

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
1 December 2011 (01.12.2011)

(10) International Publication Number
WO 2011/148374 A2

(51) International Patent Classification:
A61F 2/24 (2006.01) A61B 17/04 (2006.01)

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(21) International Application Number:
PCT/IL2011/000404

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(22) International Filing Date:
24 May 2011 (24.05.2011)

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
12/785,717 24 May 2010 (24.05.2010) US

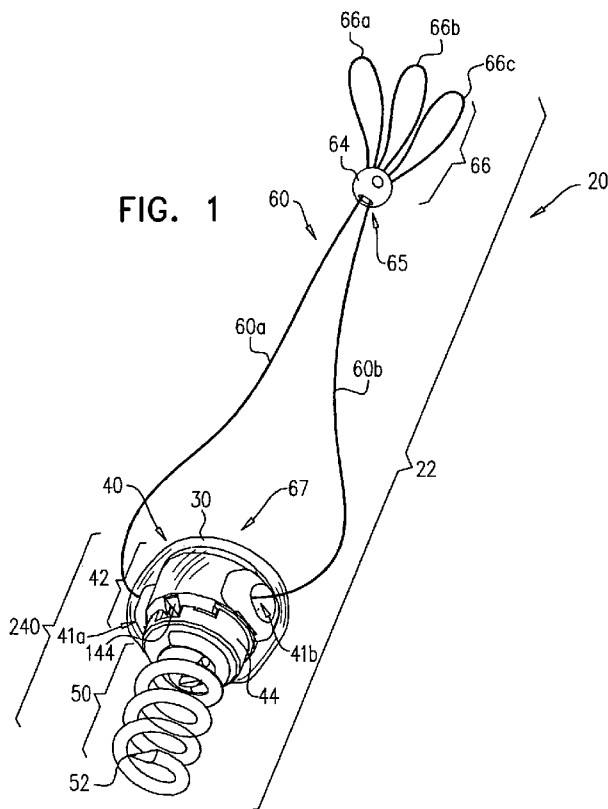
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(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ,

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(54) Title: ADJUSTABLE ARTIFICIAL CHORDEAE TENDINEAE WITH SUTURE LOOPS



(57) Abstract: Apparatus (20, 220) is provided, including an artificial-chordeae-tendineae-adjustment mechanism (40) and at least one primary artificial chordae tendinea (60) coupled at a distal portion thereof (67) to the artificial-chordeae-tendineae-adjustment mechanism (40). A degree of tension of the at least one primary artificial chordae tendinea (60) is adjustable by the artificial-chordeae-tendineae-adjustment mechanism (40). One or more loops (66) are coupled at a proximal portion (65) of the at least one primary artificial chordae tendinea (60). The one or more loops (66) are configured to facilitate suturing of the one or more loops (66) to respective portions of a leaflet of an atrioventricular valve of a patient. Other applications are also described.

WO 2011/148374 A2

TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

ADJUSTABLE ARTIFICIAL CHORDEAE TENDINEAE WITH SUTURE LOOPS**CROSS-REFERENCES TO RELATED APPLICATIONS**

The present application claims the priority from US Patent Application 12/785,717 to Miller et al, entitled, "Adjustable artificial chordae tendineae with suture loops," filed
5 May 24, 2010, which is incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates in general to valve and chordae tendineae repair. More specifically, the present invention relates to repair of an atrioventricular valve and associated chordae tendineae of a patient.

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BACKGROUND

Ischemic heart disease causes mitral regurgitation by the combination of ischemic dysfunction of the papillary muscles, and the dilatation of the left ventricle that is present in ischemic heart disease, with the subsequent displacement of the papillary muscles and the dilatation of the mitral valve annulus.

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Dilation of the annulus of the mitral valve prevents the valve leaflets from fully coapting when the valve is closed. Mitral regurgitation of blood from the left ventricle into the left atrium results in increased total stroke volume and decreased cardiac output, and ultimate weakening of the left ventricle secondary to a volume overload and a pressure overload of the left atrium.

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Chronic or acute left ventricular dilatation can lead to papillary muscle displacement with increased leaflet tethering due to tension on chordae tendineae, as well as annular dilatation.

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US 2006/0287716 to Banbury et al., describes apparatus for replacing the native chordae of a heart valve having at least two leaflets includes a prosthetic chordae assembly configured to extend from a papillary muscle to one of the at least two valve
leaflets of the heart valve. The prosthetic chordae assembly has first and second end
portions, and a middle portion extending therebetween. The prosthetic chordae assembly
further includes a plurality of loop members interconnected at the first end portion for
suturing to the papillary muscle. The middle portion is formed by two generally parallel
30 strands of each of the loop members, and the second end portion is formed by an arcuate

junction of the two strands of each of the loop members. The arcuate junctions are spaced apart and each of the junctions provides an independent location for attaching to one of the at least two valve leaflets of the heart valve.

US 7,431,692 to Zollinger et al. describes an adjustable support pad for adjustably
5 holding a tensioning line used to apply tension to a body organ. The adjustable support pad can include a locking mechanism for preventing slidable movement of the tensioning element in one or both directions. The locking mechanism may include spring-loaded locks, rotatable cam-like structures, and/or rotatable spool structures. The adjustable support pad may be formed from rigid, semi-rigid, and/or flexible materials, and may be
10 formed to conform to the outer surface of a body organ. The adjustable support pad can be configured to adjustably hold one or more separate tensioning lines, and to provide for independent adjustment of one or more tensioning lines or groups thereof.

US 2007/0118151 to Davidson describes a method and system to achieve leaflet coaptation in a cardiac valve percutaneously by creation of neochordae to prolapsing
15 valve segments. This technique is especially useful in cases of ruptured chordae, but may be utilized in any segment of prolapsing leaflet. The technique described herein has the additional advantage of being adjustable in the beating heart. This allows tailoring of leaflet coaptation height under various loading conditions using image-guidance, such as echocardiography. This offers an additional distinct advantage over conventional open-
20 surgery placement of artificial chordae. In traditional open surgical valve repair, chord length must be estimated in the arrested heart and may or may not be correct once the patient is weaned from cardiopulmonary bypass. The technique described below also allows for placement of multiple artificial chordae, as dictated by the patient's pathophysiology.

US 6,626,930 to Allen et al. describes apparatus and method for the stabilization
25 and fastening of two pieces of tissue. A single device may be used to both stabilize and fasten the two pieces of tissue, or a separate stabilizing device may be used in conjunction with a fastening device. The stabilizing device may comprise a probe with vacuum ports and/or mechanical clamps disposed at the distal end to approximate the two pieces of
30 tissue. After the pieces of tissue are stabilized, they are fastened together using sutures or clips. One exemplary application of a suture-based fastener comprises a toggle and suture arrangement deployed by a needle, wherein the needle enters the front side of the tissue and exits the blind side. In a second exemplary application, the suture-based fastener

comprises a needle connected to a suture. The needle enters the blind side of the tissue and exits the front side. The suture is then tied in a knot to secure the pieces of tissue. One example of a clip-based fastener comprises a spring-loaded clip having two arms with tapered distal ends and barbs. The probe includes a deployment mechanism which
5 causes the clip to pierce and lockingly secure the two pieces of tissue.

US 6,629,534 to St. Goar et al. describes methods, devices, and systems are provided for performing endovascular repair of atrioventricular and other cardiac valves in the heart. Regurgitation of an atrioventricular valve, particularly a mitral valve, can be repaired by modifying a tissue structure selected from the valve leaflets, the valve
10 annulus, the valve chordae, and the papillary muscles. These structures may be modified by suturing, stapling, snaring, or shortening, using interventional tools which are introduced to a heart chamber. Preferably, the tissue structures will be temporarily modified prior to permanent modification. For example, opposed valve leaflets may be temporarily grasped and held into position prior to permanent attachment.

US 6,752,813 to Goldfarb et al. describes methods and devices for grasping, and
15 optional repositioning and fixation of the valve leaflets to treat cardiac valve regurgitation, particularly mitral valve regurgitation. Such grasping will typically be atraumatic providing a number of benefits. For example, atraumatic grasping may allow repositioning of the devices relative to the leaflets and repositioning of the leaflets
20 themselves without damage to the leaflets. However, in some cases it may be necessary or desired to include grasping which pierces or otherwise permanently affects the leaflets. In some of these cases, the grasping step includes fixation.

US 2003/0105519 to Fasol et al. describes artificial chordae having a strand
25 member and a first and second pair of sutures at either longitudinal end of the strand member. The artificial chordae is preferably a unitary unit, formed from inelastic flexible material. In one application, the artificial chordae comprises multiple strand members joined together at a joined end. Different sized artificial chordae are provided sized to fit the patient's heart. The appropriately sized artificial chordae is chosen by using a chordae
30 sizing gauge having a shaft and a transverse member, to measure the space within the patient's heart where the artificial chordae is attached.

The following patents and patent application publications may be of interest:

PCT WO 07/136783 to Cartledge et al.

- PCT WO 10/128502 to Maisano et al.
- US 5,306,296 to Wright et al.
- US 6,569,198 to Wilson et al.
- US 6,619,291 to Hlavka et al.
- 5 US 6,764,510 to Vidlund et al.
- US 7,004,176 to Lau
- US 7,101,395 to Tremulis et al.
- US 7,175,660 to Cartledge et al.
- US 2003/0050693 to Quijano et al
- 10 US 2003/0167062 to Gambale et al.
- US 2004/0024451 to Johnson et al.
- US 2004/0148021 to Cartledge et al.
- US 2004/0236419 to Milo
- US 2005/0171601 to Cosgrove et al.
- 15 US 2005/0216039 to Lederman
- US 2005/0288781 to Moaddeb et al.
- US 2007/0016287 to Cartledge et al.
- US 2007/0080188 to Spence et al.
- US 2009/0177266 to Powell et al.
- 20 US 2010/0161041 to Maisano et al.
- US 2010/0161042 to Maisano et al.
- US 2010/0161043 to Maisano et al.
- US 2010/0280603 to Maisano et al.
- US 2011/0106245 to Miller et al.
- 25 The following article may be of interest:

Alfieri et al., "An effective technique to correct anterior mitral leaflet prolapse," *J Card Surg* 14(6):468-470 (1999)

Alfieri et al., "Novel suture device for beating heart mitral leaflet approximation," *Annals of Thoracic Surgery* 74:1488-1493 (2002)

5 Alfieri et al., "The double orifice technique in mitral valve repair: a simple solution for complex problems," *Journal of Thoracic Cardiovascular Surgery* 122:674-681 (2001)

Alfieri et al., "The edge to edge technique," *The European Association for Cardio-Thoracic Surgery 14th Annual Meeting October 7-11, Book of Proceedings.* (2000)

10 Alfieri, "The edge-to-edge repair of the mitral valve," [Abstract] *6th Annual NewEra Cardiac Care: Innovation & Technology, Heart Surgery Forum* pp. 103. (2000)

Dang NC et al. "Simplified Placement of Multiple Artificial Mitral Valve Chords," *The Heart Surgery Forum* #2005-1005, 8 (3) (2005)

SUMMARY OF THE INVENTION

15 In some applications of the present invention, apparatus is provided comprising one or more primary adjustable repair chords and one or more proximal loops coupled thereto, and an adjustment mechanism to adjust a length of the primary repair chord. The primary repair chord and the loops comprise flexible, longitudinal members (e.g., sutures or wires). The primary repair chord is coupled at a distal portion thereof to the adjustment
20 mechanism. In some applications, the repair chord functions as artificial chordae tendineae. For such applications, the repair chord and the adjustment mechanism serve as subvalvular apparatus. In other applications, the repair chord is used to adjust a distance between two portions of the ventricular wall. For such applications, the repair chord and the adjustment mechanism serve as subvalvular apparatus. In other applications, the
25 repair chord is used to adjust a distance between any two portions of the heart.

In some applications of the present invention, the adjustment mechanism comprises a spool assembly which adjusts a degree of tension of the at least one primary chord. The spool assembly comprises a housing, which houses a spool to which a distal portion of the primary chord is coupled. The housing is coupled to a tissue anchor, which
30 facilitates implantation of the spool assembly in a first portion of tissue of the heart (e.g.,

a portion of cardiac tissue which faces and surrounds the ventricular lumen, such as a papillary muscle or a first portion of a ventricular wall of the heart).

The second end portion (i.e., a proximal portion) of the primary chord is coupled to a proximal coupling element. The one or more proximal loops are coupled, or
5 otherwise fastened, to the second portion of the primary chord via the coupling element. An operating physician loops a respective suture through the one or more loops and sutures the suture to a second portion of tissue which faces and surrounds the ventricle, such as a leaflet of an atrioventricular valve (e.g., a mitral valve or a tricuspid valve) or a second portion of the ventricular wall. It is to be noted that the one or more loops may be
10 coupled to the primary chord directly, i.e., without the use of the proximal coupling element.

Once the sutures are coupled (e.g., tied using sutures) to the second portion of tissue via the loops, the spool is rotated in order to adjust a length of the primary chord. During the rotation of the spool in a first direction thereof, the longitudinal member of the
15 primary chord is wound around the spool thereby shortening and tensioning the longitudinal member. As a result, loops coupled to the proximal portion of the primary chord, and consequently the second portion of tissue, are pulled toward the adjustment mechanism. Thus, for applications in which the primary repair chord functions as an artificial chordae tendinea, the primary chord replaces slackened native chordae tendineae
20 and improves function of or restores normal function to the atrioventricular valve. In such an application, the adjustment mechanism is coupled to a papillary muscle or to a base of the papillary muscle, and the proximal loops are sutured to respective portions of one or more leaflets. Use of the loops distributes the adjustment force over a greater portion of the leaflet than if the primary chord would have been coupled to only one location along
25 the leaflet.

For applications in which the repair chord is coupled to two respective portions of the ventricular wall, the two portions are drawn together, thereby restoring the dimensions of the heart wall to physiological dimensions, and drawing the leaflets toward one another. For such an application, the adjustment mechanism may be placed entirely
30 within or externally to the heart.

In some applications of the present invention, the adjustment mechanism comprises a reversible locking mechanism which facilitates bidirectional rotation of the

spool in order to effect both tensioning and relaxing of the primary chord. That is, the spool is wound in one direction in order to tighten the primary chord, and in an opposite direction in order to slacken the primary chord. Thus, the spool adjustment mechanism facilitates bidirectional adjustment of the primary chord during the implantation procedure
5 and subsequently thereto.

In some applications of the present invention, the adjustable repair chord is implanted during an open-heart procedure. In these applications, the delivery tool comprises a handle and a multilumen shaft that is coupled at a distal end thereof to the adjustment mechanism. The delivery tool functions to advance the adjustment
10 mechanism to the first portion of tissue, implant the adjustment mechanism at the first portion of tissue, and effect adjustment of the repair chord by effecting rotation of the spool. For applications in which the repair chord functions as an artificial chordae tendinea, prior to implantation of the adjustment mechanism, the distal portion of the delivery tool and the adjustment mechanism coupled thereto are advanced between the
15 leaflets of the atrioventricular valve and into the ventricle toward the first portion of tissue. The incision made in the heart is then closed around the delivery tool and the heart resumes its normal function during the adjustment of the length of the artificial chordae.

In some applications of the present invention, apparatus and method described herein may be used for providing artificial chordae tendinea in a left ventricle of the
20 heart and effecting adjustment thereof. In some applications, apparatus and method described herein may be used for providing artificial chordae tendinea in a right ventricle of the heart and effecting adjustment thereof. In some applications, apparatus and method described herein may be used for providing a system to adjust a length between two portions of the heart wall.

25 There is therefore provided, in accordance with some applications of the present invention, apparatus, including:

- an artificial-chordeae-tendinea-adjustment mechanism;
- at least one primary artificial chordae tendinea coupled at a distal portion thereof to the artificial-chordeae-tendinea-adjustment mechanism, a degree of tension of the at
30 least one primary artificial chordae tendinea being adjustable by the artificial-chordeae-tendinea-adjustment mechanism; and

one or more loops coupled at a proximal portion of the at least one primary artificial chordae tendinea, the one or more loops being configured to facilitate suturing of the one or more loops to respective portions of a leaflet of an atrioventricular valve of a patient.

5 In some applications of the present invention, the apparatus includes one or more sutures configured to suture the one or more loops to the respective portions of the leaflet.

In some applications of the present invention, the at least one primary artificial chordae tendinea is shaped as a continuous loop.

In some applications of the present invention:

10 the one or more loops includes a plurality of loops,
the apparatus further includes a plurality of sutures, and
each loop of the plurality of loops is configured to facilitate suturing of each suture of the plurality of sutures to a respective portion of the leaflet.

In some applications of the present invention, the distal portion of the at least one
15 primary artificial chordae tendinea is coupled to the artificial-chordeae-tendineae-adjustment mechanism by being looped through a portion of the artificial-chordeae-tendineae-adjustment mechanism.

In some applications of the present invention, the apparatus includes a coupling
element configured to couple the one or more loops to the proximal portion of the at least
20 one primary artificial chordae tendinea.

In some applications of the present invention, the coupling element is shaped so as to define a lumen, and the proximal portion of the at least one primary artificial chordae tendinea and the one or more loops are looped through the lumen of the coupling element.

In some applications of the present invention:

25 the artificial-chordeae-tendineae-adjustment mechanism includes a spool,
the at least one primary artificial chordae tendinea is coupled to the spool; and
the spool is bidirectionally rotatable to adjust the degree of tension of the at least one primary artificial chordae tendinea.

In some applications of the present invention, the at least one primary artificial
30 chordae tendinea is configured to be wound around spool during the rotation of the spool in a first rotational direction.

In some applications of the present invention, the apparatus includes a locking mechanism displaceable with respect to the spool so as to:

release the spool during rotation of the spool, and
lock in place the spool following rotation of the spool.

5 In some applications of the present invention, the distal portion of the at least one primary artificial chordae tendineae is looped through a portion of the spool.

In some applications of the present invention, the distal portion of the at least one primary artificial chordae tendineae is wound around a portion of the spool, and the distal portion of the at least one primary artificial chordae tendineae is configured to be unwound
10 from around the portion of the spool following the suturing of the one or more loops to the respective portions of the leaflet.

In some applications of the present invention:

first and second portions of the at least one primary artificial chordae tendineae extend from the artificial-chordae-tendineae-adjustment mechanism,

15 a portion between the first and second portions of the at least one primary artificial chordae tendineae defines the distal portion of the at least one primary artificial chordae tendineae,

the first and second portions of the at least one primary artificial chordae tendineae each have free ends which define the proximal portion of the at least one primary artificial
20 chordae tendineae,

the one or more loops include one or more first loops and one or more second loops,

the free end of the first portion of the at least one primary artificial chordae tendineae is coupled to the one or more first loops, and

25 the free end of the second portion of the at least one primary artificial chordae tendineae is coupled to the one or more second loops.

In some applications of the present invention, the one or more first loops facilitate suturing of the one or more first loops to a first leaflet of the atrioventricular valve, and the one or more second loops facilitate suturing of the one or more second loops to the
30 first leaflet of the atrioventricular valve.

In some applications of the present invention, the one or more first loops facilitate suturing of the one or more first loops to a first leaflet of the atrioventricular valve, and

the one or more second loops facilitate suturing of the one or more second loops to a second leaflet of the atrioventricular valve.

In some applications of the present invention, the artificial-chordeae-tendineae-adjustment mechanism is configured to adjust a distance between the first and second
5 leaflets by adjusting the first and second portions of the at least one primary artificial chordea tendinea.

There is additionally provided, in accordance with some applications of the present invention, a method including:

coupling an artificial-chordeae-tendineae-adjustment mechanism to a first portion
10 of cardiac tissue, the chordeae-tendineae-adjustment mechanism being coupled to a distal portion of at least one primary artificial chordea tendinea;

extending a proximal portion of the at least one primary artificial chordea tendinea toward a leaflet of an atrioventricular valve of a patient, the proximal portion of the at least one primary artificial chordea tendinea being coupled to one or more loops;

15 suturing the one or more loops to respective portions of the leaflet; and

following the suturing, adjusting a degree of tension of the at least one primary artificial chordea tendinea using the artificial-chordeae-tendineae-adjustment mechanism.

In some applications of the present invention, adjusting the degree of tension of the at least one primary artificial chordea tendinea includes distributing a tension force on
20 the at least one primary artificial chordea tendinea along the respective portions of the leaflet.

In some applications of the present invention, adjusting the degree of tension of the at least one primary artificial chordea tendinea includes adjusting a distance between the leaflet and the first portion of cardiac tissue.

25 In some applications of the present invention, adjusting the degree of tension of the at least one primary artificial chordea tendinea includes adjusting a length of the at least one primary artificial chordea tendinea between the leaflet and the first portion of cardiac tissue.

In some applications of the present invention, the at least one primary artificial
30 chordea tendinea has first and second portions having respective free ends, the free end of the first portion being coupled to one or more first loops of the one or more loops, and the

free end of the second portion being coupled to one or more second loops of the one or more loops, and the method further includes:

coupling the one or more first loops to a first leaflet of the atrioventricular valve,

coupling the one or more second loops to a second leaflet of the atrioventricular
5 valve, and

adjusting a distance between the first and second leaflets by adjusting the first and second portions of the at least one primary artificial chordae tendinea with the chordae-tendineae-adjustment mechanism.

In some applications of the present invention, the at least one primary artificial
10 chordae tendinea has first and second portions having respective free ends, the free end of the first portion being coupled to one or more first loops of the one or more loops, and the free end of the second portion being coupled to one or more second loops of the one or more loops, and the method further includes:

coupling the one or more first loops to a first leaflet of the atrioventricular valve at
15 a first portion thereof, and

coupling the one or more second loops to the leaflet of the atrioventricular valve at a second portion thereof.

In some applications of the present invention, adjusting the degree of tension of the at least one primary artificial chordae tendinea includes adjusting the degree of tension
20 of the at least one primary artificial chordae tendinea during a first period thereof, and the method further includes further adjusting the degree of tension of the at least one primary artificial chordae tendinea during a second period that is after the first period.

In some applications of the present invention, the artificial-chordeae-tendineae-adjustment includes a spool coupled to the distal portion of the at least one primary
25 artificial chordae tendinea, and adjusting the degree of tension of the at least one primary artificial chordae tendinea using the artificial-chordeae-tendineae-adjustment mechanism including bidirectionally rotating the spool.

In some applications of the present invention, adjusting the degree on tension of the at least one primary artificial chordae tendinea includes unwinding a portion of the at
30 least one primary artificial chordae tendinea before applying tension to the at least one primary artificial chordae tendinea.

In some applications of the present invention, adjusting the degree on tension of the at least one primary artificial chordae tendinea includes:

- applying tension to the at least one primary artificial chordae tendinea by winding a portion of the at least one primary artificial chordae tendinea around the spool by
- 5 rotating the spool in a first direction thereof, and
- slackening the at least one primary artificial chordae tendinea by unwinding a portion of the at least one primary artificial chordae tendinea from around the spool by rotating the spool in a second direction thereof opposite the first direction.

In some applications of the present invention, the method includes unlocking the
10 spool prior to the adjusting the degree of tension of the at least one primary artificial chordae tendinea, and locking the spool following the adjusting the degree of tension of the at least one primary artificial chordae tendinea.

There is also provided, in accordance with some applications of the present invention, a method, including:

- 15 coupling an artificial-chordeae-tendineae-adjustment mechanism to a first portion of cardiac tissue, the chordeae-tendineae-adjustment mechanism being coupled to a distal portion of at least one artificial chordae tendinea;
- extending a proximal portion of the at least one artificial chordae tendinea toward an atrioventricular valve of a patient;
- 20 suturing the proximal portion of the at least one artificial chordae tendinea to at least two leaflets of the atrioventricular valve at a middle portion of the atrioventricular valve; and
- following the suturing, adjusting a degree of tension of the at least one artificial chordae tendinea using the artificial-chordeae-tendineae-adjustment mechanism.

25 In some applications of the present invention, suturing the proximal portion of the at least one artificial chordae tendinea to the at least two leaflets of the atrioventricular valve at the middle portion of the atrioventricular valve includes creating at least two orifices in the valve for blood to pass through.

In some applications of the present invention, suturing the proximal portion of the
30 at least one artificial chordae tendinea to the at least two leaflets of the atrioventricular valve at the middle portion of the atrioventricular valve includes creating a bridge between the leaflets.

In some applications of the present invention, suturing the proximal portion of the at least one artificial chorda tendinea to the at least two leaflets of the atrioventricular valve at the middle portion of the atrioventricular valve includes creating a plurality of sutures between the leaflets.

5 In some applications of the present invention, suturing the proximal portion of the at least one artificial chorda tendinea to the at least two leaflets of the atrioventricular valve includes suturing the proximal portion of the at least one artificial chorda tendinea from a ventricular surface of the valve.

In some applications of the present invention, adjusting the degree of tension of
10 the at least one artificial chorda tendinea includes adjusting a distance between the leaflets and the first portion of cardiac tissue.

In some applications of the present invention, adjusting the degree of tension of the at least one artificial chorda tendinea includes adjusting a length of the at least one artificial chorda tendinea between the leaflets and the first portion of cardiac tissue.

15 There is also provided, in accordance with some applications of the present invention, apparatus, including:

a longitudinal-chord-adjustment mechanism;

at least one primary longitudinal chord coupled at a distal portion thereof to the longitudinal-chord-adjustment mechanism, a degree of tension of the at least one primary
20 longitudinal chord being adjustable by the longitudinal-chord-adjustment mechanism; and

one or more loops coupled at a proximal portion of the at least one primary longitudinal chord, the one or more loops being configured to facilitate coupling of the one or more loops to respective portions of a cardiac tissue of a patient.

25 There is additionally provided, in accordance with some applications of the present invention, the following inventive concepts:

1. A method comprising:

coupling an artificial-chordeae-tendineae-adjustment mechanism to a first portion of cardiac tissue, the chordeae-tendineae-adjustment mechanism being coupled to a distal portion of at least one primary artificial chorda tendinea;

extending a proximal portion of the at least one primary artificial chordae tendinea toward a leaflet of an atrioventricular valve of a patient, the proximal portion of the at least one primary artificial chordae tendinea being coupled to one or more loops;

suturing the one or more loops to respective portions of the leaflet; and

5 following the suturing, adjusting a degree of tension of the at least one primary artificial chordae tendinea using the artificial-chordeae-tendineae-adjustment mechanism.

2. The method according to inventive concept 1, wherein adjusting the degree of tension of the at least one primary artificial chordae tendinea comprises distributing a tension force on the at least one primary artificial chordae tendinea along the respective
10 portions of the leaflet.

3. The method according to inventive concept 1, wherein adjusting the degree of tension of the at least one primary artificial chordae tendinea comprises adjusting a distance between the leaflet and the first portion of cardiac tissue.

4. The method according to inventive concept 1, wherein adjusting the degree of
15 tension of the at least one primary artificial chordae tendinea comprises adjusting a length of the at least one primary artificial chordae tendinea between the leaflet and the first portion of cardiac tissue.

5. The method according to inventive concept 1, wherein the at least one primary artificial chordae tendinea has first and second portions having respective free ends, the
20 free end of the first portion being coupled to one or more first loops of the one or more loops, and the free end of the second portion being coupled to one or more second loops of the one or more loops, and wherein the method further includes:

coupling the one or more first loops to a first leaflet of the atrioventricular valve,

25 coupling the one or more second loops to a second leaflet of the atrioventricular valve, and

adjusting a distance between the first and second leaflets by adjusting the first and second portions of the at least one primary artificial chordae tendinea with the chordeae-tendineae-adjustment mechanism.

6. The method according to inventive concept 1, wherein the at least one primary
30 artificial chordae tendinea has first and second portions having respective free ends, the free end of the first portion being coupled to one or more first loops of the one or more

loops, and the free end of the second portion being coupled to one or more second loops of the one or more loops, and wherein the method further includes:

coupling the one or more first loops to a first leaflet of the atrioventricular valve at a first portion thereof, and

5 coupling the one or more second loops to the leaflet of the atrioventricular valve at a second portion thereof.

7. The method according to inventive concept 1, wherein adjusting the degree of tension of the at least one primary artificial chordae tendineae comprises adjusting the degree of tension of the at least one primary artificial chordae tendineae during a first
10 period thereof, and wherein the method further comprises further adjusting the degree of tension of the at least one primary artificial chordae tendineae during a second period that is after the first period.

8. The method according to inventive concept 1, wherein the artificial-chordeae-tendineae-adjustment comprises a spool coupled to the distal portion of the at least one
15 primary artificial chordae tendineae, and wherein adjusting the degree of tension of the at least one primary artificial chordae tendineae using the artificial-chordeae-tendineae-adjustment mechanism comprising bidirectionally rotating the spool.

9. The method according to inventive concept 8, wherein adjusting the degree on tension of the at least one primary artificial chordae tendineae comprises unwinding a
20 portion of the at least one primary artificial chordae tendineae before applying tension to the at least one primary artificial chordae tendineae.

10. The method according to inventive concept 8, wherein adjusting the degree on tension of the at least one primary artificial chordae tendineae comprises:

applying tension to the at least one primary artificial chordae tendineae by winding
25 a portion of the at least one primary artificial chordae tendineae around the spool by rotating the spool in a first direction thereof, and

slackening the at least one primary artificial chordae tendineae by unwinding a portion of the at least one primary artificial chordae tendineae from around the spool by rotating the spool in a second direction thereof opposite the first direction.

30 11. The method according to inventive concept 8, further comprising unlocking the spool prior to the adjusting the degree of tension of the at least one primary artificial

chordea tendinea, and locking the spool following the adjusting the degree of tension of the at least one primary artificial chordea tendinea.

12. A method, comprising:

5 coupling an artificial-chordeae-tendineae-adjustment mechanism to a first portion of cardiac tissue, the chordeae-tendineae-adjustment mechanism being coupled to a distal portion of at least one artificial chordea tendinea;

extending a proximal portion of the at least one artificial chordea tendinea toward an atrioventricular valve of a patient;

10 suturing the proximal portion of the at least one artificial chordea tendinea to at least two leaflets of the atrioventricular valve at a middle portion of the atrioventricular valve; and

following the suturing, adjusting a degree of tension of the at least one artificial chordea tendinea using the artificial-chordeae-tendineae-adjustment mechanism.

13. The method according to inventive concept 12, wherein suturing the proximal 15 portion of the at least one artificial chordea tendinea to the at least two leaflets of the atrioventricular valve at the middle portion of the atrioventricular valve comprises creating at least two orifices in the valve for blood to pass through.

14. The method according to inventive concept 12, wherein suturing the proximal 20 portion of the at least one artificial chordea tendinea to the at least two leaflets of the atrioventricular valve at the middle portion of the atrioventricular valve comprises creating a bridge between the leaflets.

15. The method according to inventive concept 12, wherein suturing the proximal 25 portion of the at least one artificial chordea tendinea to the at least two leaflets of the atrioventricular valve at the middle portion of the atrioventricular valve comprises creating a plurality of sutures between the leaflets.

16. The method according to inventive concept 12, wherein suturing the proximal portion of the at least one artificial chordea tendinea to the at least two leaflets of the atrioventricular valve comprises suturing the proximal portion of the at least one artificial chordea tendinea from a ventricular surface of the valve.

17. The method according to inventive concept 12, wherein adjusting the degree of tension of the at least one artificial chorda tendinea comprises adjusting a distance between the leaflets and the first portion of cardiac tissue.

18. The method according to inventive concept 12, wherein adjusting the degree of tension of the at least one artificial chorda tendinea comprises adjusting a length of the at least one artificial chorda tendinea between the leaflets and the first portion of cardiac tissue.

The present invention will be more fully understood from the following detailed description of embodiments thereof, taken together with the drawings, in which:

10

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic illustration of apparatus comprising a primary adjustable repair chord, a plurality of loops, and an adjustment mechanism, in accordance with some applications of the present invention;

Fig. 2 is a schematic illustration of implantation of the apparatus of Fig. 1 in a heart of a patient, in accordance with some applications of the present invention;

Fig. 3 is a schematic illustration of tightening the primary adjustable repair chord of Fig. 1, in accordance with some applications of the present invention;

Fig. 4 is a schematic illustration of the tightened repair chord of Fig. 3, in accordance with some applications of the present invention;

Fig. 5 is a schematic illustration of the adjustment mechanism coupled to two primary adjustable repair chords, in accordance with some applications of the present invention; and

Figs 6A-C are schematic illustrations of the adjustment mechanism adjusting a distance between two leaflets of an atrioventricular valve, in accordance with some applications of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Reference is now made to Fig. 1, which is a schematic illustration of a apparatus comprising an implant 22 for adjusting a distance between first and second portions of tissue of a patient, comprising an adjustment mechanism 40, a primary repair chord 60, and one or more loops 66a, 66b, and 66c, in accordance with some applications of the

present invention. Chord 60 and loops 66 comprise flexible longitudinal members (e.g., wires, sutures, or threads) which comprise a superelastic, biocompatible material (e.g., nitinol, ePTFE, PTFE, polyester, stainless steel, or cobalt chrome). Typically, repair chord 60 comprises an artificial chordae tendineae. Chord 60 has a proximal portion 65 and a distal portion 67. Typically, chord 60 is shaped as a continuous loop having proximal and distal portions 65 and 67. Distal portion 67 is coupled to (e.g., looped through) adjustment mechanism 40 which comprises a housing 42. For applications in which repair chord 60 comprises an artificial chordae tendinea, adjustment mechanism 40 comprises an artificial-chordeae-tendineae-adjustment mechanism. Proximal portion 65 is coupled to a coupling element 64 (e.g., a bead, as shown, or a knot) by being looped therethrough or by being fixedly coupled thereto. Loops 66a, 66b, and 66c are looped through, fixedly attached, or otherwise coupled to coupling element 64, and thereby loops 66a, 66b, and 66c are coupled to primary chord 60. That is, for some applications of the present invention, loops 66 and proximal portion 65 of chord 60 share the same lumen of coupling element 64.

As described hereinbelow, loops 66a, 66b, and 66c facilitate coupling of implant 22 to a plurality of portions of tissue of the patient. Although three loops 66 are shown, it is to be noted that any suitable number of loops 66 may be coupled to primary chord 60. The scope of the present invention includes knotting of loops 66 to proximal portion 65 of chord 60. For some applications, loops 66 are looped around a proximal looped portion of chord 60. For other applications, loops 66 are directly coupled to chord 60.

For example, for applications in which primary chord 60 comprises an artificial chordae tendinea, loops 66a, 66b, and 66c are coupled to a plurality of locations on a leaflet of an atrioventricular valve. Loops 66a, 66b, and 66c facilitate the passage of respective sutures therethrough which are sutured by the operating physician to the plurality of locations on the leaflet, as is described hereinbelow. The suturing of the loops to the plurality of locations distributes the adjustment force applied to the leaflet during the subsequent adjustment of primary chord 60 by adjustment mechanism 40, as described hereinbelow.

Distal portion 67 of primary chord 60 is looped through a rotatable structure (e.g., a spool, as shown hereinbelow) that is disposed within housing 42 of adjustment mechanism 40, thereby defining first and second portion 60a and 60b of chord 60. First portion 60a of primary repair chord 60 extends through a first opening 41a of housing 42,

and second portion 60b of primary repair chord 60 extends through a second opening 41b in housing 42. In such an application, distal portion 67 of chord 60 defines a portion of chord 60 that is looped through the spool of adjustment mechanism 40.

Adjustment mechanism 40, comprising housing 42 and a distal cap 44, is coupled
5 to a helical tissue anchor 50, by way of illustration and not limitation. That is, adjustment mechanism 40 may be coupled to any suitable tissue anchor known in the art. Together, adjustment mechanism 40 and tissue anchor 50 define a spool assembly 240. Helical tissue anchor 50 comprises a pointed distal tip 52 for puncturing tissue of the patient during implantation of spool assembly 240 in the first portion of tissue of the patient.
10 Housing 42 and distal cap 44 are surrounded by a braided mesh 30 comprising biocompatible material, e.g., nitinol, polyester, ePTFE, or PTFE. Mesh 30 enhances biocompatibility and fibrosis which occurs following implantation. Additionally, during the initial implantation of assembly 240, spool housing 42 may be sutured via mesh 30 to the cardiac tissue. It is to be noted that the scope of the present invention includes a spool
15 housing that is not coupled to a tissue anchor.

Reference is now made to Figs. 2-4 which are schematic illustrations of implantation and adjustment of apparatus 20, in accordance with some applications of the present invention. Typically, implant 22 is implanted in a heart 2 of the patient. Spool assembly 240 is implanted in a first portion of tissue 5 which faces a ventricle of heart 2,
20 and loops 66a, 66b, and 66c are coupled to a second portion of tissue 7 which faces the ventricle of heart 2. For example, as shown, first portion 5 of tissue includes a papillary muscle 4, and second portion 7 of tissue includes a posterior leaflet 14 of a mitral valve 8 of heart 2. For some applications, first portion 5 of tissue includes the base of the papillary muscle. For other applications, first portion 5 of tissue includes a portion of the
25 wall of heart 2, e.g., a portion of a free wall of the ventricle, a portion of the septum facing the ventricle, or a portion of the wall at the apex of the ventricle. For some application, second portion 7 includes an anterior leaflet 12. For other applications, second portion 7 includes portions of tissue from both anterior and posterior leaflets 12 and 14.

The scope of the present invention includes coupling loops 66 to a portion of
30 tissue at the wall of heart 2 such that apparatus 20 effects remodeling of the walls of heart 2. For such an application, assembly 240 may be implanted intraventricularly or externally to the heart.

Typically, apparatus 20 is implanted during an open heart procedure. Implant 22 may be implanted using a delivery tool 300. For clarity of illustration, tool 300 is not shown in Fig. 2.

Reference is now made to Fig. 2. First, the operating physician implants spool assembly 240 at first portion of tissue 5, e.g., papillary muscle 4, as shown. It is to be noted that, during corkscrewing of anchor 50 into tissue of the patient, the operating physician may use his or her hands to hold spool assembly 240 during corkscrewing, without using tool 300 (step not shown). Following the implanting of spool assembly 240 at papillary muscle 4, the operating physician extends primary chord 60 toward second portion of tissue 7, e.g., posterior leaflet 14, as shown. Primary chord 60 is then indirectly coupled to leaflet 14 via loops 66. The physician loops a first suture 68a through loop 66a, sutures suture 68a through a first portion of leaflet 14, and then ties suture 68a in a first knot 69a to a first location on leaflet 14. Knot 69a is typically tied at the atrial surface of leaflet 14, and then excess portions of suture 68a are clipped and removed from the body. The physician then repeats this process by suturing two other sutures 68b and 68c to leaflet 14 via loops 66b and 66c, respectively. Two other knots 69b and 69c are tied at respective locations to leaflet 14. Thus, loops 66 indirectly couple chord 60 to leaflet 14.

It is to be noted that the scope of the present invention includes the implanting of spool assembly 240 at any suitable location other than papillary muscle 4, as shown. For example, spool assembly 240 may be implanted at the base of papillary muscle 4 or at a portion of the wall of the ventricle.

Fig. 3 shows the adjusting of chord 60 by adjustment mechanism 40. Adjustment mechanism 40 is actuated by tool 300. For some applications of the present invention, tool 300 is coupled to adjustment mechanism 40 during the advancement of spool assembly 240 toward first portion 5 of tissue and during the initial implantation of assembly 240 and the suturing of loops 66 to leaflet 14. For applications in which the physician uses his or her hands to implant spool assembly 240, tool 300 is coupled to adjustment mechanism 40 following initial implantation of spool assembly 240 and the suturing of loops 66 to leaflet 14. In either application, during the subsequent adjustment of tension of primary chord 60 by adjustment mechanism 40, the incision made in heart 2 is closed around tool 300, and heart 2 resumes its normal function during the adjustment of the length of chord 60.

As shown, tension is applied to chord 60 by adjustment mechanism 40 which pulls chord 60 from a slackened state (Fig. 2) to a tensioned state (Fig. 3). This applying of tension to chord 60 adjusts a length of chord 60 between adjustment mechanism 40 and proximal portion 65 of chord 60. Additionally, this applying of tension to chord 60
5 adjusts a length between first and second portions 5 and 7 of tissue. As shown in the cross-sectional image in Fig. 3, adjustment mechanism 40 comprises a rotatable structure comprising a spool 46 through which distal portion 67 of chord 60 is looped.

Tool 300 has an elongate multilumen shaft 322 and a proximal handle portion. It is to be noted that shaft 322 may be shaped to define only a single central lumen for
10 passage therethrough of a torque-delivering tool 26 that is surrounded by an overtube 90. Typically, shaft 322 is sized for open-heart and/or minimally-invasive procedures and comprises a flexible material (e.g., a plastic or a plurality of strands of flexible metal such as stainless steel 304 that are bundled together) which may be bent to a desired angle. Shaft 322 is slidable along overtube 90 such that prior to tool 300 facilitating adjustment
15 of primary chord 60 by adjustment mechanism 40, shaft 322 is slid proximally such that a distal end thereof is disposed proximally to mitral valve 8, as shown in Fig. 3. This leaves behind overtube 90, which has a smaller diameter than shaft 322, such that the portion of tool 300 disposed between leaflets 12 and 14 has a smaller diameter which interferes less with the beating of the heart during the adjustment of primary chord 60 by adjustment
20 mechanism 40.

A distal end portion of overtube 90 is coupled to, e.g., welded to, an adjustment mechanism holder 29 having a distal end that is reversibly coupled to a proximal portion of housing 42 surrounding the rotatable structure of adjustment mechanism 40. Holder 29 is shaped to define a lumen for slidable passage therethrough of a manipulator 120 which
25 comprises a distal screwdriver head 122. Screwdriver head 122 is ultimately coupled to spool 46 and facilitates rotation of spool 46 responsively to the rotation of manipulator 120. Manipulator 120 is coupled at a proximal end thereof to a distal end of torque-delivering tool 26 which delivers torque to manipulator 120 and effects rotation of screwdriver head 122. A proximal end of torque-delivering tool 26 is coupled to a
30 rotating mechanism at the proximal handle portion of tool 300. Shaft 322 is shaped to define a central lumen through which torque-delivering tool 26 and overtube 90 pass.

Housing 42 of adjustment mechanism 40 defines a recessed portion 142 at a distal portion thereof. Prior to rotation of spool 46, a portion of longitudinal chord 60 is wound

a few times (e.g., 3 times) around the cylindrical body portion of spool 46. Prior to rotation of spool 46, portions 60a and 60b of longitudinal chord 60 are in a slackened state (as shown in Fig. 2) and longitudinal chord 60 is wrapped a few times (e.g., 3 times) around the cylindrical portion of spool 46. Fig. 3 shows spool 46 following rotation
5 thereof. As shown in the enlarged cross-sectional image in Fig. 3, longitudinal chord 60 is further wound around spool 46 a few more times (e.g., an additional 5 times, as shown) around the cylindrical body portion of spool 46. Following the rotation of spool 46, portions 60a and 60b of longitudinal chord 60 are pulled taut.

In the resting state (i.e., prior to the rotation of spool 46 in order to adjust primary
10 chord 60 and following coupling of chord 60 to leaflet 14 via loops 66) chord 60 is wrapped around spool 46 a few times (e.g., three times, by way of illustration and not limitation). This winding provides excess slack to chord 60 (in case portions 60a and 60b are coupled too tightly to leaflet 14 following coupling of chord 60 to leaflet 14 via loops 66). If the physician wishes to provide slack to chord 60 or to any one of portion 60a or
15 60b, the physician unwinds (e.g., by unwinding chord 60 a few times from around spool 46, or by unwinding chord 60 entirely from around spool 46 so that chord 60 slides freely through spool 46 within a channel provided therein) a bit of the wrapped portion of chord 60 from around spool 46. In order to accomplish such unwinding, the physician rotates spool 46 in a direction in which it unwinds the wrapped portion of chord 60. Since chord
20 60 is looped through spool 46 in the channel provided therein, when chord 60 is unwound from spool 46, the physician can pull on one or both portions 60a and 60b so as to adjust, make even, or further slacken any one of or both portions 60a and 60b that extend from spool 46.

When the physician desires to pull tight chord 60, he or she effects rotation of
25 spool 46 in a first direction, i.e., the direction opposite the second direction in which spool 46 is rotated during the unwinding of chord 60 from spool 46. Rotation of spool 46 in the first direction winds chord 60 around spool 46, while rotation of spool 46 in a second direction opposite the first direction, unwinds the portion of longitudinal chord 60 from around spool 46.

30 Spool 46 defines an upper surface 150, a lower surface 152, and a cylindrical body portion disposed vertically between surfaces 150 and 152. Spool 46 is shaped to provide a driving interface, e.g., a channel, which extends from an opening 43 (shown in Fig. 4) provided by upper surface 150 to an opening 47 (shown in Fig. 4) provided by lower

surface 152. A proximal portion of the driving interface is shaped to define a threaded portion 146 which may or may not be tapered. Threaded portion 146 of spool 46 is engageable by a threaded portion of screwdriver head 122. Rotation of screwdriver head 122 rotates spool 46 as the respective threaded portions of spool 46 and screwdriver head 122 engage. The cylindrical body portion of spool 46 is shaped to define one or more holes which function as respective coupling sites for coupling (e.g., looping through the one or more holes, or welding to spool 46 in the vicinity of the one or more holes) of any number of chords 60 to spool 46.

Lower surface 152 of spool 46 is shaped to define one or more (e.g., a plurality, as shown) recesses 154 which define structural barrier portions 155 of lower surface 152. It is to be noted that any suitable number of recesses 154 may be provided, e.g., between 1 and 10 recesses. For some applications, recesses 154 are disposed circumferentially with respect to lower surface 152 of spool 46.

As shown in Figs. 3 and 4, a locking mechanism 45 is disposed in communication with lower surface 152 of spool 46 and disposed in communication with at least in part to a lower surface of housing 42. Typically, a cap 44 maintains locking mechanism 45 in place with respect to lower surface 152 of spool 46 and lower surface of housing 42. For some applications, locking mechanism 45 is coupled, e.g., welded, to the lower surface of housing 42. Typically, locking mechanism 45 defines a mechanical element having a planar surface that defines slits. It is to be noted that the surface of locking mechanism 45 may also be curved, and not planar. Locking mechanism 45 is shaped to provide a protrusion 156 which projects out of a plane defined by the planar surface of the mechanical element. The slits of mechanism 45 define a depressible portion 128 that is disposed in communication with and extends toward protrusion 156. Depressible portion 128 is moveable in response to a force applied thereto typically by an elongate locking mechanism release rod 70 which slides through a lumen of torque-delivering tool 26.

It is to be noted that the planar, mechanical element of locking mechanism 45 is shown by way of illustration and not limitation and that any suitable mechanical element having or lacking a planar surface but shaped to define at least one protrusion may be used together with locking mechanism 45.

Cap 44 is provided that is shaped to define a planar surface and an annular wall having an upper surface thereof. The upper surface of the annular wall is coupled to, e.g.,

welded to, a lower surface provided by housing 42. The annular wall of cap 44 is shaped to define a recessed portion 144 of cap 44 that is in alignment with recessed portion 142 of spool housing 42.

As shown in Fig. 3, a distal end 72 of locking mechanism release rod 70 pushes
5 distally on depressible portion 128 in order to unlock locking mechanism 45 from spool 46. Pushing depressible portion 128 by locking mechanism release rod 70 pushes distally protrusion 156 within recessed portion 142 of housing 42 and within recessed portion 144 of cap 44, which frees protrusion 156 from recesses 154 of spool 46. Once protrusion 156 is released from recesses 154 of spool 46, the physician is able to rotate spool 46
10 bidirectionally in order to adjust a tension of chord 60.

When the physician rotates spool 46 in the first direction, as indicated by the arrow in Fig. 3, chord 60 is pulled tight and leaflet 14 is drawn toward adjustment mechanism 40 and toward anterior leaflet 12 of mitral valve 8.

Fig. 4 shows apparatus 20 following the removal of tool 300 of Fig. 3. As shown,
15 portions 60a and 60b are pulled tight so as to resemble a native chord. The pulling tight of portions 60a and 60b applies tension to leaflet 14. Since loops 66a, 66b, and 66c are sutured via sutures 68a, 68b, and 68c to respective locations along leaflet 14, the tension applied to chord 60 is distributed to the plurality of locations on leaflet 14. Thus, loops 66 replace the need for implanting and adjusting a plurality of elongate artificial chords
20 which would otherwise be coupled to the respective locations along leaflet 14. By providing loops 66, tension is applied over a greater portion of leaflet 14 using a single primary artificial chord 60. Following the removal of tool 300, depressible portion 128 is no longer depressed by tool 300, and protrusion 156 returns within a recess 154 of spool 46 so as to lock spool 46 in place and restriction rotation thereof in either direction.

25 For some applications of the present invention, a guidewire (not shown) remains coupled to housing 42 in order to facilitate further adjustment of chord 60 subsequently to the initial adjusting of chord 60 by tool 300.

Reference is now made to Fig. 5, which is a schematic illustration of apparatus
220 comprising an implant 132 for indirectly coupling a first primary chord 160 to leaflet
30 14 and a second primary chord 162 to leaflet 12, in accordance with some applications of the present invention. Respective distal portions of chords 160 and 162 are coupled to spool 46 by being looped through, welded to, or otherwise coupled to spool 46. Spool

assembly 240 and adjustment mechanism 40 are as described hereinabove. One or more (e.g., 2, as shown) secondary chords, or loops 168a and 168b are coupled to primary chord 162 via a first coupling 166 (e.g., a knot), and one or more (e.g., 2, as shown) secondary chords, or loops 168c and 168d are coupled to primary chord 160 via a second
5 coupling 164 (e.g., a knot).

As described hereinabove, the operating physician indirectly couples chord 162 to leaflet 12 by (a) looping respective sutures 170a and 170b through loops 168a and 168b, (b) suturing sutures 170a and 170b to leaflet 12 at respective locations, (c) creating knots 172a and 172b at the respective locations, and (d) clipping excess portions of sutures 170a
10 and 170b. As described hereinabove, the operating physician indirectly couples chord 160 leaflet 14 by (a) looping respective sutures 170c and 170d through loops 168c and 168d, (b) suturing sutures 170c and 170d to leaflet 14 at respective locations, (c) creating knots 172c and 172d at the respective locations, and (d) clipping excess portions of sutures 170c and 170d.

15 Following the indirect coupling of chords 160 and 162 to leaflets 14 and 12, respectively, adjustment mechanism 40 is rotated, as described hereinabove, and chords 160 and 162 are pulled tight in order to draw leaflets 14 and 12 toward each other and to pull leaflets 14 and 12 toward adjustment mechanism 40.

The scope of the present invention includes the indirect coupling of both primary
20 chords 160 and 162 to only one of leaflets 12 or 14, via loops 168a-d. The scope of the present invention includes the use of any number of primary chords coupled to adjustment mechanism 40.

It is to be noted that the scope of the present invention include the use of only one primary chord in apparatus 220. That is, for such applications, chords 160 and 162 define
25 portions of the primary chord which extend from adjustment mechanism 40.

Reference is now made to Figs. 6A-C, which are schematic illustrations of apparatus 400 comprising spool assembly 240 and portions 60a and 60b of a primary chord that are sutured to leaflets 12 and 14, in accordance with some applications of the present invention. As shown in Fig. 6A, portions 60a and 60b of the primary chord
30 extend from adjustment mechanism 40 of spool assembly 240. The proximal free ends of each portion 60a and 60b (i.e., the proximal portion) of the primary chord are coupled to suture needles 402a and 402b, respectively. As described herein above, the primary chord

is looped through adjustment mechanism 40. For other applications, portions 60a and 60b comprise independent portions which are coupled to (e.g., fixedly coupled to) a portion of adjustment mechanism 40.

In Fig. 6B, the physician sutures portions 60a and 60b to leaflets 12 and 14 from
5 ventricular surfaces of leaflets 12 and 14. That is, needle 402a punctures leaflet 12 from a ventricular surface thereof in order to pass a proximal portion of portion 60a through leaflet 12, and needle 402b punctures leaflet 14 from a ventricular surface thereof in order to pass a proximal portion of portion 60b through leaflet 14. Portions 60a and 60b are then sutured a few times through both leaflets 12 and 14 to create a plurality of stitches
10 404, or a bridge between leaflets 12 and 14, e.g., as an Alfieri stitch, or edge-to-edge repair.

In Fig. 6C, portions 60a and 60b of primary chord 60 are then adjusted as described hereinabove. The adjusting pulls further together the middle portion of mitral valve 8, as shown in the atrial view of the heart. The firm coupling of leaflets 12 and 14
15 prevents prolapsing of leaflets 12 and 14, facilitates coaptation of leaflets 12 and 14, and creates orifices 462 and 464 in mitral valve 8 so as to facilitate blood flow from the atrium to the ventricle. Additionally, the adjusting of portions 60a and 60b of the primary chord draws downward leaflets 12 and 14 and adjusts the primary chord such that it functions as an artificial chorda tendinea.

Reference is now made to Figs. 6A-C. It is to be noted that the scope of the
20 present invention includes the use of only one of portions 60a and 60b. That is, only one chord extends from adjustment mechanism 40 and is sutured to both leaflets 12 and 14.

For some applications of the present invention, apparatus 20, 220, and 400 are used to treat an atrioventricular valve other than the mitral valve, i.e., the tricuspid valve.
25 For these applications, apparatus 20, 220, and 400 described hereinabove as being placed in the left ventricle, are instead placed in the right ventricle.

Reference is now made to Figs. 1-5 and 6A-C. It is to be noted that following implantation and adjustment of the primary chords, as described herein, the patient's incisions are closed. At a later stage following implantation, the primary chords may be
30 further adjusted by reopening the incision and recoupling tool 300 to adjustment mechanism 40 in order to tighten or loosen chords 60, 160, or 162, or portions 60a and 60b of the primary chord.

Reference is again made to Figs. 1-5 and 6A-C. It is to be noted that the scope of the present invention includes the coupling of any number of primary chords 60 to adjustment mechanism 40.

Reference is yet again made to Figs. 1-5 and 6A-C. It is to be noted that the scope
5 of the present invention includes the coupling of any loops 66 to cardiac tissue using clips, tissue anchors, or any other suitable fastener.

Reference is still yet again made to Figs. 1-5 and 6A-C. The scope of the present invention includes use of apparatus 20, 220, and 400 to effect remodeling of the walls of heart 2. For such an application, assembly 240 may be implanted intraventricularly or
10 externally to the heart.

For some applications, techniques described herein are practiced in combination with techniques described in one or more of the references cited in the Background section of the present patent application.

Additionally, the scope of the present invention includes applications described in
15 the following applications, which are incorporated herein by reference. In an application, techniques and apparatus described in one or more of the following applications are combined with techniques and apparatus described herein:

- PCT Publication WO 06/097931 to Gross et al., entitled, "Mitral Valve treatment techniques," filed March 15, 2006;
- 20 • US Provisional Patent Application 60/873,075 to Gross et al., entitled, "Mitral valve closure techniques," filed December 5, 2006;
- US Provisional Patent Application 60/902,146 to Gross et al., entitled, "Mitral valve closure techniques," filed on February 16, 2007;
- US Provisional Patent Application 61/001,013 to Gross et al., entitled,
25 "Segmented ring placement," filed October 29, 2007;
- PCT Patent Application PCT/IL07/001503 to Gross et al., entitled, "Segmented ring placement," filed on December 5, 2007;
- US Patent Application 11/950,930 to Gross et al., entitled, "Segmented ring placement," filed on December 5, 2007, which published as US
30 Patent Application Publication 2008/0262609;

- US Provisional Patent Application 61/132,295 to Gross et al., entitled, "Annuloplasty devices and methods of delivery therefor," filed on June 16, 2008;
- 5 • US Patent Application 12/341,960 to Cabiri, entitled, "Adjustable partial annuloplasty ring and mechanism therefor," filed on December 22, 2008, which published as 2010/0161047;
- US Provisional Patent Application 61/207,908 to Miller et al., entitled, "Actively-engageable movement-restriction mechanism for use with an annuloplasty structure," filed on February 17, 2009;
- 10 • US Patent Application 12/435,291 to Maisano et al., entitled, "Adjustable repair chords and spool mechanism therefor," filed on May 4, 2009, which published as 2010/0161041;
- US Patent Application 12/437,103 to Zipory et al., entitled, "Annuloplasty ring with intra-ring anchoring," filed on May 7, 2009, which published as 2010/0286767;
- 15 • PCT Patent Application PCT/IL2009/000593 to Gross et al., entitled, "Annuloplasty devices and methods of delivery therefor," filed on June 15, 2009, which published as WO 10/004546;
- US Patent Application 12/548,991 to Maisano et al., entitled, "Implantation of repair chords in the heart," filed on August 27, 2009, which published as 2010/0161042;
- 20 • US Patent Application 12/608,316 to Miller et al., entitled, "Tissue anchor for annuloplasty ring," filed on October 29, 2009, which published as 2011/0106247;
- 25 • PCT Patent Application PCT/IL2009/001209 to Cabiri et al., entitled, "Adjustable annuloplasty devices and mechanisms therefor," filed on December 22, 2009, which published as WO 10/073246;
- US Patent Application 12/689,635 to Zipory et al., entitled, "Over-wire rotation tool," filed on January 19, 2010, which published as 2010/0280604;
- 30

- US Patent Application 12/689,693 to Hammer et al., entitled, "Application Deployment techniques for annuloplasty ring," filed on January 19, 2010, which published as 2010/0280605;
- 5 • US Patent Application 12/706,868 to Miller et al., entitled, "Actively-engageable movement-restriction mechanism for use with an annuloplasty structure," filed on February 17, 2010, which published as 2010/0211166; and/or
- 10 • US Patent Application 12/795,026 to Miller et al., entitled, "Apparatus for guide-wire based advancement of a rotation assembly," filed on June 7, 2010, which published as 2011/0106245.

It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove, as well as variations and modifications thereof that are not in the prior art, which would occur to persons skilled in the art upon reading the
15 foregoing description.

CLAIMS

1. Apparatus, comprising:
an artificial-chordeae-tendineae-adjustment mechanism;
at least one primary artificial chordea tendinea coupled at a distal portion thereof
5 to the artificial-chordeae-tendineae-adjustment mechanism, a degree of tension of the at
least one primary artificial chordea tendinea being adjustable by the artificial-chordeae-
tendineae-adjustment mechanism; and
one or more loops coupled at a proximal portion of the at least one primary
artificial chordea tendinea, the one or more loops being configured to facilitate suturing of
10 the one or more loops to respective portions of a leaflet of an atrioventricular valve of a
patient.
2. The apparatus according to claim 1, further comprising one or more sutures
configured to suture the one or more loops to the respective portions of the leaflet.
3. The apparatus according to claim 1, wherein the at least one primary artificial
15 chordea tendinea is shaped as a continuous loop.
4. The apparatus according to claim 1, wherein:
the one or more loops comprises a plurality of loops,
the apparatus further comprises a plurality of sutures, and
each loop of the plurality of loops is configured to facilitate suturing of each suture
20 of the plurality of sutures to a respective portion of the leaflet.
5. The apparatus according to claim 1, wherein the distal portion of the at least one
primary artificial chordea tendinea is coupled to the artificial-chordeae-tendineae-
adjustment mechanism by being looped through a portion of the artificial-chordeae-
tendineae-adjustment mechanism.
- 25 6. The apparatus according to any one of claims 1-5, further comprising a coupling
element configured to couple the one or more loops to the proximal portion of the at least
one primary artificial chordea tendinea.
7. The apparatus according to claim 6, wherein the coupling element is shaped so as
to define a lumen, and wherein the proximal portion of the at least one primary artificial
30 chordea tendinea and the one or more loops are looped through the lumen of the coupling
element.

8. The apparatus according to any one of claims 1-5, wherein:
the artificial-chordeae-tendineae-adjustment mechanism comprises a spool,
the at least one primary artificial chordea tendinea is coupled to the spool; and
the spool is bidirectionally rotatable to adjust the degree of tension of the at least
5 one primary artificial chordea tendinea.
9. The apparatus according to claim 8, wherein the at least one primary artificial
chordea tendinea is configured to be wound around spool during the rotation of the spool
in a first rotational direction.
10. The apparatus according to claim 8, further comprising a locking mechanism
10 displaceable with respect to the spool so as to:
release the spool during rotation of the spool, and
lock in place the spool following rotation of the spool.
11. The apparatus according to claim 8, wherein the distal portion of the at least one
primary artificial chordea tendinea is looped through a portion of the spool.
- 15 12. The apparatus according to claim 11, wherein the distal portion of the at least one
primary artificial chordea tendinea is wound around a portion of the spool, and wherein
the distal portion of the at least one primary artificial chordea tendinea is configured to be
unwound from around the portion of the spool following the suturing of the one or more
loops to the respective portions of the leaflet.
- 20 13. The apparatus according to any one of claims 1-5, wherein:
first and second portions of the at least one primary artificial chordea tendinea
extend from the artificial-chordeae-tendineae-adjustment mechanism,
a portion between the first and second portions of the at least one primary artificial
chordea tendinea defines the distal portion of the at least one primary artificial chordea
25 tendinea,
the first and second portions of the at least one primary artificial chordea tendinea
each have free ends which define the proximal portion of the at least one primary artificial
chordea tendinea,
the one or more loops comprise one or more first loops and one or more second
30 loops,
the free end of the first portion of the at least one primary artificial chordea
tendinea is coupled to the one or more first loops, and

the free end of the second portion of the at least one primary artificial chordae tendinea is coupled to the one or more second loops.

14. The apparatus according to claim 13, wherein the one or more first loops facilitate suturing of the one or more first loops to a first leaflet of the atrioventricular valve, and
5 wherein the one or more second loops facilitate suturing of the one or more second loops to the first leaflet of the atrioventricular valve.

15. The apparatus according to claim 13, wherein the one or more first loops facilitate suturing of the one or more first loops to a first leaflet of the atrioventricular valve, and
10 wherein the one or more second loops facilitate suturing of the one or more second loops to a second leaflet of the atrioventricular valve.

16. The apparatus according to claim 15, wherein the artificial-chordeae-tendineae-adjustment mechanism is configured to adjust a distance between the first and second leaflets by adjusting the first and second portions of the at least one primary artificial chordae tendinea.

15 17. Apparatus, comprising:
a longitudinal-chord-adjustment mechanism;
at least one primary longitudinal chord coupled at a distal portion thereof to the longitudinal-chord-adjustment mechanism, a degree of tension of the at least one primary longitudinal chord being adjustable by the longitudinal-chord-adjustment mechanism; and
20 one or more loops coupled at a proximal portion of the at least one primary longitudinal chord, the one or more loops being configured to facilitate coupling of the one or more loops to respective portions of a cardiac tissue of a patient.

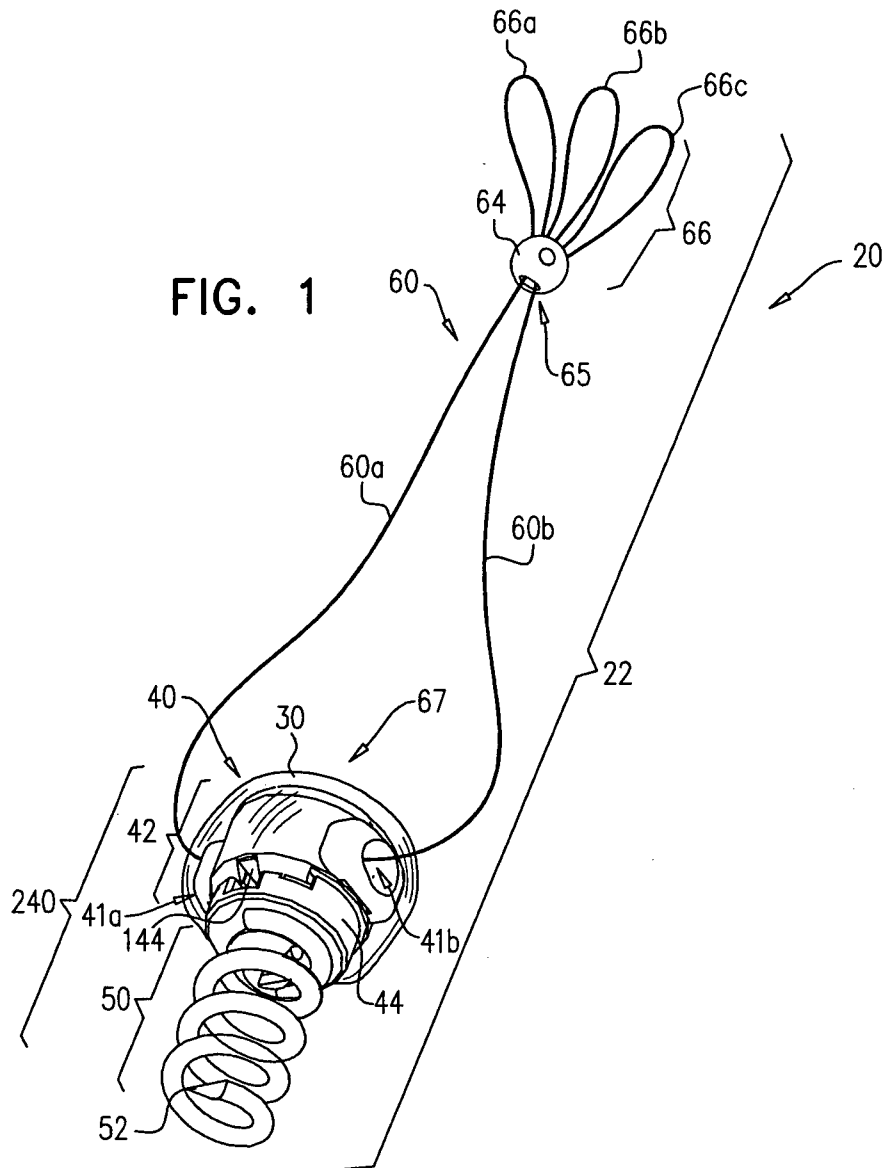


FIG. 3

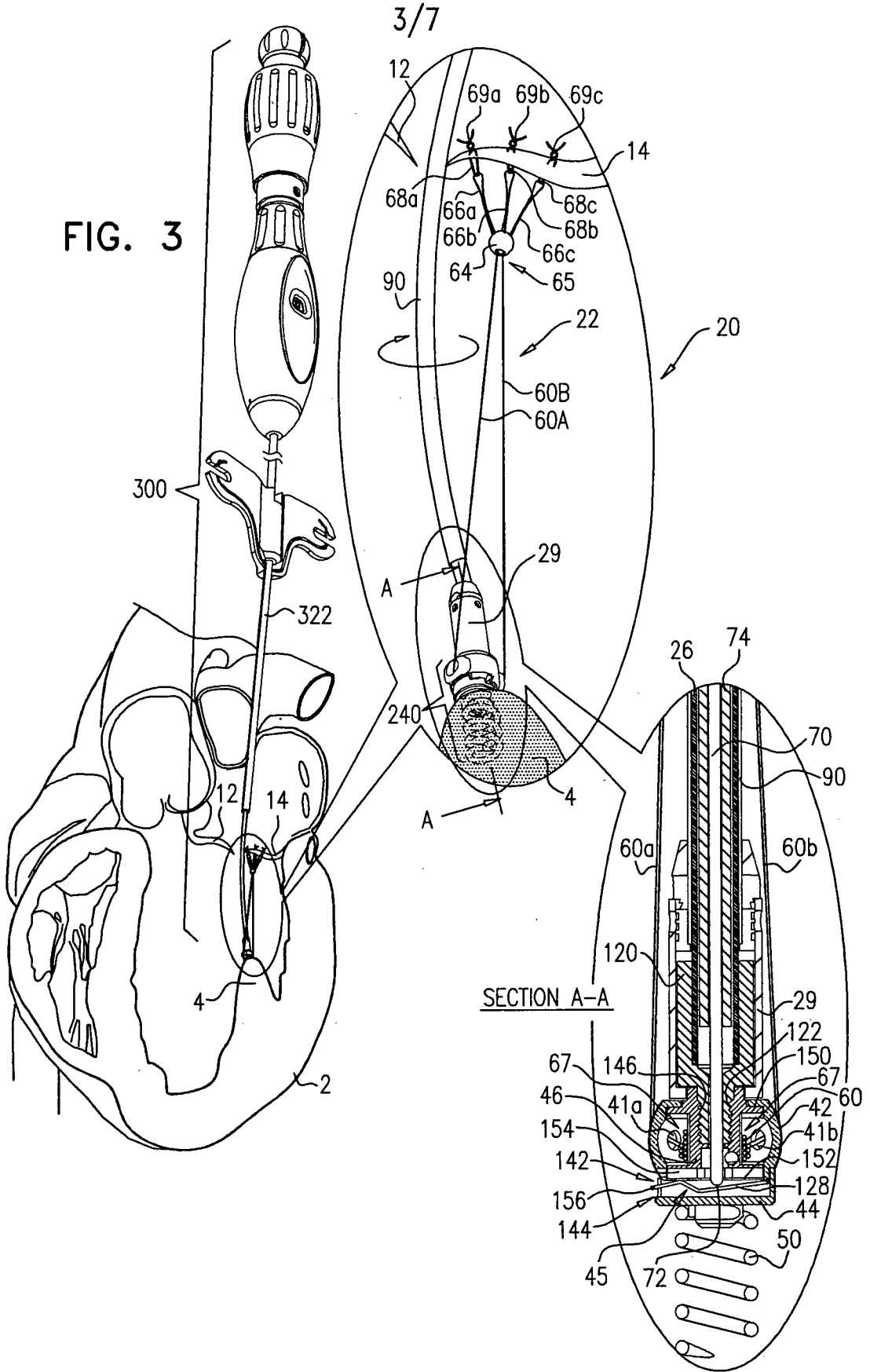


FIG. 4

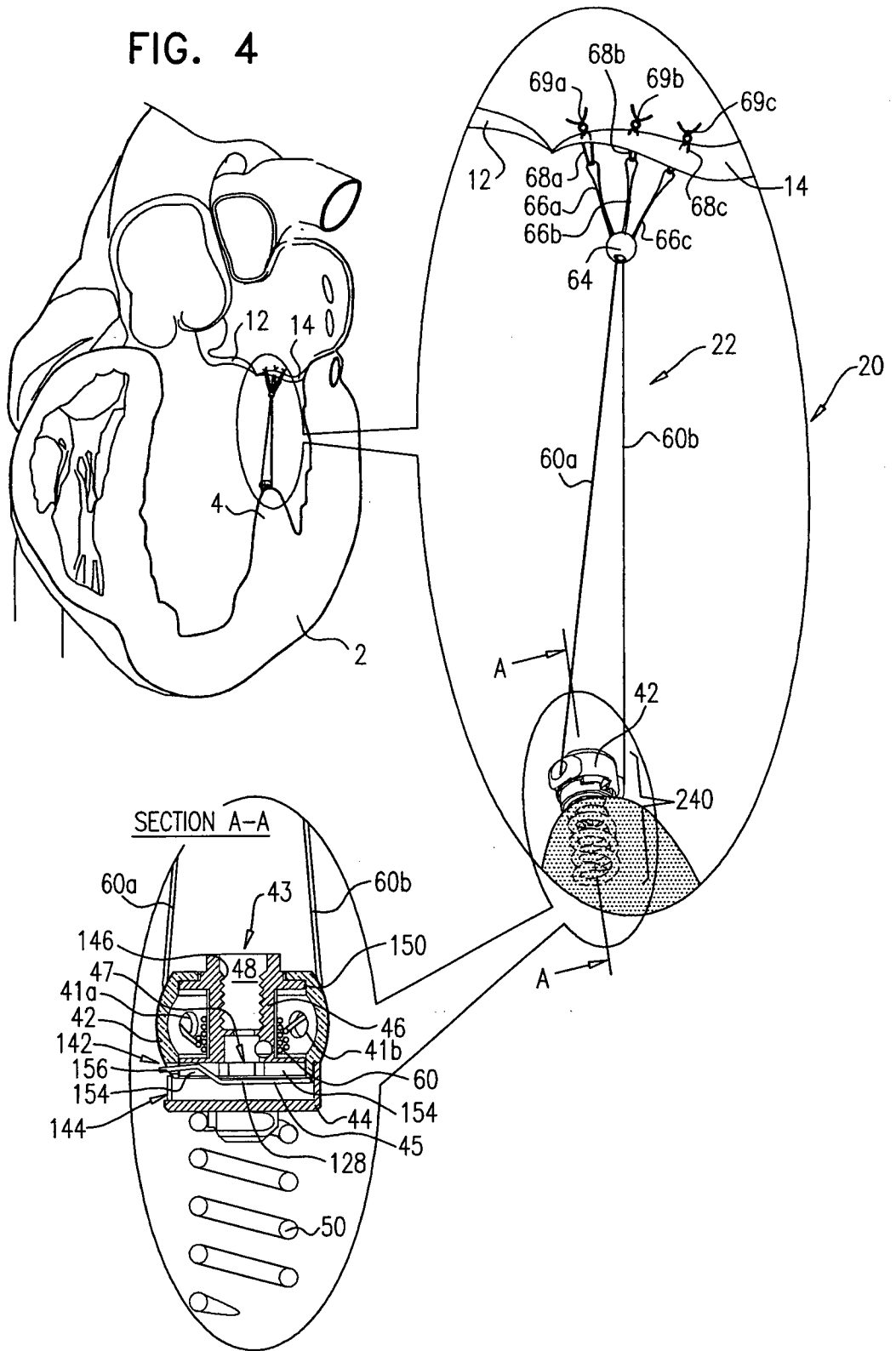


FIG. 5

