitch knot.

74. The method of claim 72, wherein said step of tying a knot comprises alteration in the shape of an element made with a shape memory material.

75. The method of claim 74, wherein said shape memory shape alteration is effective to tie said knot.

76. The method of claim 72, wherein said defect has two sides, and wherein said knot is tied on one side of said defect.

77. The method of claim 72, wherein said defect has two sides, and wherein said knot is tied on both sides of said defect.

78. The device of claim 1, wherein said shape memory material has more than one shape memory configuration.

79. The device of claim 1, wherein said shape memory material is a shape memory polymer selected from thermoset polymers and thermoplastic polymers.

80. The device of claim 79, wherein said shape memory material comprises a shape memory polymer selected from copolymers, and block copolymers, homopolymers, crystalline polymers, amorphous polymers, thermosetting polymer networks, semi-interpenetrating networks, interpenetrating networks, and mixed interpenetrating networks.

81. The device of claim 79, wherein said shape memory material is a thermoplastic polymer comprising a blend of one or more homo- or co-polymer with one or more diblock-, triblock-, tetrablock, or multiblock copolymers, branch or graft polymers.

82. The device of claim 1, wherein said device comprises a biodegradable polymer selected from the group of biodegradable polymers consisting of polymers, block copolymers, biodegradable polymers and or mixtures, blends, and or copolymers of polyethers, polyacrylates, polyamides, polysiloxanes, polyurethanes, polyetheramides, polyurethane/ urea, polyester esters, urethane/ butadiene copolymers, polylactide polymers, polyglycolide polymers, polycaprolactone polymers, polylactide-poly glycolide copolymers, polylactide-polycaprolactone copolymers, polyglycolide-polycaprolactone copolymers, polylactide-polyglycolide-polycaprolactone copolymers, polyacrylate, and other polymers and copolymers, including mixtures, blends, and or copolymers of any of the above mentioned polymers.

83. The device of claim 1, wherein said device comprises a material selected from the group consisting of a sheet, a molded shape, an extruded profile, a hydrogel, a foams, a membrane, a balloon-covered hydrogel, a membrane, and a balloon-covered foam.

84. The device of claim 1, comprising a surface selected from a smooth surface, a rough surface, a pitted surface, a mesh surface, a fabric surface, a radiopaque surface, a surface reflective of visible light, a surface reflective of non-visible electromagnetic radiation, an ultrasound reflective surface, and combinations thereof.

85. The device of claim 1, comprising a retrieval element.

86. The device of claim 85, wherein said retrieval element is selected from a loop, a hook, a mesh, a netting, a tab, a threaded element, a socket, a receptacle, and combinations thereof.

87. The device of claim 1, comprising an anchoring element.

88. The device of claim 87, wherein said anchoring element is selected from a barb, a hook, a spur, an adhesive, a suction element, and combinations thereof.

89. The method of claim 72, wherein said step of tying a knot comprises activating a shape change in a shape memory polymer effective to tie a self-tying knot.

90. The device of claim 57, wherein said triggering action comprises submersion in a bath having a temperature of about 42° C.

91. The device of claim 55, wherein said biodegradable shape memory material is configured for multiple shape-memory transformations of shape upon activation by triggering actions.

92. The device of claim 91, wherein said biodegradable shape memory material is configured for two shape-memory transformations.

93. The device of claim 91, wherein said biodegradable shape memory material is configured for three shape-memory transformations.

94. The device of claim 91, wherein said biodegradable shape memory material is configured for four or more shape-memory transformations.

95. The device of claim 55 configured for a shape memory transformation of shape within a patent foramen ovale, wherein said biodegradable shape memory material is configured for a shape-memory transformation of shape upon activation by a triggering action.

96. The device of claim 55 configured for a shape memory transformation of shape within a patent foramen ovale, wherein said biodegradable shape memory material is configured for multiple shape-memory transformations of shape upon activation by triggering actions.

97. The device of claim 96, wherein said biodegradable shape memory material is configured for two shape-memory transformations.

98. The device of claim 96, wherein said biodegradable shape memory material is configured for three shape-memory transformations.

99. The device of claim 96, wherein said biodegradable shape memory material is configured for four or more shape-memory transformations.

100. The device of claim 1 configured for a shape memory transformation of shape within a patent foramen ovale, wherein said biodegradable shape memory material is configured for a shape-memory transformation of shape upon thermal activation.

101. The device of claim 100, wherein said thermal activation comprises warming at least a portion of the device to or above a transition temperature, wherein said transition temperature is between about 30 °C and about 70 °C.

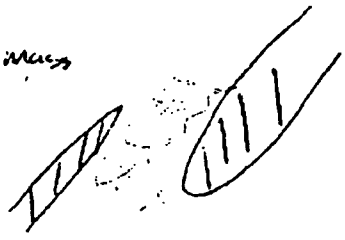
102. The device of claim 101, wherein said transition temperature is between about 40 °C and about 50 °C.

103. The device of claim 102, wherein said transition temperature is about 42 °C.

104. The device of claim 101, wherein said transition temperature is between about 35 °C and about 40 °C.

105. The device of claim 104, wherein said transition temperature is about 37 °C.

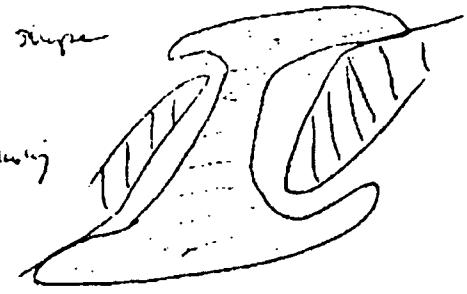
Plug A) expanding coils or mass
Polymer
may need end caps



1A

B) Grommet shape

Polymer
Expanding into/occluding



1B

C) Expanding foam

1C

1D

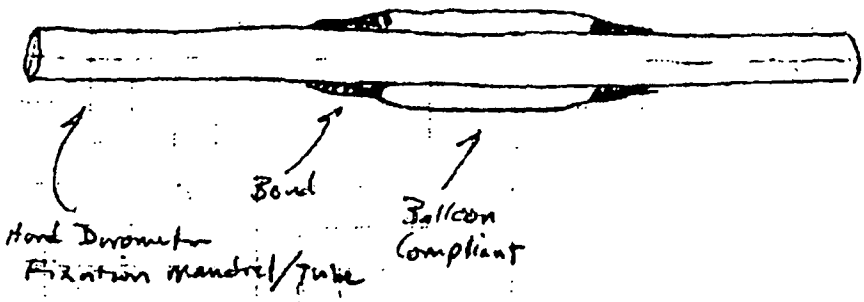
Frame occluder A) 2 sheets +
Structural members

Actuated tie: middle tie may
shorten bringing
closer

Actuated Umbrella: Unfolds from compressed
structure.

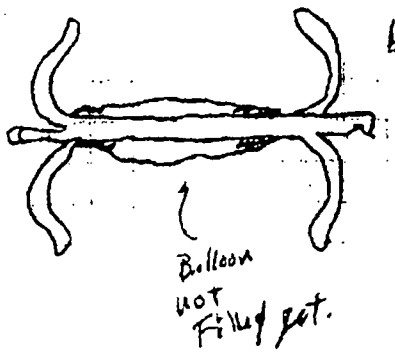
2A

① : Introduced Configuration



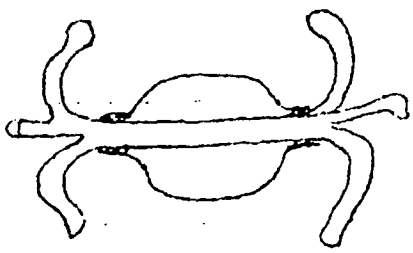
Balloon Length ≈ 6 mm
Balloon size ≈ .100 OD stretch to .400
Metric or 2.5 mm and 10 mm

② Actuated Configuration.
Heat Δ



2B

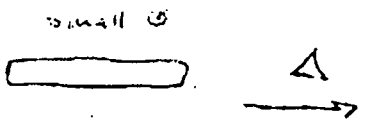
③ Fill Balloon



2C

Self expanding Polymer (Plug)

Same / similar to balloon
Replace w/ self expanding polymeric material



⌀ ≤ .080
or 2mm
or smaller

as much
as 200%

⌀ ≤ 7.5mm or larger
what can we get?

Material could be Soft Polymer or Foam.

Fixation Elements would be ① hooks 3A

② Braid 3B

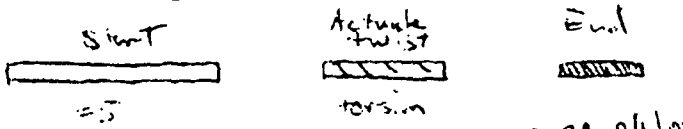
③ Coil 3C

④ Clock Spring coil 3D
coil in plane

⑤ clip 3E

Member shortens?

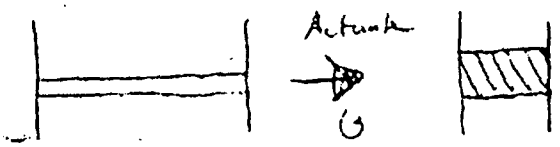
4A



Diameter would increase

WIT. RB 8/1/07

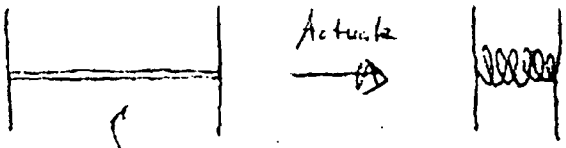
4B



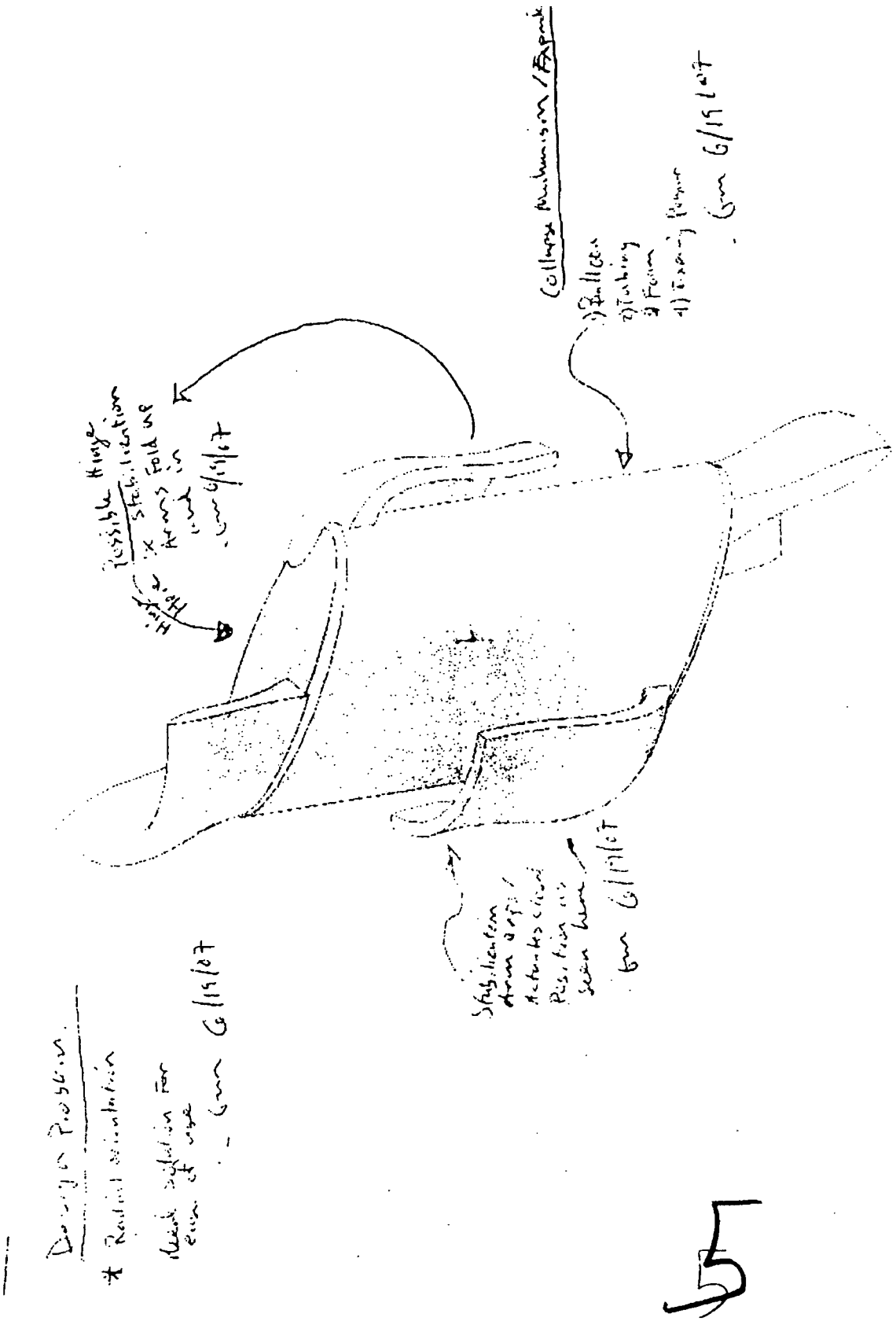
Flange members can be smooth as torsion occurs easily. -or- one or both.
Flange members could have screw-like feature help to fix element in PPO.

Motor Instrument could be coil

4C



Thin member coils up bringing Flanges closer together.



1) coil design cut from 1 sheet of polymer.

6A

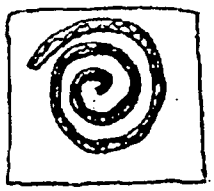
6B

coils in tunnel would form plug

* coil can be extended and introduced w/ very small catheter.

2) Slinky design
- cut from 1 sheet of polymer a coil

6C



- when extended again it will distort and fit into very small catheter.
- Occluder w/o plug.
- similar to "slinky"

3) sheet opposing Occluder.

6D

- The smaller side sheet is cut from the same sheet as the larger sheet. Also the Attachment is not bonded but is some creative cut.
- Everything is cut from one sheet.
- Flat sheets shrink wrap.

4) Plates w/ Zip tie attachment

7A

- pull on one end the other pinches down
- next to cut tie.
- 2 opposing plates.

7B

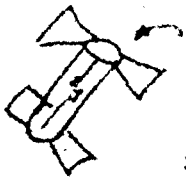
or

Disc.

Stretching Polymer Recovers w/ heat.

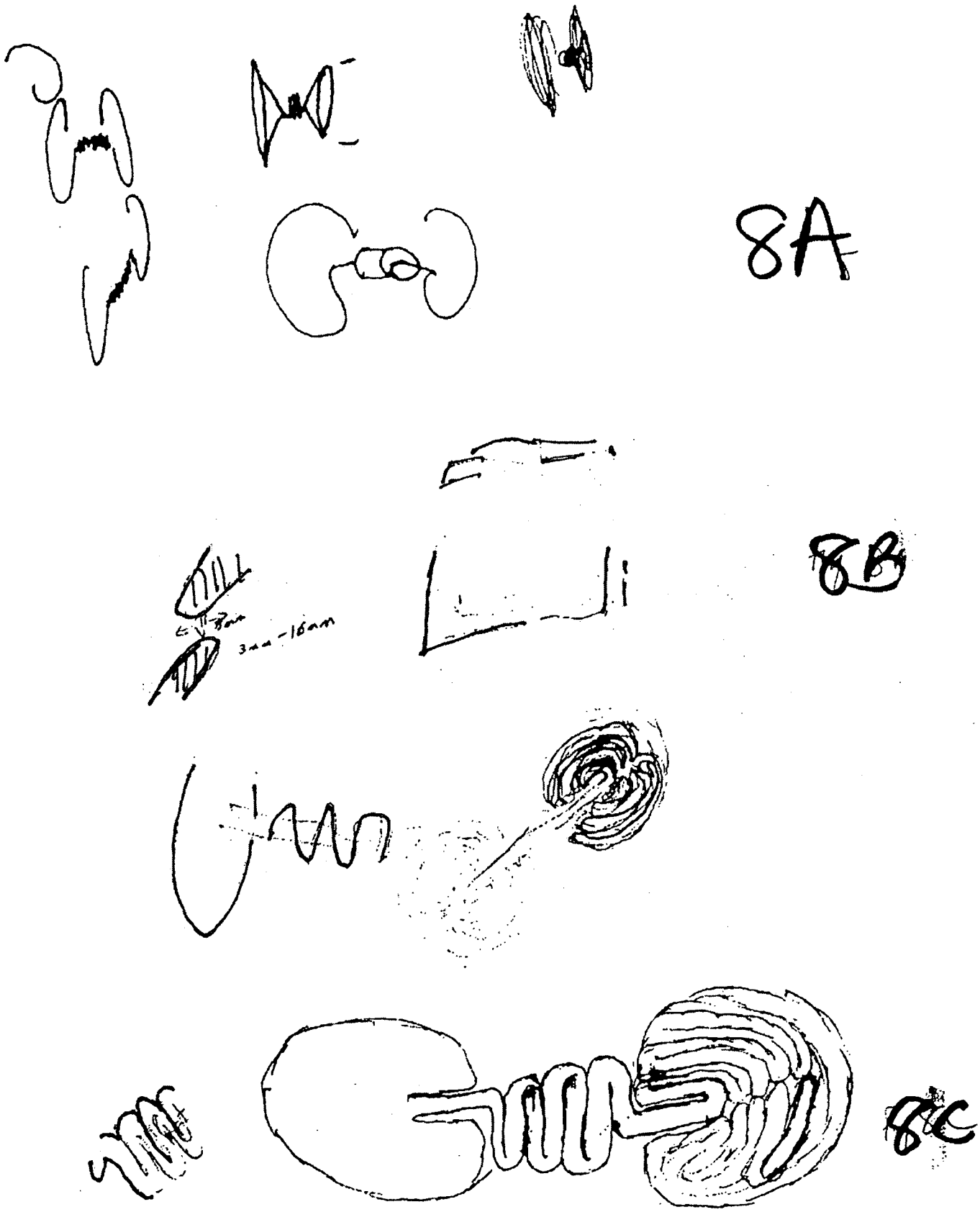
5)

7C



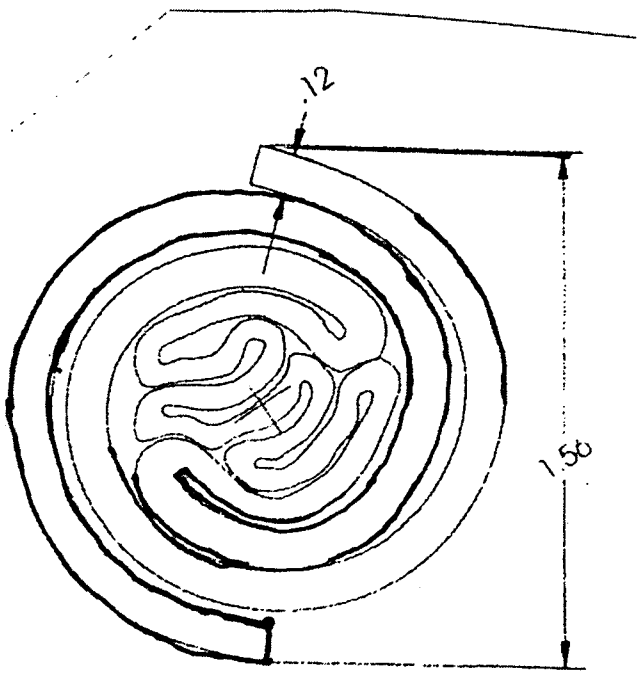
Rolled up/Joined Flat Polymer somehow attach to ends

* Plug w/ occluder Flaps.

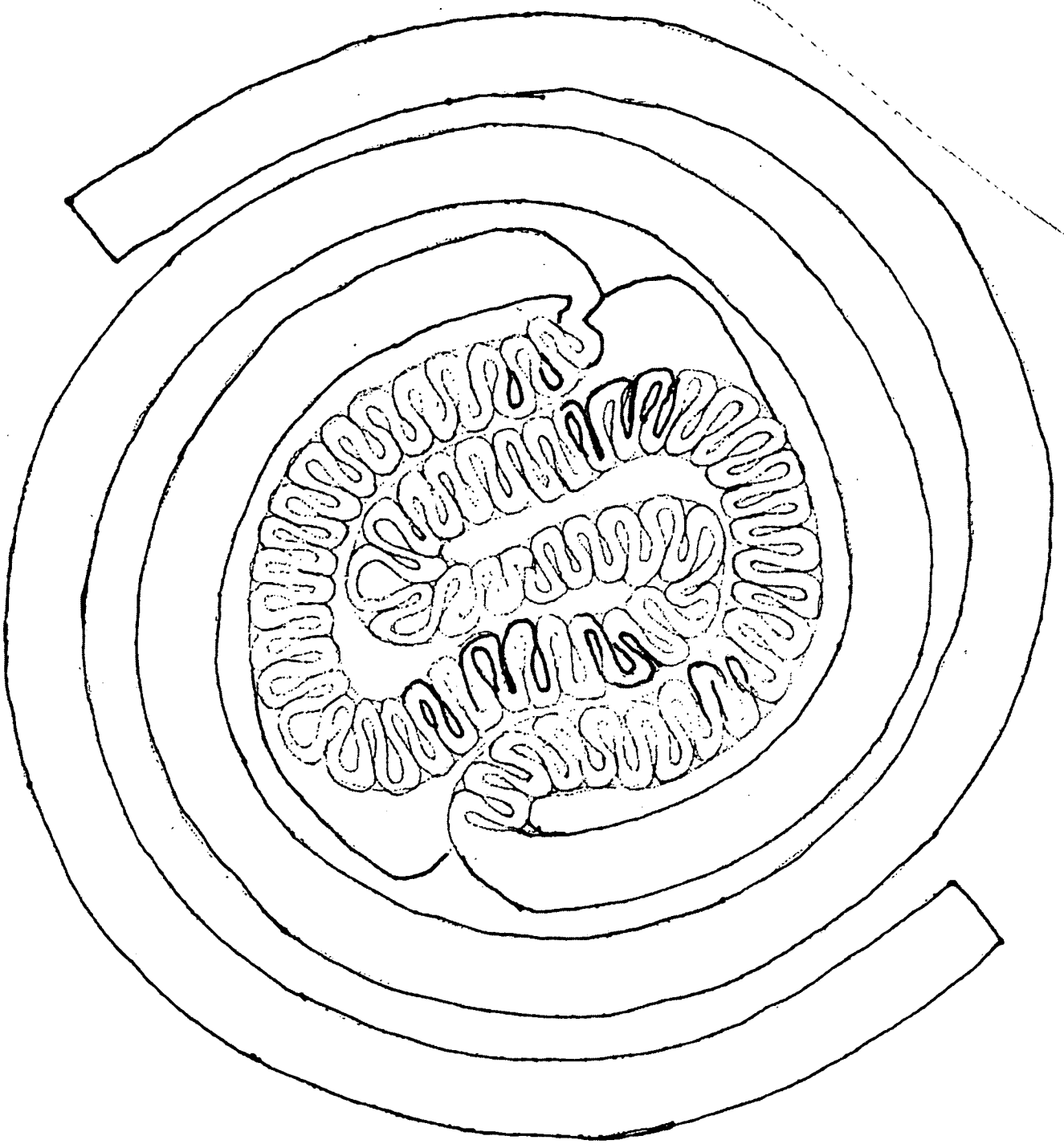

8A
8B
3mm-16mm
8C

6
side view
54
44

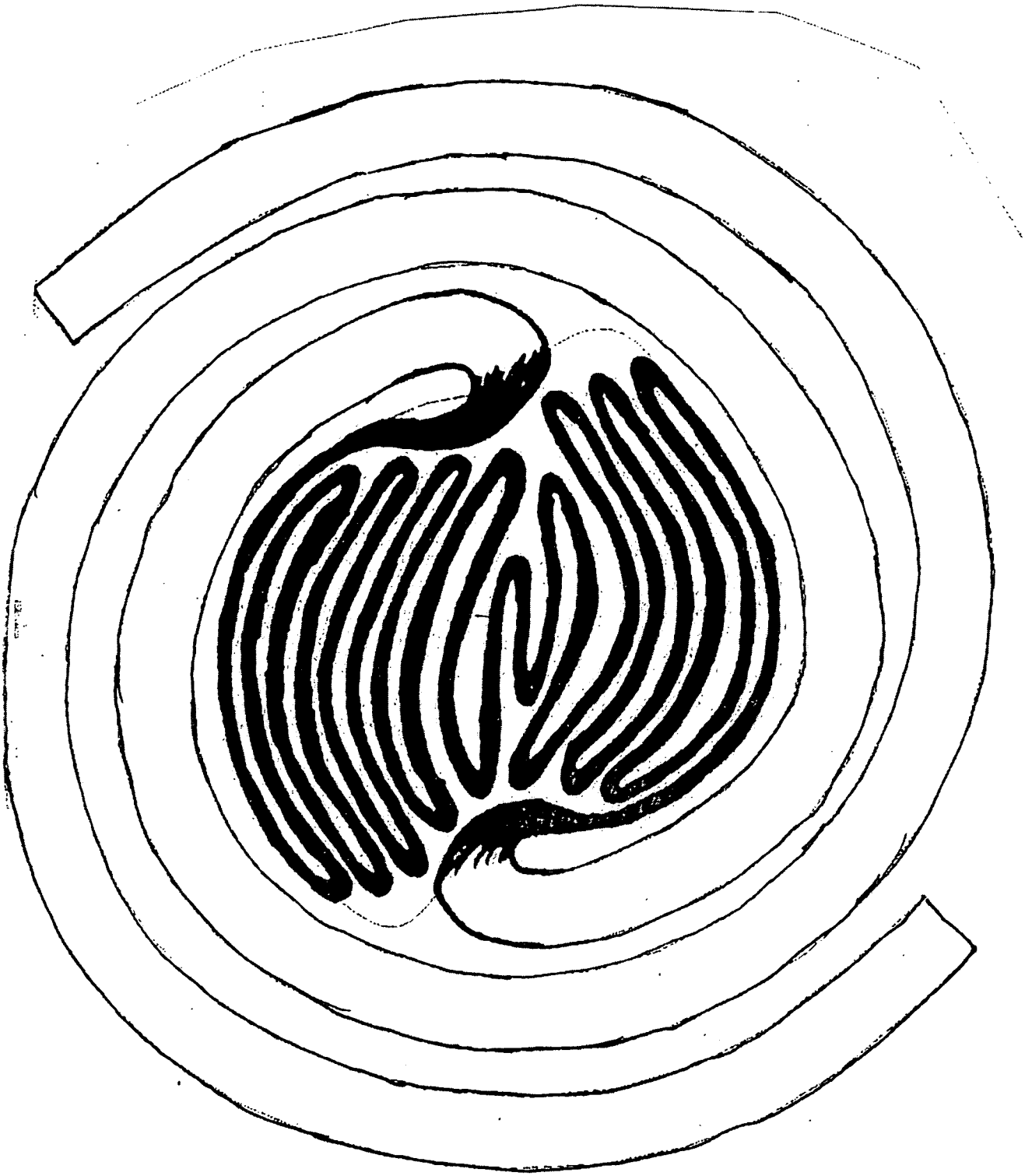
10 A

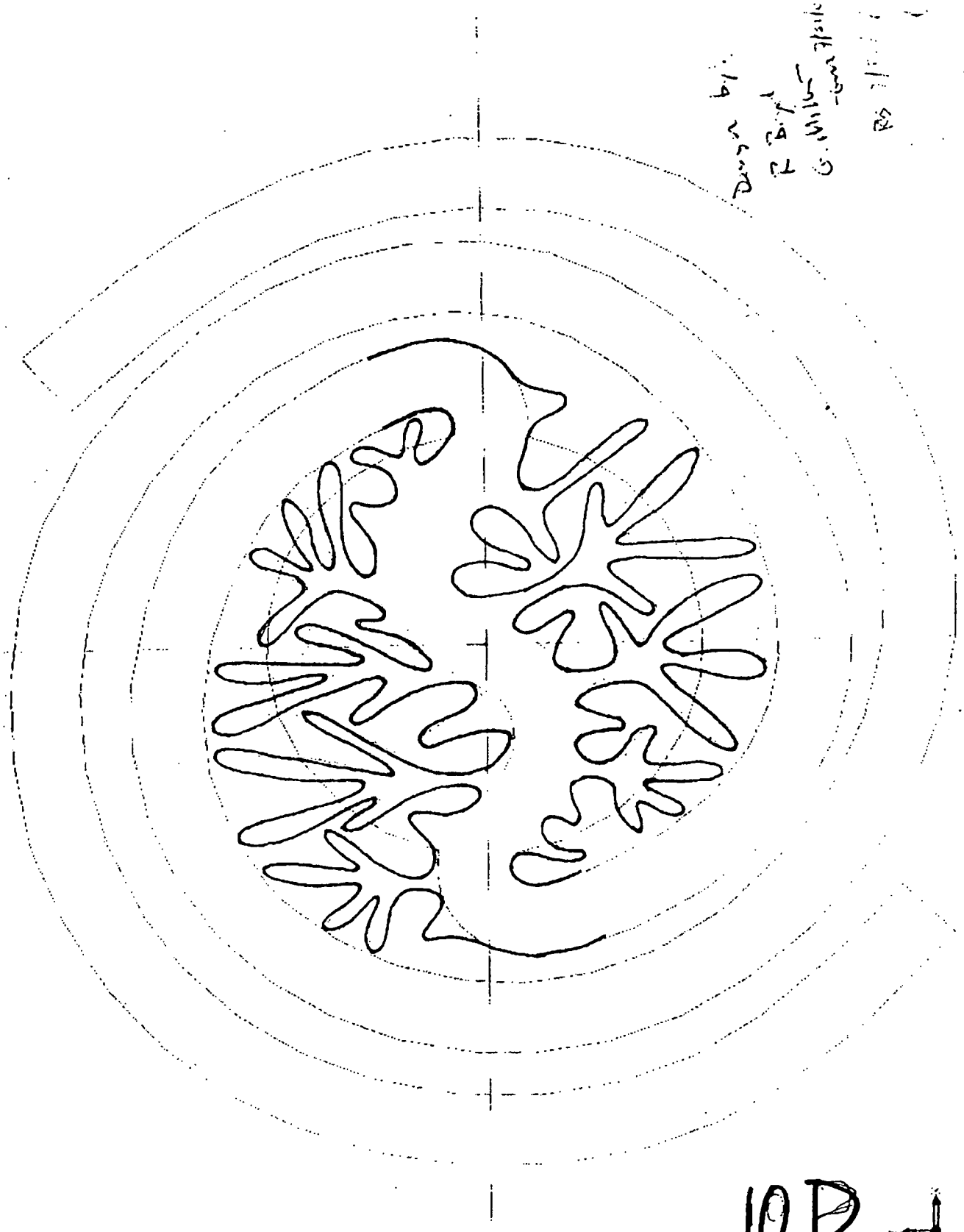


10 B

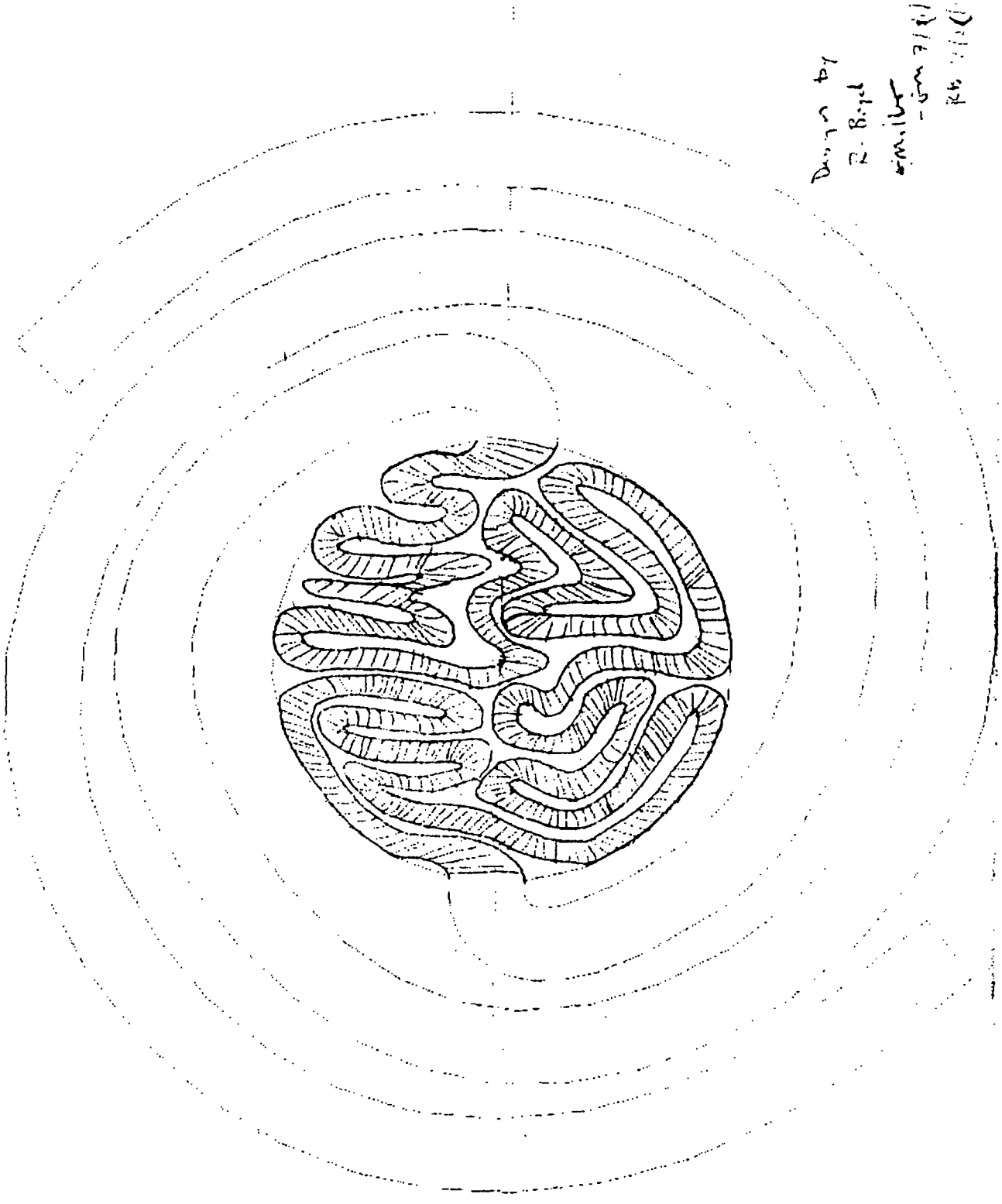


10 C

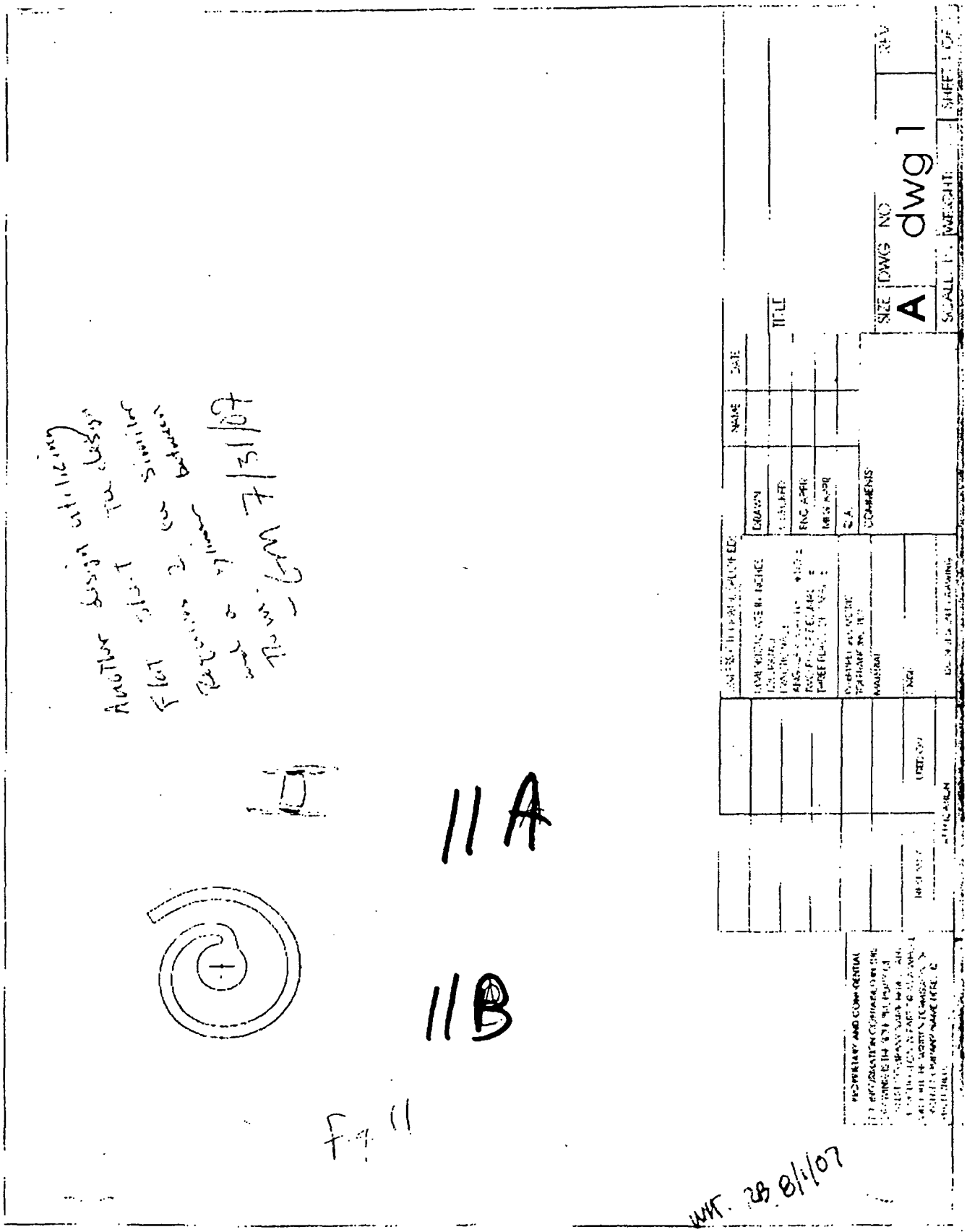




10B



10E


11A
11B
SIZE A
DWG NO dwg 1
TITLE
DRAWN
ENG APPR
MFG APPR
Q.A.
COMMENTS
NAME
DATE
SCALE
WEIGHT
SHEET

Ryan Boyd 8/1/07

DESIGN IDEAS FOR PFO CLOSURE DEVICE FOR APORO/PPB

- PLUG (BIODEGRADABLE) SIMILAR TO NIPPON ZEON CO. DESIGN W/ "TRIGGER" OR CATALYST BEING HEPARIN FOR EXPANDING PROPERTIES TO REACT. (E 192-301-SER 6/11/07)

SMALL SHAPE 4 DEPLOYMENT

HEPARIN

AFTER CONTACT W/ HEPARIN (OR SIMILAR ANTITHROMBOGENIC MATL.) EXPANDS INTO PLUG SHAPE

Fig 12

- HEART-SHAPED "EAR MUFF" DESIGN
  MOLDED HEART DESIGN (MARKETING)
  BROKEN HEART (SPLIT IN HALF) COMES TOGETHER WITH INTERNAL SPRING TO JOIN THE HALFS TO THE SEPTUM WALL.

13A

CUT-OUT SIDE VIEW

SEPERATED "BROKEN" HEART

13B

Fig 13A

C

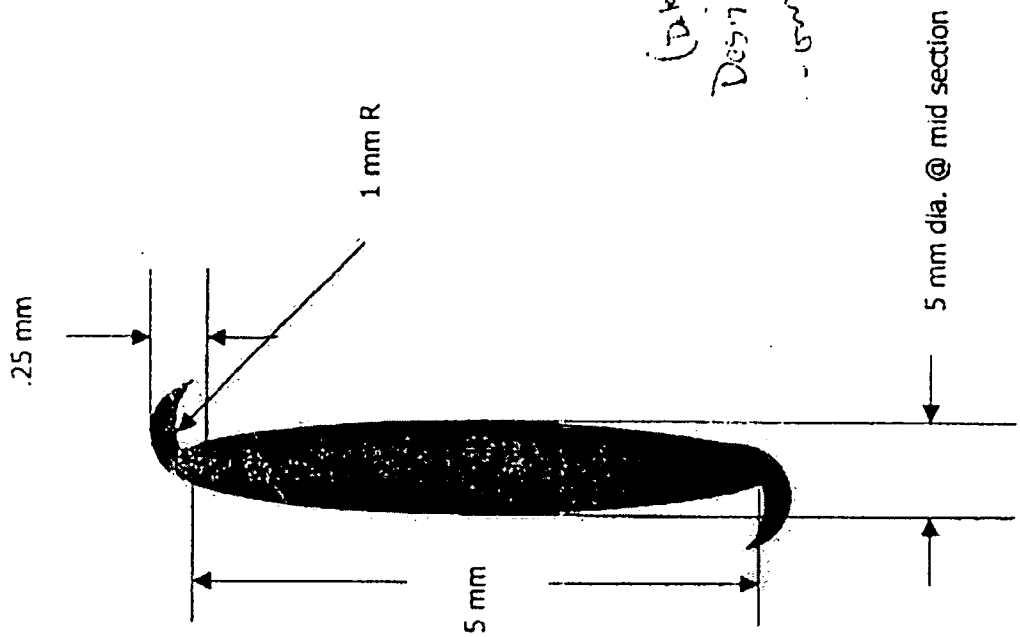
13C

DEPLOYED IN PFO, HEART HALFS FLATTEN & CONFORM TO SEPTUM OPENINGS WHILE SPRING DRAWS THEM TOGETHER

wit-Gm 8/1/07

8/6/07

14



15A

15B

WIT - A. Rivett 7/9/07

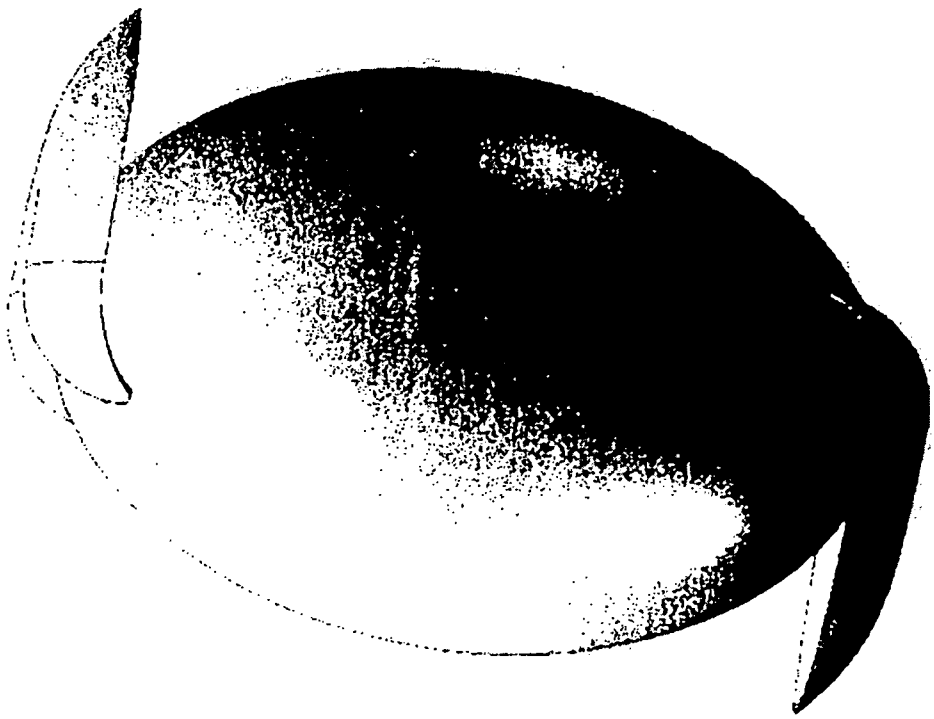
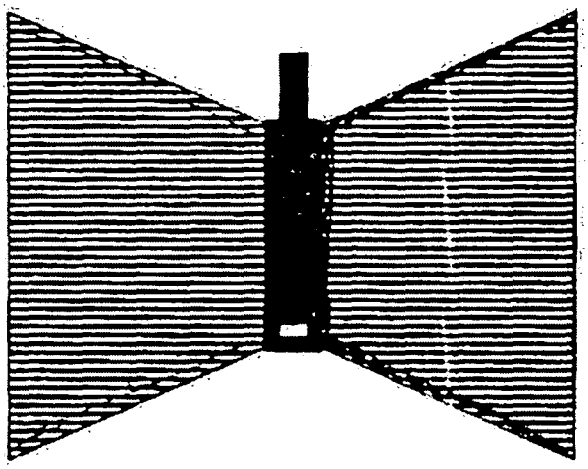


FIG. 5G

Note:
30 Glins' Diam
For DFO Play from Flat
Sheet. Cut by Laser and
Rolled up. Roll it the
Brown Bristle.
— Gm 9/9/07

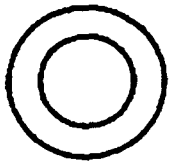


Flat sheet

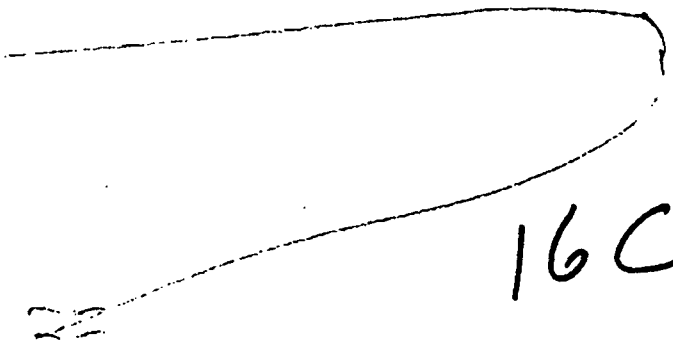
16A

16B

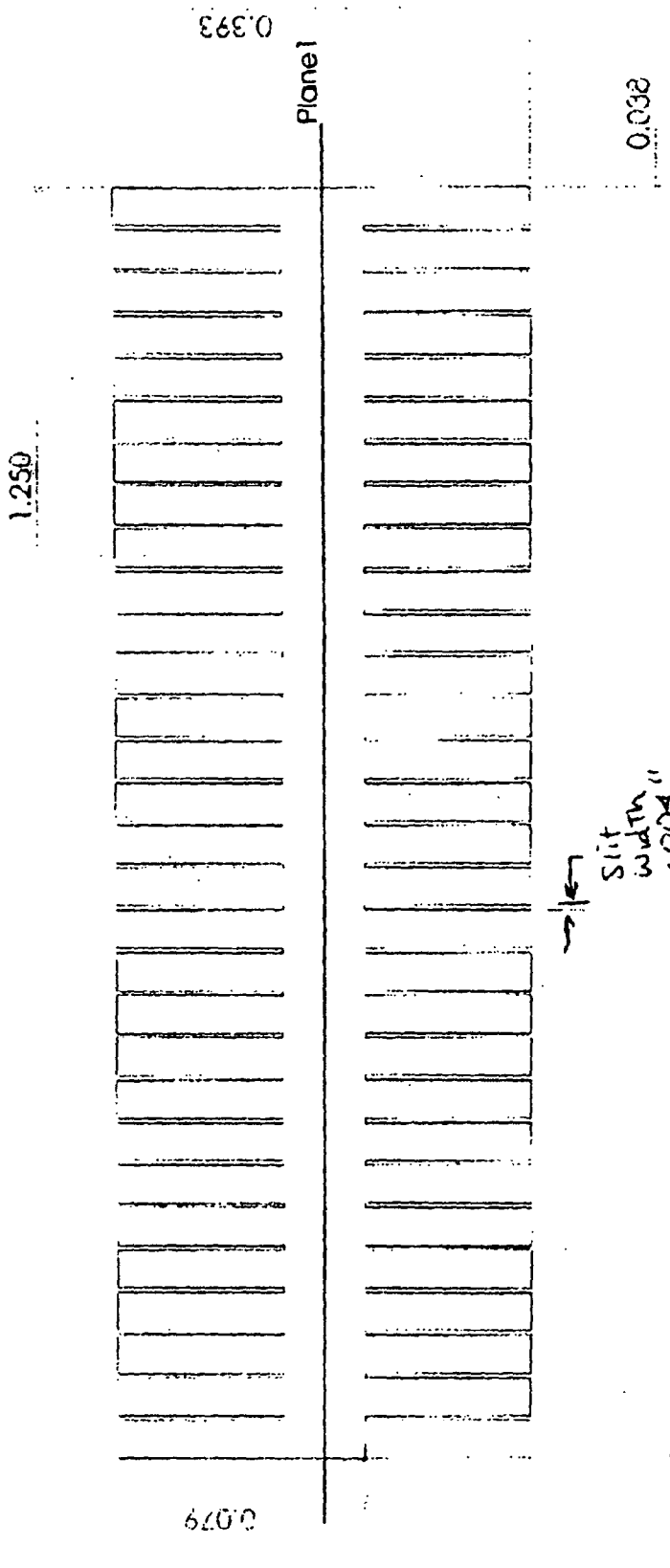
Rolled up



16D



16C



16E

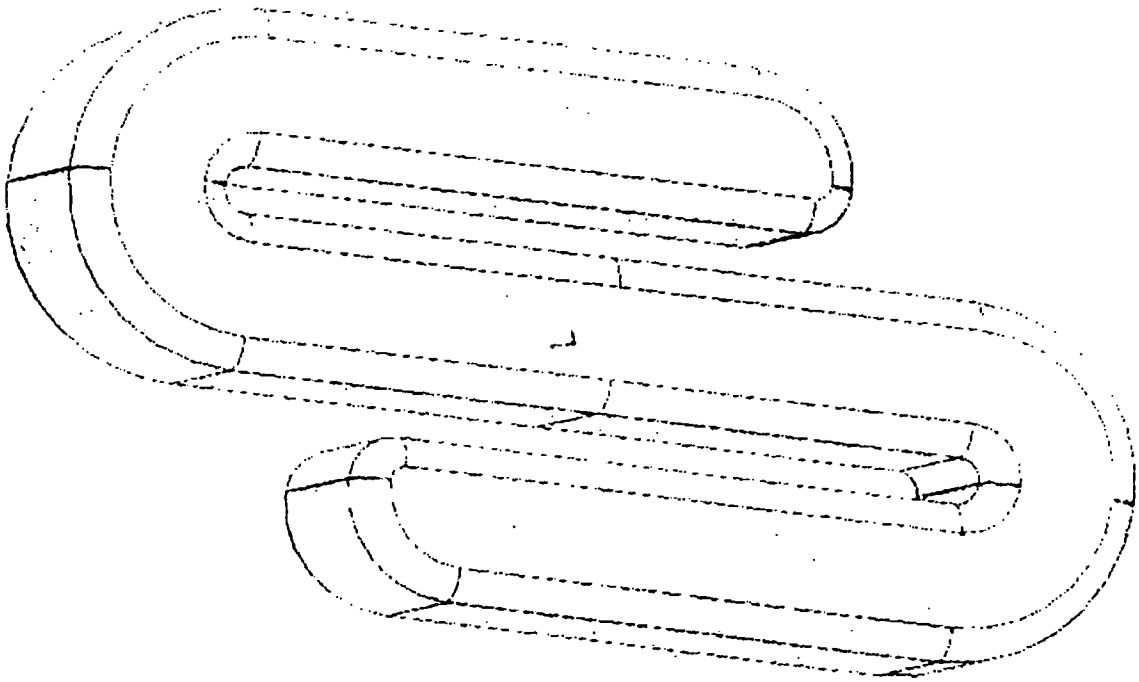
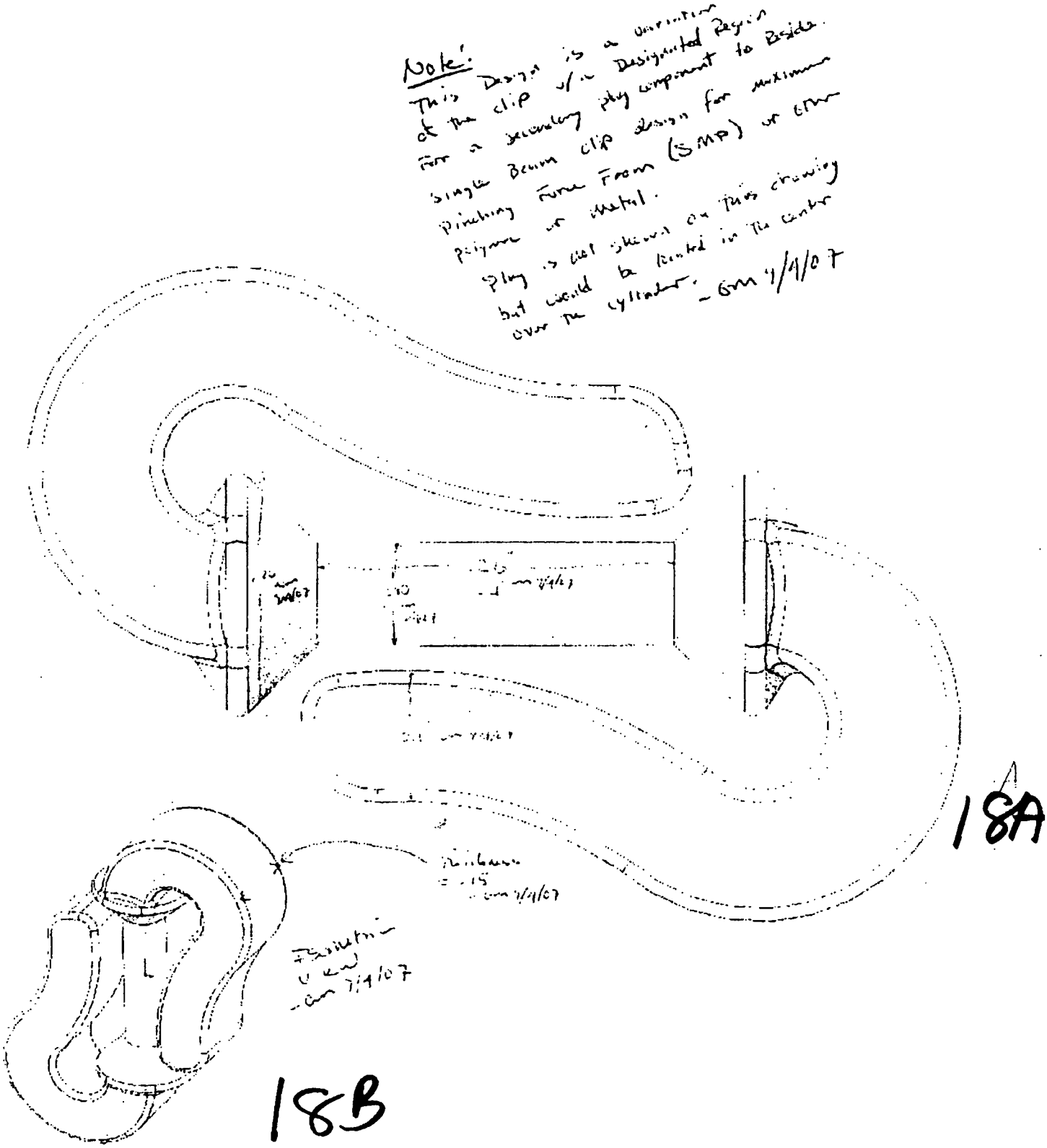
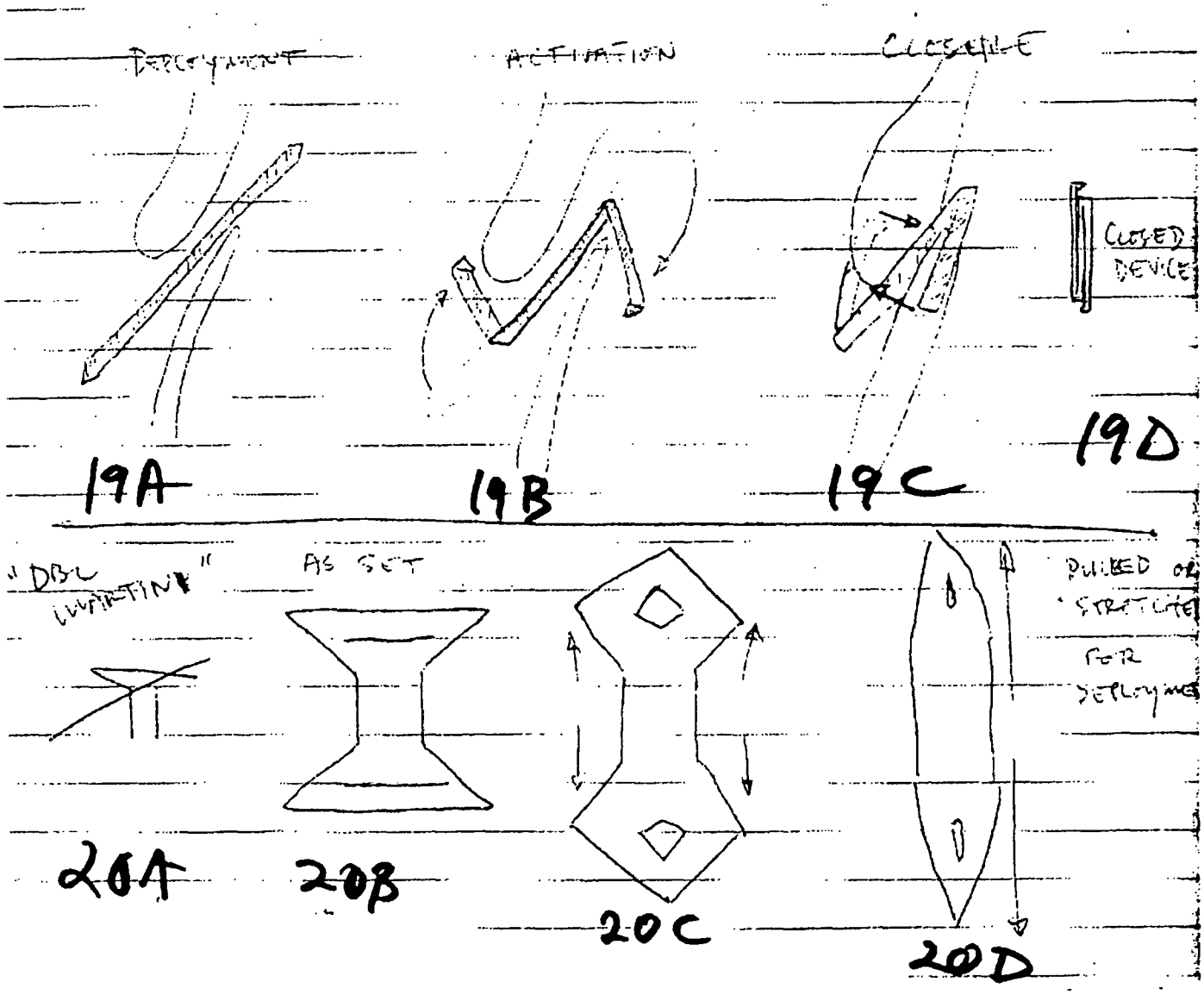
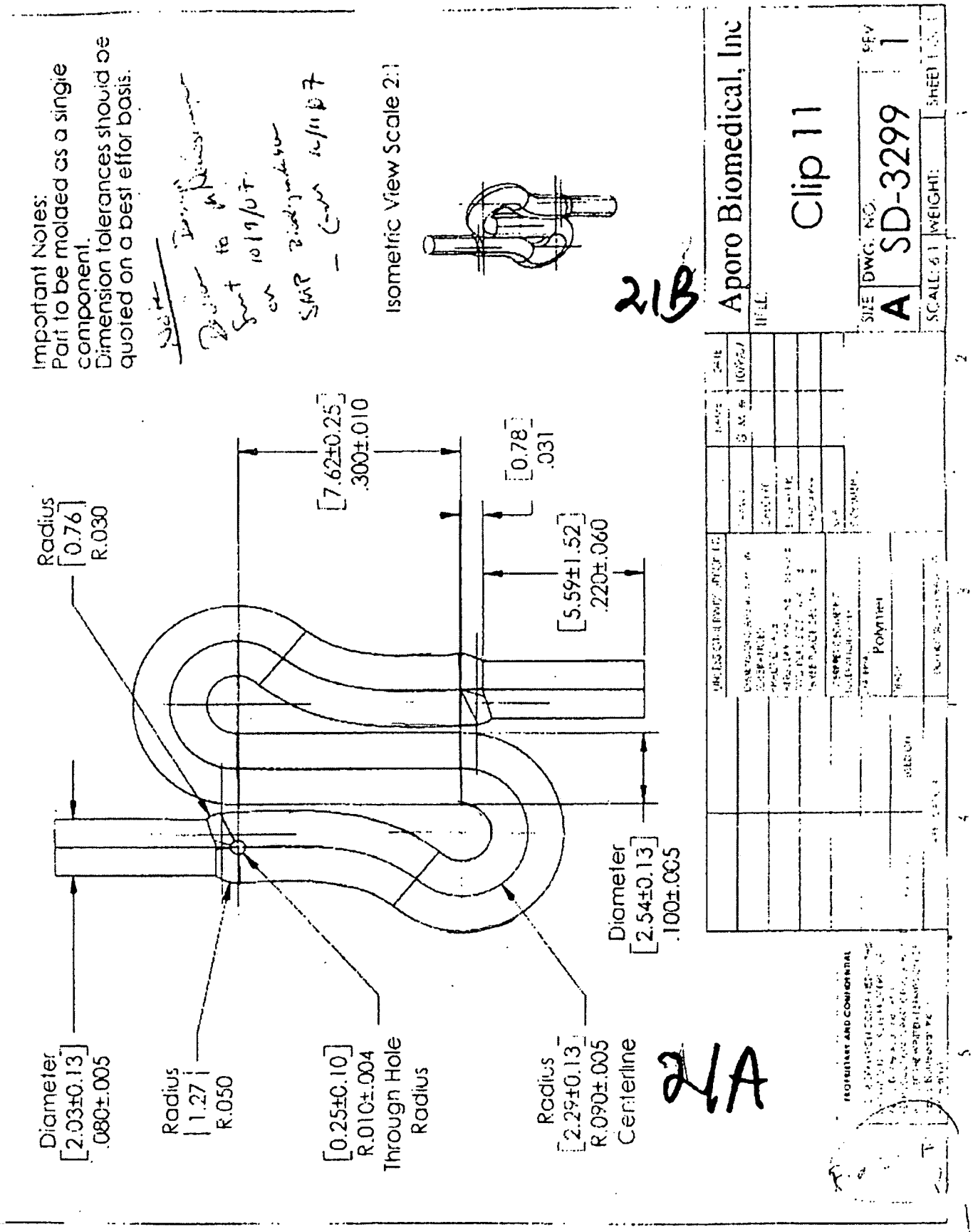


Fig 17


Note:
This Design is a variation of the clip w/ a Designated Region for a secondary play component to Beside. Single Beam clip shown for maximum Pinching Force From (SMP) or other Polymer or Metal.
Play is not shown on this drawing but could be located in the center over the cylinder. GM 7/1/07
18A
18B


DEPLOYMENT
ACTIVATION
CLOSED DEVICE
19A
19B
19C
19D
AS SET
PULLED OR STRETCHED FOR DEPLOYMENT
20A
20B
20C
20D


Important Notes:
Part to be molded as a single component.
Dimension tolerances should be quoted on a best effor basis.
Isometric View Scale 2:1
21B
Aporo Biomedical, Inc
Clip 11
SIZE A
DWG. NO. SD-3299
SCALE: 6:1
WEIGHT:
SHEET 1 OF 1
Radius [0.76] R.030
[7.62±0.25] .300±.010
[0.78] .031
[5.59±1.52] .220±.060
Diameter [2.54±0.13] .100±.005
Diameter [2.03±0.13] .080±.005
Radius [1.27] R.050
[0.25±0.10] R.010±.004 Through Hole Radius
Radius [2.29±0.13] R.090±.005 Centerline
24A

.10
.30
22A

22B

22C

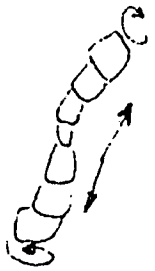
A. CUT OUT FIGURE 8 SHAPE FROM .060" SHEET STOCK W/ SCALPEL BLADE. CONNECTED TO END OF SOLDERING IRON SET @ 385°F.

NOT TO SCALE

FIG 23A

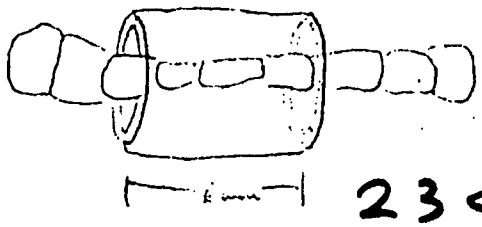
23A

B. BENDING IN 3 STRETCHED ARMS AS IF IN DEPLOYMENT POSITION.



23B

C. INSERTED & CENTERED IN 6mm ID SILICONE TUBE



23C

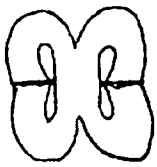
D. SUBMERSED PART OF SILICONE TUBE IN 40°C BATH FOR SHAPE MEMORY TO OCCUR.

RESULTS:

23D

DEPLOYED W/ TWIST REMAININGS IN TUBING

A. CUT OUT SHAPE BELOW FROM .010" SHEET STOCK W/ SCALPEL BLADE CONNECTED TO END OF SOLDERING IRON SET @ 385°F.



NOT TO SCALE.

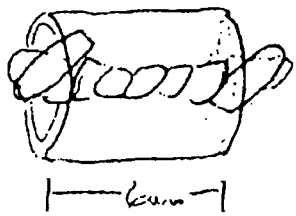
24A

Fig: 24 A B C D

B. ROLLED & STRETCHED FOR DEPLOYMENT

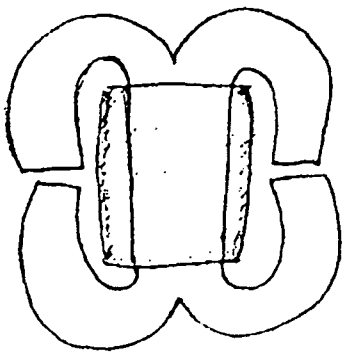
24B

C INSERTED & CENTERED IN 6mm LONG SILICONE TUBE.



24C

D. SUBMERGED PART & TUBE (FIG C) IN 46°C BATH FOR SHAPE MEMORY TO RECOVER. RESULT:



DEPLOYED AS DESIRED

24D

E. WITH SAME PIECE OF MATERIAL, ROLLED UP (FIG B) & INSERTED & CENTERED INTO 6 mm THICK ACRYLIC SHEET W/ 6mm DIA HOLE DRILLED INTO IT. SHEET TO REPRESENT SEPTUM WALLS.

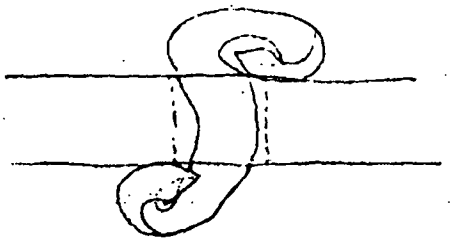
WHEN SUBMERGED THE RESULT WAS INCOMPLETE RECOVERY.

CUT INTO "S"
SHAPE W/ HOT SCALPEL

- ROLLED ENDS & STRETCHED MID SECTION

25A

- SUBMERGED INTO 46C BATH WHILE CENTERED IN HOLE IN 6mm ACRYLIC SHEET.
RESULTS AS EXPECTED - ARMS (OR LEGS) UNFOLD AND PRESS AGAINST ACRYLIC SHEET, REPRESENTING SEPTAL WALLS, DOES NOT COMPLETELY FLATTEN ONTO SHEET DUE TO SECTION IN TUNNEL.



25B

26D

26B

26C

26A

UNLESS OTHERWISE SPECIFIED: NAME DATE

DIMENSIONS ARE IN INCHES DRAWN
TOLERANCES:
FRACTIONAL ± CHECKED
ANGULAR MACH ± BEND ± ENG APPR.
TWO PLACE DECIMAL ± MFG APPR
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC Q.A
TOLERANCING PER COMMENTS:

MATERIAL
Polymer

FINISH

NEXT ASSY USED ON

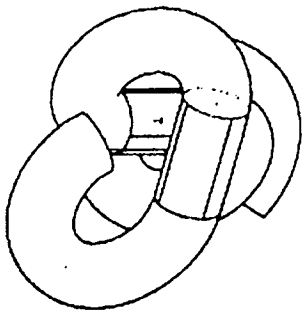
APPLICATION

DO NOT SCALE DRAWING

TITLE:
Out of plane 3

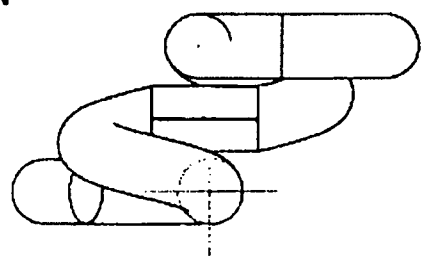
SIZE DWG. NO. REV
A

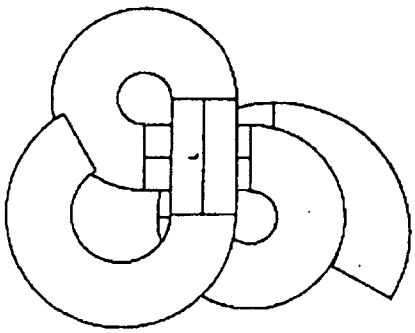
SCALE: 4:1 WEIGHT: SHEET 1 OF 1



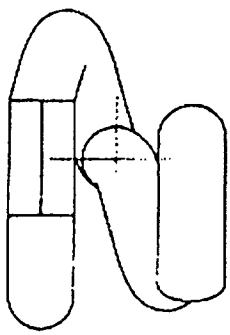
27D

27B

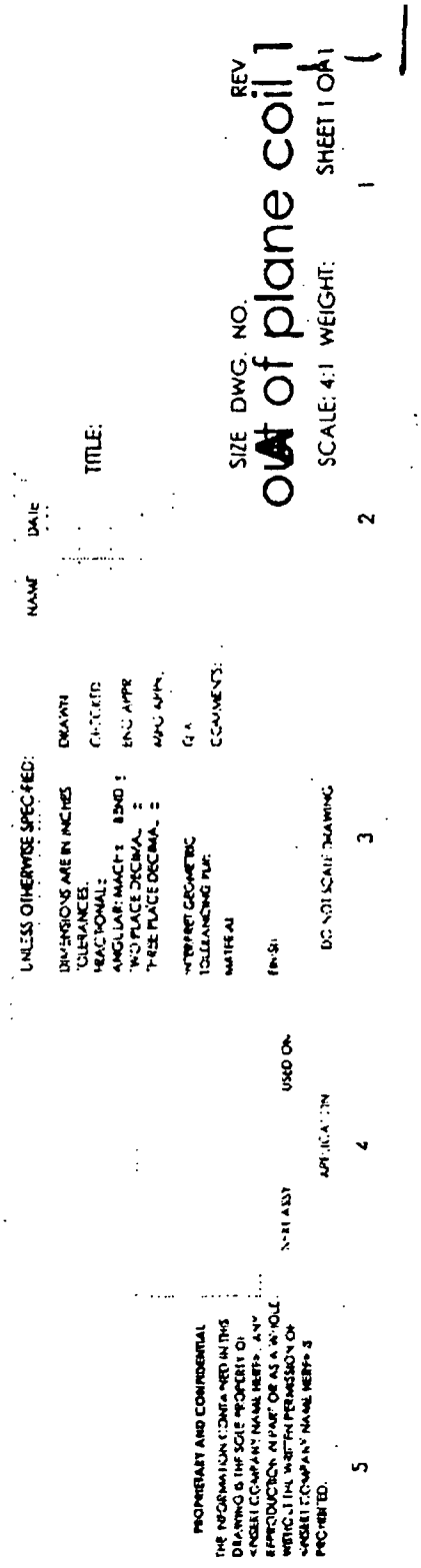


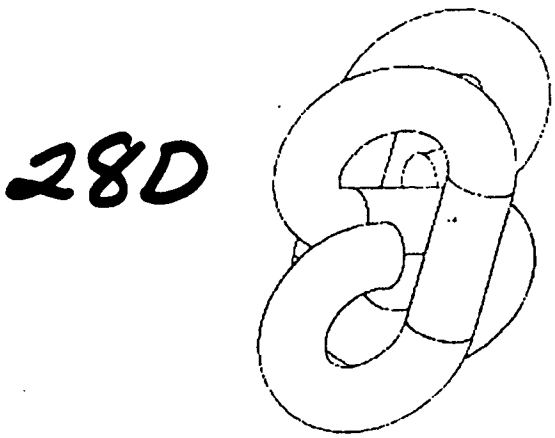


27A

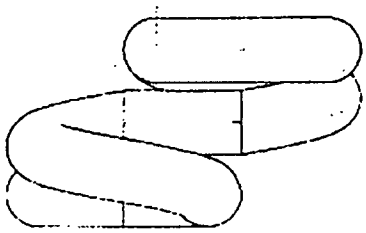


27C

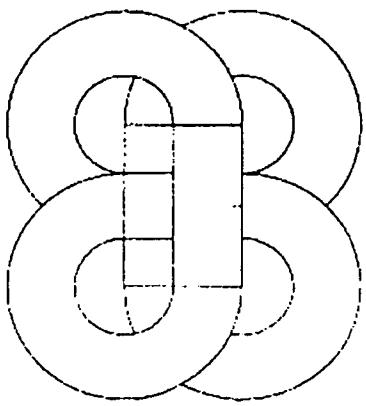




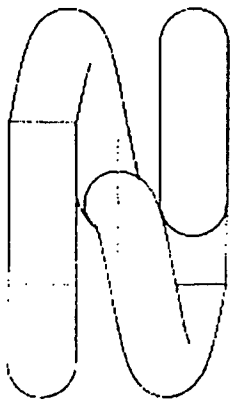
28D



28B

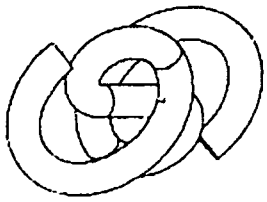


28A

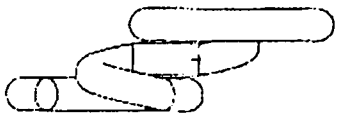


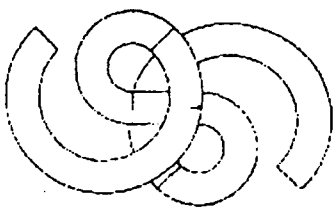
28C

29D



29B





29A

29C

SIZE DWG. NO. REV
Clip improved coil 1
SCALE: 2:1 WEIGHT: SHEET 1 OF 1

30D

30B

30A

30C

TITLE:
Clip Improved
Coil 3 + Plug 1

SIZE DWG. NO. REV
A

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

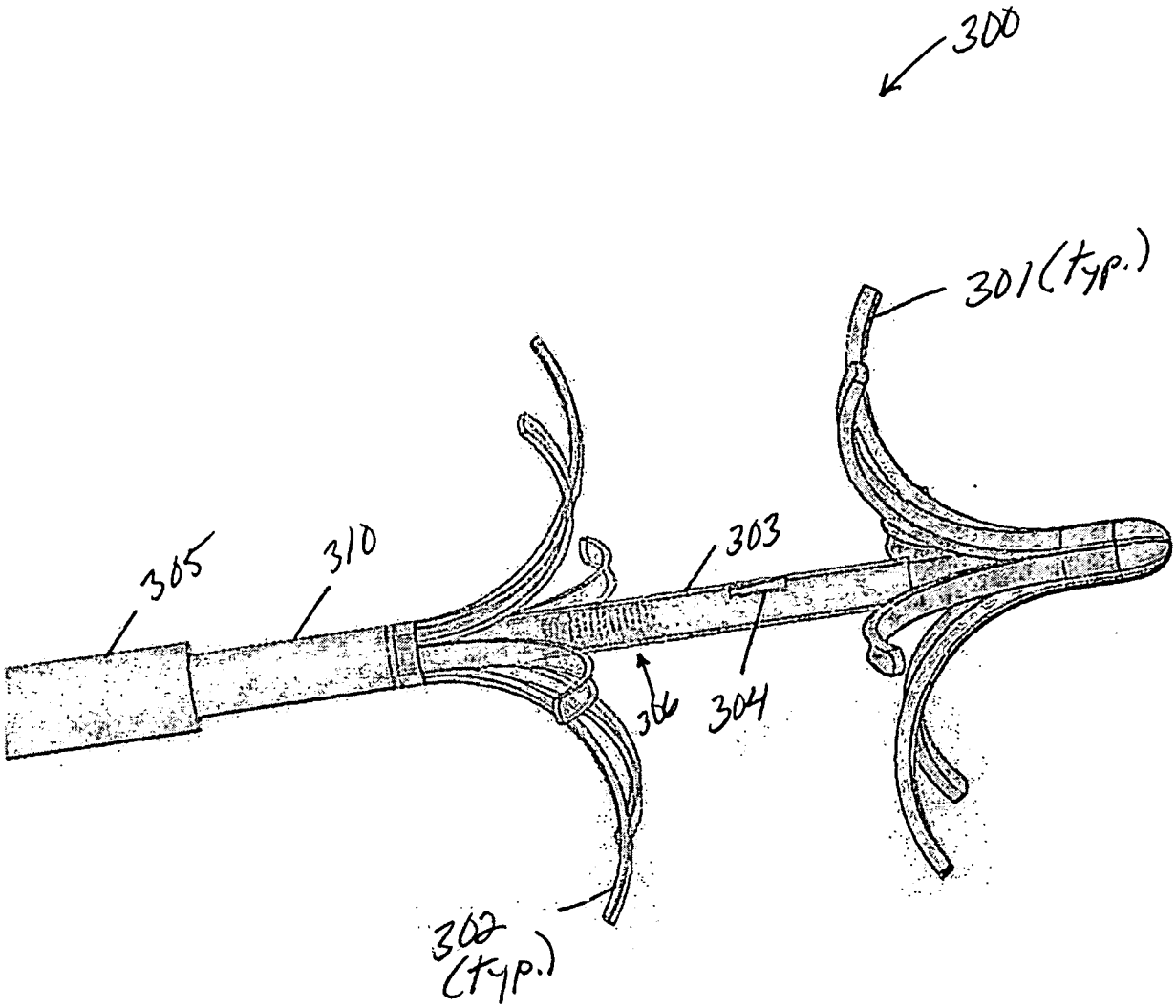


FIG. 31A

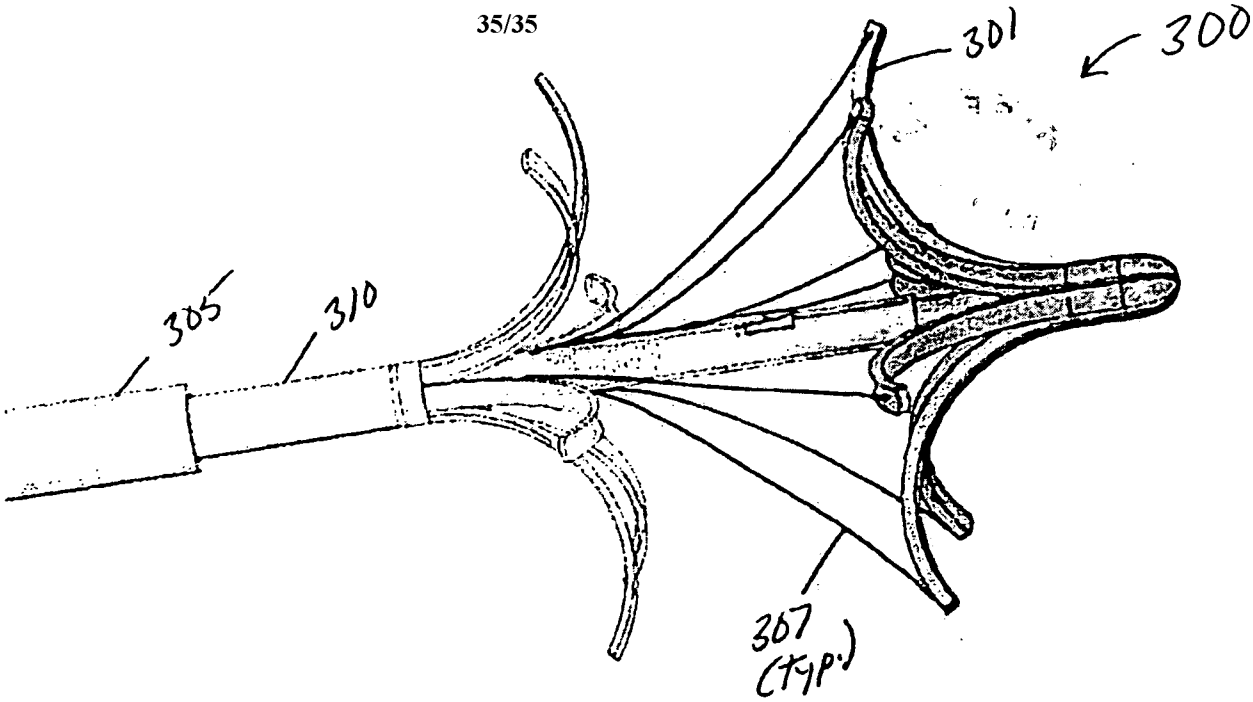


FIG. 31B

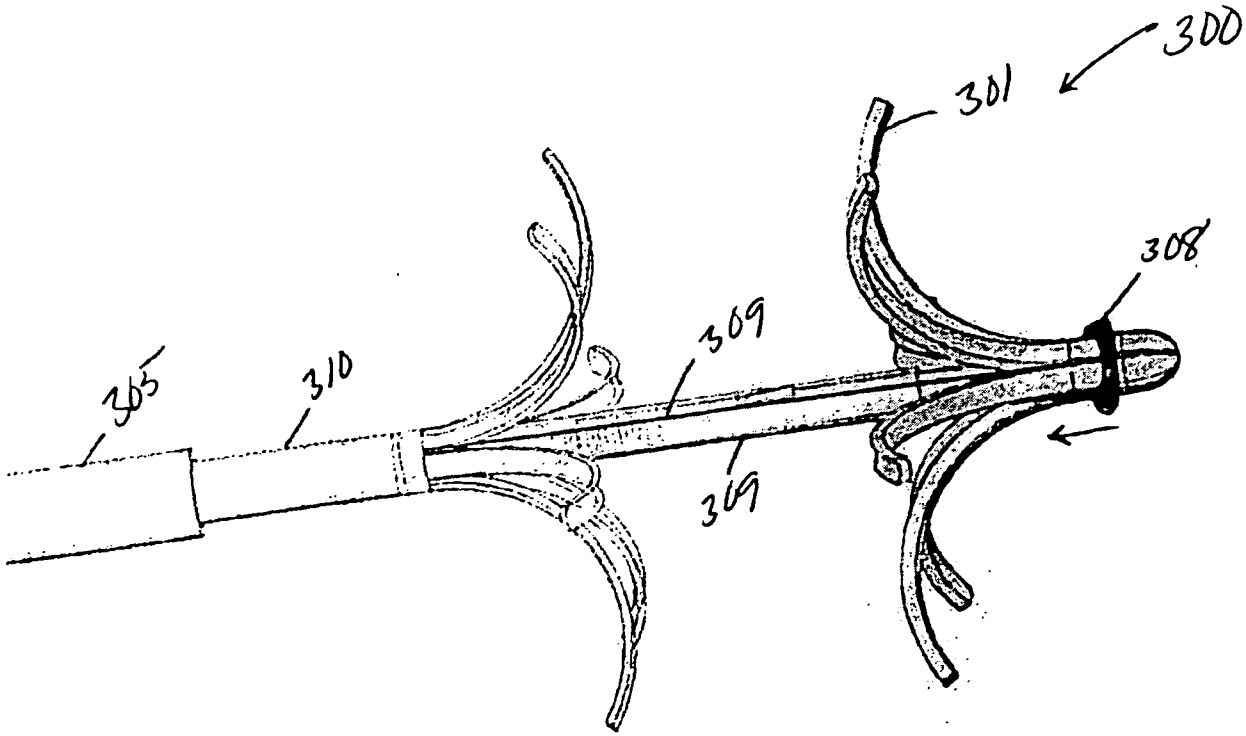


FIG. 31C