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Apparatus and method for minimally invasive suturing

Abstract

An apparatus and method for minimally invasive suturing is disclosed. A suturing device for minimally invasive suturing includes proximal section having a proximal end, a distal end, and a longitudinal axis therebetween; a suture head assembly extending from the distal end of the proximal section; a suturing needle having a pointed end and a blunt end, the suturing needle capable of rotating about an axis approximately perpendicular to a longitudinal axis of the proximal section, wherein the pointed end of the suturing needle is positioned within the suture head assembly prior to and after rotation of the suturing needle; and an actuator extending from the proximal end of the proximal section to actuate a drive mechanism having a needle driver for engaging and rotating the suturing needle.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This patent application is a continuation of and claims the benefit of priority to U.S. patent application Ser. No. 16/384,640, filed Apr. 15, 2019, which in turn is a continuation of and claims the benefit of priority to U.S. patent application Ser. No. 15/720,853, filed Sep. 29, 2017, which in turn claims the benefit of priority to U.S. Provisional Application Ser. No. 62/463,724, filed Feb. 26, 2017. This patent application is a continuation of and claims the benefit of priority to U.S. patent application Ser. No. 16/384,640, filed Apr. 15, 2019, which in turn is a continuation of and claims the benefit of priority to International Application No. PCT/US2018/018627, filed Feb. 19, 2018, which in turn claims the benefit of priority to U.S. patent application Ser. No. 15/720,853, filed Sep. 29, 2017, and U.S. Provisional Application Ser. No. 62/463,724, filed Feb. 26, 2017. Each of the aforementioned patent applications is incorporated by reference herein in its entirety for any purpose whatsoever.

FIELD
(1) The embodiments disclosed herein relate to a medical device for suturing tissue, and more particularly to a device for the manipulation and control of a suturing needle during minimally invasive suturing, methods for making such a device and methods for using such a device for suturing tissue.
BACKGROUND
(2) Minimally invasive surgery (MIS) has allowed physicians to carry out many surgical procedures with less pain and disability than conventional, open surgery. Unlike conventional open surgery, where the surgical site is readily accessible through a large incision, enabling the surgeon to easily visualize and manipulate both tissue and instruments, MIS requires the surgeon to operate remotely by inserting and manipulating instruments through small punctures (“keyhole surgery”) or through natural orifices, including for example the vagina, the esophagus, or the anus.
(3) In MIS, a small puncture is typically made in the body. Medical instruments are then inserted through a cannula. A cannula has a small inside diameter, typically 5-10 millimeters (mm), and sometimes up to 20 millimeters (mm) or more. A number of such cannulas may be inserted into the body for any given operation. Minimally invasive surgical instruments are necessarily smaller, and are also generally longer and therefore are more difficult to manipulate with precision.
(4) Perhaps the most problematic surgical task in MIS is suturing. Suturing requires coordinated manipulation with both hands of small needles and sutures that are difficult to visualize (particularly when only indirect, two-dimensional video imaging is available) as well as the several

instruments (including needle-drivers and pick-up forceps) ordinarily used to suture by hand. In an environment characterized by limited space, limited visualization, and limited mobility, many surgeons find minimally invasive suturing by hand an extremely difficult, often virtually impossible, surgical task.

(5) In the preferred method of suturing by hand, a grasping forceps (“needle driver”) is held by the surgeon and is used to grip a curved needle near the needle's tail. Pronation of the surgeon's wrist drives the needle into the tissue. When the point of the curved needle emerges from the tissue, the surgeon releases the needle from the grip of the needle driver and grasps the point with another forceps (“pick-ups”). The surgeon then pulls the curved needle by the needle point, preferably in a circular path following the arc of the needle's curvature to follow the most atraumatic path through the tissue, until the entire length of the needle has exited the tissue. Each time a stitch is placed, the curved needle is thus driven around in a complete circular arc. Individual (interrupted) stitches are placed by tying off the suture following placement of each stitch. Running (continuous) stitches are placed by repeatedly driving the curved needle in a complete circular arc repeatedly until the desired length of suture and number of stitches has been placed. In order to place additional interrupted or continuous stitches, the surgeon must let go of the point of the needle and re-grasp the needle near the needle's tail.

(6) In the manual suturing technique described above, the direct handling of the needle can result in accidental needle pricks through a surgeon or nurse's gloves, posing a potential risk of infection for the surgeon, nurse, staff, and patient, or cause the needle to become contaminated with pathogenic bacteria that can cause onset of infection at the site of the sutures. There is also a risk of the needle penetrating internal organs or vessels and causing a serious, and often fatal infection.

(7) Various devices for suturing for MIS are described in U.S. Pat. No. 5,643,295 entitled “Methods and Apparatus for Suturing Tissue”; U.S. Pat. No. 5,665,096 entitled “Needle Driving Apparatus and Methods of Suturing Tissue”; U.S. Pat. No. 5,665,109 entitled “Methods and Apparatus for Suturing Tissue”; U.S. Pat. No. 5,759,188 entitled “Suturing Instrument with Rotatably Mounted Needle Driver and Catcher”; U.S. Pat. No. 5,860,992 entitled “Endoscopic Suturing Devices and Methods”; U.S. Pat. No. 5,954,733 entitled “Suturing Instrument with Rotatably Mounted Needle Driver and Catcher”; U.S. Pat. No. 6,719,763 entitled “Endoscopic Suturing Device”; and U.S. Pat. No. 6,755,843 entitled “Endoscopic Suturing Device”, all of which are incorporated by reference in their entireties for the teachings therein.

(8) Assignees' U.S. Pat. Nos. 5,437,681, 5,540,705 and 6,923,819 disclose a suturing device with thread management comprising a protective cartridge, suturing needle and needle rotation drive, the disclosures of which are hereby incorporated by reference. The devices described in the above-mentioned patents and patent application comprise a mechanism for driving a protected needle however, the needle is rotated about an axis that is parallel to the axis of the device. In addition, the orientation and size of the suturing device makes it difficult to visualize and cumbersome to use for MIS.

(9) Therefore, there remains a need in the art for a minimally invasive suturing device that is easily manipulated within the small diameter of the cannula; functions in an environment characterized by limited space, limited visualization, and limited mobility; mimics the preferred method of suturing used by surgeons; permits the surgeon to secure and tie knots quickly and with controlled tension; places continuous stitches; and protects user's from accidental needle sticks during needle handling, as well as internal organs and vessels, from inadvertent needle-pricks.

SUMMARY

(10) Devices and methods for minimally invasive suturing of tissue internal to a body are disclosed herein.

(11) According to aspects illustrated herein, there is provided a medical device for closing openings internal to a patient's body, which closely emulates or replicates the manual suturing actions carried out by a surgeon. The device offers several advantages over conventional methods used by

surgeons for suturing tissue during minimally invasive surgery in that the device provides a hand-held suturing instrument of relatively simple mechanical construction that requires no external motive source. The presently disclosed embodiments provide relative ease of operation for the surgeon with only one hand.

(12) According to aspects illustrated herein, a suture head assembly may be removably attached to an actuator mechanism of the suturing device. The diameter of the device is small enough to fit into a typical cannula, thus making the device extremely easy to maneuver, as well as suture, during endoscopic or other MIS procedures. Also, the suture head assembly of the device can be laterally articulated to the left of center, to the right of center, up, and down, once inside the cannula, which is ideal for use in the course of endoscopic surgery, including laparoscopy, thoracoscopy and arthroscopy, as well as other less-invasive surgical procedures.

(13) The device of the present disclosed embodiments closely emulates or replicates the manual suturing actions carried out by a surgeon. For example, during manual suturing by hand, the needle is held in forceps and travels in a circular arc with no obstructions anywhere in the interior of the arc. The design of the suturing device of the present disclosed embodiments allows for a lack of obstruction in the center of the arc of the needle during suturing. In other words, there is no hub at the center of the circular arc of the suturing needle. The entire area within the circular arc of the needle is unobstructed. This allows for the user to have better visualization during operation, unlike the present mechanical suturing methods, while maintaining control over needle movement.

(14) In accordance with one embodiment a “locomotive-type” drive mechanism is provided for advancing the needle about a path of travel. This embodiment of a drive enables the small diameter of the device and affords better visualization during operation because of the lack of a hub. There are many benefits afforded by the design of the suturing device of the presently disclosed embodiments, including, but not limited to, more tissue being able to fit into the device, thus enabling a bigger bite of tissue and a more secure suture; the device can be used to ligate, that is, place a loop of suture around a blood vessel, duct, or other tubular structure; and the device can be inserted further into smaller incisions/openings (one side of the aperture can be inserted deeply, for example).

(15) A benefit provided by the suturing device of the presently disclosed embodiments is that the device enables maneuvering a suturing material through a tissue incision in a manner substantially similar to the way a surgeon would do so by hand. In particular, the suturing device first pushes a suturing needle from the tail of the needle and drives the point of the needle through the tissue. The device then picks up the point of the needle that passed through the tissue, and pulls the remainder of the suturing needle and the suture attached to the suturing needle through the tissue. The suturing needle thus consistently follows the arc of the needle's own curve, which is the preferred method of suturing, in the most atraumatic way of passing a needle through tissue. A benefit provided by the suturing device of the presently disclosed embodiments is the ability of the suturing needle to pull the suturing thread entirely through the tissue segments being closed, following each stitch. When using the suturing device of the presently disclosed embodiments, no ancillary instruments or tools such as needle holders, pick-up forceps or the like are needed to complete the stitch. A forceps can be used to tighten the knots.

(16) According to aspects illustrated herein, there is provided a suturing device that includes a suturing needle that is protected by a housing, the suturing needle is not exposed to or handled directly by the user, thereby preventing inadvertent needle sticks. The configuration of the suturing device of the presently disclosed embodiments also protects against inadvertent penetration of internal organs or vessels by the needle, since the housing acts as a shield between the organs and the needle.

(17) The suturing device of the presently disclosed embodiments is useful for suturing tissue internal to a body. An embodiment of the device includes an elongated barrel having a proximal end, a distal end, and a longitudinal axis therebetween; a suture head assembly extending from the

distal end of the elongated barrel; a suturing needle having a pointed end and a blunt end, the suturing needle capable of rotating about an axis approximately perpendicular to a longitudinal axis of the elongated barrel, wherein the pointed end of the suturing needle is positioned within the suture head assembly prior to and after rotation of the suturing needle; and an actuator extending from the proximal end of the elongated barrel to actuate a drive mechanism having a needle driver for engaging and rotating the suturing needle.

(18) According to aspects illustrated herein, there is provided a method for suturing tissue during minimally invasive surgery that includes: (a) engaging a cartridge to a suture head assembly at a distal end of a suturing device, the cartridge having a protective housing and a suturing needle with a pointed end and a blunt end; (b) introducing the distal end of the suturing device into a body cavity; (c) positioning an opening in the cartridge to span a plurality of separated tissue segments or a single tissue segment; (d) activating an actuator coupled to a drive mechanism that engages the suturing needle to cause rotational movement of the suturing needle about an axis approximately perpendicular to a longitudinal axis of the suturing device and advance the suturing needle through the plurality of separated tissue segments or the single tissue segment; (e) pulling a suturing material attached to the suturing needle through the plurality of separated tissue segments or the single tissue segment forming a stitch; and repeating steps (c) through (e) to cause a plurality of stitches to be placed through the separated tissue segments or the single tissue segment.

(19) According to aspects illustrated herein, there is provided a method for suturing tissue during minimally invasive surgery that includes: (a) engaging a suturing needle with a pointed end and a blunt end to a suture head assembly at a distal end of a suturing device, the suture head assembly includes a curved track, whereby the suturing needle follows a curved path along the track during rotation of the suturing needle, and a latch that provides a protective housing for the suturing needle; (b) introducing the distal end of the suturing device into a body cavity; (c) positioning an opening in the needle holder assembly to span a plurality of separated tissue segments or a single tissue segment; (d) activating an actuator coupled to a drive mechanism that engages the suturing needle to cause rotational movement of the suturing needle about an axis approximately perpendicular to a longitudinal axis of the suturing device and advance the suturing needle through the plurality of separated tissue segments or the single tissue segment; (e) pulling a suturing material attached to the suturing needle through the plurality of separated tissue segments or a single tissue segment forming a stitch; and repeating steps (c) through (e) to cause a plurality of stitches to be placed through the separated tissue segments or a single tissue segment.

(20) In further accordance with the disclosure, a suturing device is provided that includes an arced needle having a leading end, a second end, and a length of suture, a housing defining a track therein that receives the needle and defines a path for the needle to traverse, a needle driver operable to rotate the needle along the circular path, and a needle position detection circuit. The needle position detection circuit is preferably configured and arranged to indicate when a portion of the needle is positioned at a predetermined location along the circular needle path.

(21) In various implementations, the needle position detection circuit is configured to be operably coupled to an electrical power supply. If desired, the needle can be configured to close an electrical circuit when it is present at the predetermined location, thereby revealing the location of the needle. For example, electrical current can flow through or along a portion of the needle in order to close the electrical circuit. In some implementations, the needle can be configured to actuate a mechanical switch that closes the electrical circuit.

(22) In other implementations, the needle can open an electrical circuit when the needle is present at the predetermined location in order for the position of the needle to be detected. For example, the needle can actuate a mechanical switch that opens the electrical circuit.

(23) In some implementations, the needle position detection circuit can be configured to be electrically coupled to an anti-rotate spring of the suturing device of the suturing device, to a drive pawl of the suturing device, or to another portion of the suturing device. For example, the needle

position detection circuit is configured to be electrically coupled to a needle track of the suturing device that defines the path for the needle to traverse.
(24) In some embodiments, the needle position detection circuit can be configured to activate an indicator when the needle is positioned in the predetermined location. The indicator can include, for example, at least one light emitting diode, or other lighting device, vibratory device (e.g., piezoelectric element), or sound emitting device. In further implementations, the circuit can be operably coupled to a computing device or wireless device to transmit needle position information to a computing device so that the needle position can be indicated on a screen of a user device, operating room monitor, or the like.
(25) In some implementations, the at least one light emitting diode can be located in or on a handle of the suturing device. If desired, the indicator can include a plurality of light emitting diodes. For example, the plurality of light emitting diodes can be arranged in an arc shape and are spaced to indicate the needle location in the suturing device.
(26) According to aspects illustrated herein, there is provided a method for suturing tissue during minimally invasive surgery that includes inserting a distal end of a suturing device having a suturing needle with a pointed end into a body; positioning the suturing needle to span a plurality of separated tissue segments; activating an actuator a first time causing the pointed end of the suturing needle to extend beyond a protective housing of a cartridge to engage the plurality of separated tissue segments; and activating the actuator a second time to cause the suturing needle to complete a revolution and pull a suture extending from the suturing needle through the plurality of separated tissue segments to form a stitch.
(27) In addition to the advantages discussed above, the suturing device of the presently disclosed embodiments is relatively simple and cost efficient to manufacture. Therefore, the suturing device should find widespread suturing applications that include single stitches or continuous stitches, e.g. spiral, mattress, purse string, etc., that are required to close tissue incisions, attach grafts, or the like.
(28) These and other advantages of the presently disclosed embodiments are illustrated through the embodiments described hereinafter. The presently disclosed embodiments accordingly comprise the features of construction, combination of elements and arrangement of parts that will be exemplified in the following detailed description.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) The presently disclosed embodiments will be further explained with reference to the attached drawings, wherein like structures are referred to by like numerals throughout the several views. The drawings shown are not necessarily to scale, with emphasis instead generally being placed upon illustrating the principles of the presently disclosed embodiments.
(2) FIG. **1** is a perspective view of a suturing device of the presently disclosed embodiments.
(3) FIGS. **2**A and **2**B are views of the suture head assembly of the suturing device of FIG. **1**. FIG. **2**A is a perspective assembly view of the suture head. FIG. **2**B is a cutaway perspective view of the suture head.
(4) FIGS. **3**A and **3**B are segmented assembly views of the suture head assembly of FIG. **2**.
(5) FIGS. **4**A and **4**B are cutaway segmental views of the suture head assembly showing interaction points of a suturing needle with a portion of the drive mechanism. FIG. **4**A shows the position of the suturing needle and drive mechanism in a “home” position prior to use or after a complete full cycle. FIG. **4**B shows the position of the suturing needle and drive mechanism after one full actuation of the handle, where the suturing needle is in a “rotation” position.
(6) FIGS. **5**A and **5**B are expanded views of the working end of the suture head assembly with a

suturing needle in the home position presented in FIG. **5**. FIG. **5**A shows the relationship between the pawl and anti-rotate spring when the suturing needle is in the home position. FIG. **5**B shows a close-up view of the anti-rotate spring.

(7) FIGS. **6**A and **6**B are expanded views of the working end of the suture head assembly during use of the device. FIG. **6**A shows the position of the suturing needle and the pawl immediately after the user squeezes the handle. The user then releases the handle and the pawl returns to the start position (FIG. **6**B) while the suturing needle remains in the rotation position.

(8) FIGS. **7**A and **7**B are expanded views of the pawl in contact with the C-brace while driving the suturing needle presented in FIG. **7**. FIG. **7**A shows a close-up view of the pawl spring loaded with a spring. FIG. **7**B shows a close-up view of the pawl, showing the heel and tip.

(9) FIGS. **8** and **9** are side elevational views of a much larger scale of the internal portions of the drive mechanism located within the handle and elongated barrel. FIG. **8** shows the drive mechanism when the handle is in an open position and FIG. **9** shows the drive mechanism when the handle is in a closed position.

(10) FIGS. **10**-**13** are top and bottom views of the suture head assembly, including cables that provide the connection between the drive mechanism located in the suture head assembly and the elongated barrel when the handle is in the open and closed positions. FIG. **10** shows a top view when the handle is in the open position. FIG. **11** shows a bottom view when the handle is in the open position. FIG. **12** shows a top view when the handle is in the closed position. FIG. **13** shows a bottom view when the handle is in the closed position.

(11) FIG. **14** is a close-up view of the cartridge holder with a tab that locks into a mating groove on the cartridge holder assembly.

(12) FIG. **15** is a view depicting the suturing needle positioned in the track of the cartridge.

(13) FIG. **16** is a view showing the relation between the cartridge holder assembly, cartridge, latch and C-brace.

(14) FIGS. **17**A, **17**B and **17**C show the suture head assembly. FIG. **17**A shows a side view of the suture head assembly. FIG. **17**B is a close-up side view showing the relationship between the lever and latch during attachment and ejection of the needle and cartridge from the cartridge holder assembly. FIG. **17**C shows a top view of the suture head assembly.

(15) FIG. **18** is an expanded view of a curved suturing needle with notches depicted on the surface of the needle.

(16) FIGS. **19**A and **19**B depict two exemplary embodiments of the curved suturing needle.

(17) FIGS. **20**-**23** show different views of the suture head assembly attached to the elongated barrel via a rotation rod. The primary fixation point of the suture head assembly to the elongated barrel is depicted as being at the axis of lateral rotation. FIG. **20** shows a side view of the suture head assembly. FIG. **21** shows a bottom view of the suture head assembly. FIG. **22** shows a bottom view of the suture head assembly articulated to the left. FIG. **23** shows a bottom view of the suture head assembly articulated to the right.

(18) FIGS. **24** and **25** are perspective views of a suturing device. FIG. **24** shows a perspective view of the suturing device with the handles in the open position. FIG. **25** shows a perspective view of the suturing device with the handles in the closed position.

(19) FIG. **26** is a segmented assembly view of the suture head assembly of FIGS. **24** and **25**.

(20) FIGS. **27**A and **27**B are cutaway segmental views of the suture head assembly of FIGS. **24** and **25** showing interaction points of a suturing needle with a portion of the drive mechanism. FIG. **27**A shows the position of the suturing needle and drive mechanism in a “home” position prior to use or after a complete full cycle. FIG. **27**B shows another view of the suturing needle and drive mechanism.

(21) FIG. **28** is a close-up view of the needle holder assembly for the suture head assembly of FIGS. **24** and **25**.

(22) FIG. **29** is a close-up view of the distal end of the suture head assembly of FIGS. **24** and **25**.

(23) FIGS. **30** and **31** show the suture head assembly of FIGS. **24** and **25**. FIG. **30** shows the suture head assembly with the latch in the open position. FIG. **31** shows the suture head assembly with the latch in the closed or locked position.
(24) FIG. **32** is a view of a curved suturing needle with notches on the face of the suturing needle to be used with the suturing device of FIGS. **24** and **25**.
(25) FIG. **33** shows a view of the pawl in contact with the suturing needle for the suturing device of FIGS. **24** and **25**.
(26) FIGS. **34** and **35** show a close-up view of the suture head assembly of FIGS. **24** and **25** and the associated pulleys that move the drive mechanism. FIG. **34** shows a top view of the suture head assembly. FIG. **35** shows a side view of the suture head assembly.
(27) FIGS. **36** and **37** are top views of the suture head assembly and cables that connect the drive mechanism located in the suture head assembly and the elongated barrel when the handle is in the open position for the suture device of FIGS. **24** and **25**. FIG. **36** shows a top view of the front pulley and cable when the handle is in the open position. FIG. **37** shows a top view of the return pulley and cable when the handle is in the open position.
(28) FIG. **38** shows a side elevational view of the suturing device of FIGS. **24** and **25** showing parts of the drive mechanism.
(29) FIG. **39**A shows a top perspective view of a second embodiment of the suture head assembly made in accordance with the teachings of the invention, in which a resilient elongated member moves proximally and distally to actuate movement of the suturing needle about a circular path. FIG. **39**B depicts the suturing head of FIG. **39**A incorporated into a suturing device having a flexible steerable proximal segment.
(30) FIG. **40** shows a sectional view of the drive track of the second embodiment of the suture head assembly, depicting the course of the drive tendon, the drive pawl, and the anti-rotate spring in relation to the suturing needle.
(31) FIG. **41** is a close-up view of the distal end of the drive tendon with attached pawl.
(32) FIG. **42**A is an isolated view of the tendon and pawl engaging a notch in the suturing needle
(33) FIG. **42**B is an isolated view of an exemplary suturing needle that may be used with the second suturing head embodiment, showing a leading notch and a trailing notch on the side of the needle, and an anti-rotate notch on the outer circumference of the needle.
(34) FIG. **43** is a sectional view of the inside structure of the drive track component of the second embodiment of the suture head assembly, without the tendon, pawl, anti-rotate spring and needle present to highlight the engagement and disengagement tracks, including a flat spring in the proximal chamber used to press the pawl against the drive notch of the needle.
(35) FIG. **44** is a perspective view of a portion of the inside structure of the needle track component of the second embodiment of the suture head assembly, showing one of the pawl body guides, and the aperture through which the anti-rotation spring engages the outer circumference of the needle.
(36) FIG. **45** is a top perspective view of the second embodiment of the suture head assembly, showing the placement of the thrust collar over the lateral side of the needle track, enclosing the needle within it.
(37) FIG. **46**A is a sectional view through the upper portion of the second embodiment of the suture head assembly, revealing the cross-section of the pawl as it engages the trailing notch of the needle, and showing the distal ends of both pawl body guides, separating the engagement track from the disengagement track. The relationship of the thrust collar to the needle and needle track is also apparent.
(38) FIG. **46**B is a view of the thrust collar in isolation.
(39) FIG. **47** is a sectional view of the second embodiment of the suture head assembly showing the pawl body positioned against the flat spring, which urges the pawl tip against the side of the needle. In this view, the needle is partially spanning the aperture of the suture head assembly, and the anti-rotate spring is visible as it contacts the outer circumference of the needle.

(40) FIG. **48** is an isolated view of the anti-rotate spring.
(41) FIG. **49** is an isolated view of the flat spring, which presses against the pawl body to urge the pawl tip against the side of the needle.
(42) FIG. **50**A is a sectional view of the second embodiment of the suture head assembly in which the pawl is at the proximal end of the engagement drive track, immediately proximal to the trailing notch of the needle.
(43) FIG. **50**B is a view through section B-B of FIG. **50**A showing the pawl tip pressed against the side of the needle above the notch by a compressed flat spring.
(44) FIG. **50**C is a top view through section C-C of FIG. **50**A showing how the flat spring is deflected, pressing the pawl against the side of the needle.
(45) FIG. **51**A is a sectional view of the second embodiment of the suture head assembly in which the pawl is within the trailing notch of the needle at the proximal end of the engagement drive track.
(46) FIG. **51**B is a view through section B-B of FIG. **51**A showing how the flat spring is relaxed against the pawl when the pawl tip is within the notch of the needle.
(47) FIG. **51**C is a top view through section C-C of FIG. **51**A showing the flat spring in a non-deflected state with the pawl tip advanced within the notch of the needle, now in position to drive the needle forward.
(48) FIG. **52** is a sectional side view of the second embodiment of the suture head assembly, showing the needle in the ‘home’ position, the anti-rotate spring engaging the needle, and the pawl within the trailing notch, in position to drive the needle through a suturing cycle.
(49) FIG. **53** is a sectional side view of the second embodiment of the suture head assembly, showing the needle at the end of the push stroke of the first suturing cycle, the pawl having pushed the needle through the aperture, and ready to disengage from the trailing notch.
(50) FIG. **54** is a sectional side view of the second embodiment of the suture head assembly, showing the pawl being released from the trailing notch into the distal end of the disengagement track.
(51) FIG. **55** is a sectional side view of the second embodiment of the suture head assembly, showing the pawl being pulled by the tendon to the proximal end of the track in the pull stroke of the first suturing cycle.
(52) FIG. **56** is a sectional side view of the second embodiment of the suture head assembly, showing the pawl approaching the proximal chamber where the proximal ends of the engagement and disengagement tracks merge. The distal end of the tendon has been deflected away from the leading notch of the needle.
(53) FIG. **57** is a sectional side view of the second embodiment of the suture head assembly, showing the pawl being released into the leading notch of the needle by spring force from the distal tendon that had been deflected as shown in FIG. **56**.
(54) FIG. **58** is a sectional side view of the second embodiment of the suture head assembly, showing the push stroke of the second suturing cycle, in which the pointed end of the needle is being advanced to the ‘home’ position by the pawl.
(55) FIG. **59** is a sectional side view of the second embodiment of the suture head assembly, showing the push stroke of the second suturing cycle having been completed, the pawl being urged into the distal end of the disengagement track by the spring force of the distal tendon, and the trailing notch in proper alignment with the proximal chamber.
(56) FIG. **60** is a sectional side view of the second embodiment of the suture head assembly, showing the pull stroke of the second suturing cycle, bringing the pawl back to the proximal end of the disengagement track to be positioned to re-initiate the suturing cycle. Backward rotation of the needle is prevented in this stroke by the anti-rotate spring engaging the anti-rotate notch of the needle.
(57) FIGS. **61**-**71**B describe a further embodiment of a device made in accordance with the

invention.
(58) FIGS. **72-85** describe still a further embodiment of a device made in accordance with the invention.
(59) FIGS. **86-93** describe embodiments of a suturing device having a needle position indicator.
(60) While the above-identified drawings set forth presently disclosed embodiments, other embodiments are also contemplated, as noted in the discussion. This disclosure presents illustrative embodiments by way of representation and not limitation. Numerous other modifications and embodiments can be devised by those skilled in the art which fall within the scope and spirit of the principles of the presently disclosed embodiments.

DETAILED DESCRIPTION

(61) The suturing device of the presently disclosed embodiments is shown generally at **50** in FIG. **1**. Referring to FIG. **1**, the suturing device **50** can be used to produce a continuous or interrupted stitch or suture so as to enable closure of openings internal to a patient's body. The suturing device **50** can be utilized to suture any type of anatomical tissue in any type of anatomical cavity; and, accordingly, while the device **50** is described hereinafter for use with a cannula in endoscopic procedures, such as laparoscopy, the device **50** can be used in open surgery and with catheters and other small and large diameter tubular or hollow, cylindrical members providing access to small cavities, such as veins and arteries, as well as large cavities, such as the abdomen.
(62) In an embodiment suturing device **50** includes an actuator mechanism shown generally at **52** which comprises an elongated barrel **54** and a handle **60** that extends from the undersides at a proximal end of the elongated barrel **54**. A suture head assembly **56** is attached to the distal end of the elongated barrel **54**. In an embodiment, the suture head assembly **56** is removably attached to the distal end of the elongated barrel **54**. The length of the suture head assembly **56** can range from about 20 mm to about 100 mm. In an embodiment, the length of the suture head assembly **56** is about 50 mm. The length of the elongated barrel **54** can range from about 50 mm to about 400 mm. Those skilled in the art will recognize that the elongated barrel **54** can be made shorter or longer depending on the intended use of the device **50**. In an embodiment, the elongated barrel **54** is about 300 mm. In an embodiment, the elongated barrel **54** is about 350 mm. An articulation lever **66**, just distal to the top of the handle **60** is pushed or pulled to cause the suture head assembly **56** to rotate. Moving the articulation lever **66** clockwise, moves the suture head assembly **56** to the right and moving the articulation lever **66** counterclockwise, moves the suture head assembly **56** to the left. The articulation lever **66** can also be moved to articulate the suture head assembly **56** up and down. The suture head assembly **56** is locked in place with a locking lever **64** located on an underside of the device **50**, below the articulation lever **66**. The suture head assembly **56** may be articulated, and the elongated barrel **54** may be any length appropriate for the intended clinical application of the device **50**. The diameter of the device **50** can range from about 3 mm to about 20 mm. In an embodiment, the diameter of the device **50** is about 12 mm. In an embodiment, the diameter of the device **50** is about 3 mm. A flush port **62** is located on the side of the elongated barrel **54** in order to provide a port of entry for cleaning fluids or suction such that the device **50** can be cleaned prior to or after use.
(63) The handle **60** is a grip that is squeezed in order to actuate the suturing device **50**. The suturing device **50** is actuated by the actuator mechanism **52** coupled to a drive mechanism **70**. The actuator mechanism **52** of the suturing device **50** may comprise a triggering mechanism that is known in the art, such as for example, the triggering mechanisms disclosed in U.S. Pat. Nos. 6,053,908 and 5,344,061, both of which are hereby incorporated by reference. Alternatively, the actuator mechanism can be either a manually operable button or switch, or a mechanically operable by an automated electrical or a fuel driven device, such as for example, an electrical, electromagnetic or pneumatic motor powered by electrical, electromagnetic, compressed air, compressed gas, hydraulic, vacuum or hydrocarbon fuels. Those skilled in the art will recognize that any actuator mechanism of any type known in the art can be within the spirit and scope of the presently

disclosed embodiments.
(64) The suturing needle (e.g., **120**, **220**) used with the suturing device **50** has an engagement or gripping surface at one or more locations along its length. By way of this surface, an engagement mechanism in the suture head assembly **56** can grip the needle to advance it through the target tissue. This gripping surface can take on a number of different forms, including, for example, one or more serrations or teeth raised above or depressed below the generally toroidal surface of the suturing needle, and properly oriented to allow the suturing needle to advance smoothly through tissue. In this case, the engagement mechanism in the suture head assembly **56** can include one or more number of interfitting teeth. The gripping or engagement surface of the suturing needle can also take the form of hatch marks engraved on the surface of the suturing needle, which either may be raised above or depressed slightly below the surface of the suturing needle. In this embodiment, the engagement mechanism in the suture head assembly **56** can comprise a rubberized contact surface, or a collapsible mesh that can surround the body of the needle at the gripping surface to apply a trapping force against the needle.
(65) In a preferred embodiment, the gripping surface may include one or more notches that penetrate the surface of a suturing needle that is generally toroidal in shape, with the notches located on the outer circumference, inner circumference, or on one or both sides of the suturing needle. A corresponding engagement mechanism in the suture head assembly **56** can comprise a pawl, which can take many forms, but which at a minimum must effectively contact the leading or forward wall of a notch on the suturing needle, either to drive the needle in a forward direction, or to prevent the needle from moving in a reverse direction. The following description uses a particular embodiment of the gripping surface for illustrative purposes, and is not intended to limit the scope of the invention illustrated herein.
(66) FIG. **2**A is a perspective view of the suture head assembly **56** with a cartridge holder assembly **90** located at the distal end to which a cartridge **88** can be attached. In accordance with one embodiment, the suture head assembly **56** may be fabricated as a single piece. FIG. **2**B is a perspective assembly view of the suture head assembly of the presently disclosed embodiments showing part of the drive mechanism **70**, shown as a gear train/pulley system including pulleys **72**, **74**, **76** and **78**. Located within the elongated barrel **54** are mechanical parts including drive shafts, belts, rods, cables, or hydraulic tubes which run from the elongated barrel **54** through the spherical portion **58** and then engages with the drive mechanism **70** in the suture head assembly **56**. Connected at the proximal end of the suture head assembly **56** there is depicted a spherical portion **58** that contains part of the drive mechanism **70** including two idler pulleys **80** and cables **84** and **86**. The spherical portion **58** resides within the distal portion of the elongated barrel **54** and rotates in a substantially frictionless fashion. In one embodiment, the drive mechanism **70** includes a gear train/pulley system (“locomotive-type” drive mechanism) and cables and rods that extend from the distal end of the suture head assembly **56** to the proximal end of the elongated barrel **54**.
(67) The suture head assembly **56** is that portion of the device **50** within which the mechanism for driving the curved needle **120** in a complete 360-degree circular arc, as well as the cartridge holder assembly **90** for attaching and releasing the cartridge **88** are situated. The suturing device **50** is unique in the fact that the orientation of the suture head assembly **56** is such that when the cartridge **88** is attached to the suture head assembly **56** the needle **120** is driven in a curved path about an axis approximately perpendicular to the longitudinal axis of the device **50**. In this way, the needle **120** may be optimally visualized as the needle **120** is driven in a circular arc. Also, as shown in FIG. **2**B, the needle **120** and cartridge **88** are in a plane parallel to the drive mechanism **70** and fit into the same space in the suture head assembly **56**.
(68) The improved visibility offered by the shape and configuration of the suture head assembly **56** enables precise device placement over the incision or other target tissue of interest, and uniform advancement of the suturing device **50** after every stitch to provide a uniform and symmetric suture, thereby minimizing the risk of tearing tissue and bleeding due to a stitch being positioned

too close to the edge of the incised tissue. In one embodiment, the entire device **50** or parts of the device **50**, such as the suture head assembly **56**, the elongated barrel **54**, the handle **60**, and the needle **120** and cartridge **88**, may be composed of a sterilizable medical grade plastic material, in which case, the entire device **50** or parts of the device **50** may discarded and disposed after a single use. In another embodiment, the device **50** may be composed of a sterilizable medical grade metallic material such as stainless steel to enable reuse subsequent to sterilization following a prior use. In still another embodiment, the device **50** is composed of a sterilizable medical grade metallic material such as titanium to enable reuse subsequent to sterilization following a prior use. The use of titanium is ideal for certain procedures including Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) because they are X-Ray radiolucent and do not interfere with MRI and CT scans.

(69) FIGS. **3**A and **3**B provide detailed segmental views of the suture head assembly **56** showing the cartridge holder assembly **90**, the disposable needle cartridge **88**, a curved suturing needle **120**, and parts of the drive mechanism **70** including a plurality of pulleys, **72**, **74**, **76**, **78** and **80** involved in driving the needle driver **98** through a semicircular path. In one embodiment, the needle driver is a pawl **98**. As depicted, a shoulder screw **108** is used to keep a latch **110** locked in place over the disposable cartridge **88** and the suturing needle **120**. Pulleys **72**, **74**, **76** and **78** are engaged with an actuator arm **102**, which is attached to the pawl **98**. The pawl **98** interfits with two notches **132** (as depicted in FIG. **15**) located on the needle **120** at 180 degrees apart from each other which drives the curved needle **120** in a completely circular arc. The suture head assembly **56** is preferably configured so that the pawl **98** (or other needle driver), does not intrude into or obstruct the area within the curve of the needle **120**. The entire area within the circular arc of the needle **120** is unobstructed; there is no hub at the center of the circular arc so that the device **50** can encompass the maximum volume of tissue within the circular arc of the curved needle **120**. In this way, the needle **120** may be rotated through a relatively large arc, allowing the needle **120** to obtain a sufficient “bite” into the tissue. Preferably, the needle **120** will have a radius of curvature of about 3 mm to about 40 mm. In an embodiment, the device **50** sutures within the limit of the diameter of the suture head assembly **56**, which is advantageous to suturing through small cannulas during minimally invasive surgery. In an embodiment, the diameter of the curved needle **120** does not exceed the diameter of the suture head assembly **56**.

(70) FIGS. **4**A and **4**B show detailed views of the drive mechanism **70** located in the suture head assembly **56** with respect to driving the needle **120** during use of the device **50** (the cartridge housing **88** has been removed to show the drive mechanism **70** in detail). The drive mechanism **70** includes a plurality of pulleys, **72**, **74**, **76** and **78**, and the associated axel pins **82**, involved in driving the pawl **98** through a semicircular path. The actuator arm **102** engages pulleys **72** and **76** and are pinned **75** to pulleys **72** and **76**. As pulleys **76** and **78** rotate with the motion of the cables **86** and **84**, respectively, which reside in the elongated barrel **54** (not shown), pulley **74** acts as an idler pulley, transferring the motion to the most distal pulley **72**. Pulley **72** and pulley **76** rotate through identical arcs. The actuator arm **102** provides a connection to the pawl **98**. The pawl **98** is located in the distal end of the actuator arm **102**. The pawl **98** is attached to the actuator arm **102** by an integral shaft and collar **100** that fits loosely into the actuator arm **102** allowing smooth movement. As the handle **60** is closed and opened, the pawl **98** moves through the same arc as pulleys **72** and **76**. The pawl **98** at the distal end of the actuator arm **102** is capable of engaging the notches **132** located along the radially inner edge of the needle **120**. The actuator arm **102** is activated by the user upon squeezing of the handle **60**, and is capable of sweeping back and forth in an arc spanning about 190 degrees or more. FIG. **4**A shows a detailed view of the drive mechanism **70** and the suturing needle **120** either prior to using the device **50** or after one complete full cycle of the device **50**. FIG. **4**B shows a detailed view of the drive mechanism **70** and the suturing needle **120** after one squeeze of the handle **60**. As shown, the drive mechanism **70** has moved in a circular arc greater than about 180 degrees, (about 190 degrees), while the suturing needle **120** has moved

in a circular arc of about 190 degrees to drive through the tissue or vessel to be sutured.
(71) The outer surface of the actuator arm **102** is shaped to accommodate a C-brace (shown as **106** in FIG. **7**) that causes the pawl **98** to engage the needle **120** and thereby remain in contact. The advancing movement of the needle **120** during operation causes the notches **132** along the radially inner edge of the needle **120** to align with the pawl **98** in the actuator arm **102**, thereby causing the pawl **98** to engage the notches **132** due to a positive pressure exerted by the C-brace (not shown), and to "lock" into the notches **132**. The rotary advancing movement of the needle **120** is therefore controlled to occur sequentially through about 190 degrees each time the needle is actuated.
(72) FIG. **5**A shows a close-up view of the distal end of the suture head assembly **56** with the cartridge **88** and the needle **120** in view as well as the relationship between the pawl **98** and the actuator arm **102** with respect to the needle **120**. The needle **120** is enclosed within the cartridge **88**, so the sharp pointed end **124** is not exposed. This needle position, as loaded, is referred to as the "home" position (FIG. **5**A). In the home position, the needle **120** is fully contained within the cartridge housing **88** to eliminate needle-pricks during handling of the cartridge **88** or the loaded device. Squeezing the device handle **60** fully, two times, operates the device **50** through one full cycle. As shown in FIG. **6**A, the first full actuation of the handle **60** drives the needle **120** through an about 190 degree arc. The pointed end of the needle **124** exits the protective enclosure of the cartridge **88**, drives through the tissue to be sutured, and re-enters the protection of the cartridge **88** of the device **50**. This position, after the first squeeze of the handle **60**, is referred to as the "rotation" position. As shown in FIG. **6**B, the handle **60** is then released, and the needle **120** remains in the rotation position while the pawl **98** and the actuator arm **120** return to their start position. The handle **60** is then squeezed again driving the needle **120** through an about 190 degree arc and returning the needle **120** to the home position.
(73) FIG. **5**A shows the needle **120** in the home position, the pawl **98** is engaged in the notch **132** near the suture end of needle **126**. An anti-rotate spring **136** is engaged in the notch **134** on the outer surface of the needle **120**, not allowing the needle **120** to move backwards in the cartridge **88** of the device **50**. A close-up view of the anti-rotate spring **136** is shown in FIG. **5**B. In an embodiment, the needle **120** comprises at least one anti-rotate notch **134** and is engaged with at least one anti-rotate spring **136**. As the pawl **98** drives the needle **120** through a first semi circular arc, the anti-rotate spring **136** slips out of the notch **134** and slides over the outer surface of the needle **120**. As the pawl **98** reaches the end of a first drive stroke, the anti-rotate spring **136** snaps in behind the rear corner of the needle **120**, near the suturing material or thread **146** (see FIG. **6**A). As the pawl **98** returns to the start position, the anti-rotate spring **136** holds the needle **120** in place, preventing the needle **120** from moving with the pawl **98** back toward the start position. The pawl **98** returns to the start position and engages the notch **132** in the needle **120** near the pointed end **124** (see FIG. **6**B). When the handle **60** is squeezed a second time, the needle **120** is driven back to the home position.
(74) The width of the aperture **118** in the cartridge **88** is comparable to and corresponds with the width of the gap in the needle **120** so that when the needle **120** is in the home position (as shown in FIG. **5**A) the needle **120** does not project materially into the aperture **118**. Such an alignment causes the needle **120** to reside entirely within the cartridge **88**, thereby preventing inadvertent contact of the sharp pointed end **124** with the user's fingers during handling of the disposable needle cartridge **88** for placement on the cartridge holder assembly **90** or disposal after use, and while operating the suturing device **50**. Such protection of the needle **120** in the suturing device **50** prevents accidental "needle-pricks" from occurring, thereby substantially reducing the risk of infection caused by pathogenic bacteria or viruses that may contaminate the needle **120** during or after use prior to disposal. The needle **120** may be rotated in a curved track **92** of the cartridge **88** about the longitudinal axis of the suturing device **50** to advance the pointed needle end **124** so that the needle **120** first spans the aperture **118** and then returns to the home position. The suturing material or thread **146** is attached to the needle **120**, and therefore follows the path of the needle

120. The suturing material or thread **146** may then be cut and secured by an appropriate method, such as for example, by tying, or additional stitches may be placed along the entire wound or incision by repeating the aforementioned process. Every stitch, whether a single, interrupted stitch, or one of a series of continuous, running stitches may be placed in like manner. The suturing device **50**, therefore, may be used to insert either a single stitch, or to insert a suture comprising a plurality of continuous stitches as a replacement method for a more tedious and time-consuming manual suturing process. The terminal end of the suturing material or thread **146** may contain a knot or button to prevent the suturing material or thread **146** from pulling through the sutured tissue during placement of the first stitch. In an embodiment, the cartridge **88** comprises the suturing needle **120** attached to the terminal end suturing material or thread **146**, and an appropriate length of suturing material or thread **146** are all packaged in a sterilizable medical packaging material.

(75) FIG. **7**A shows a close-up view of the pawl **98** which rides in a track formed by the C-brace **106** and the suture head assembly **56**. The pawl **98** is spring loaded with a spring **104**. The spring **104** is engaged to the tip of the pawl **98***b* as shown in FIG. **7**A. The spring **104** engages the pawl tip **98***b* into the notch **132** in the needle **120** during the driving stroke of the device **50** when the handle **60** is closed. The spring **104** also allows the tip of the pawl **98***b* to rotate out of notch **132** of the needle **120** during the return of the pawl **98** to the start position when the handle **60** is opened. The heel of the pawl **98***a* stays in contact with the C-brace **106** during the driving stroke of the device **50**, preventing the pawl **98** from over-rotating and locking the needle **120**. FIG. **7**B shows a close-up view of the pawl **98** showing the pawl heel **98***a* and the pawl tip **98***b*.

(76) Referring now to FIGS. **8** and **9** in conjunction with FIG. **1**, the user introduces the distal end portion of suturing device **50** into a body cavity, via a cannula assembly (not shown), and then laterally articulates the suture head assembly **56** using the articulation lever **66** located just distal to the top of the handle **60**. The suture head assembly **56** is then positioned relative to the tissue/vessel to be sutured, and the user locks the suture head assembly **56** in place using the locking lever **64**. The user then, through manipulation of suturing device **50**, positions a plurality of separated tissue segments into the opening defined at the distal end portion of the suture head assembly **56** and within the aperture of the cartridge **118**. The user, using only one hand, may manipulate the device **50** while actuating the handle **60** to close an incision with a continuous suture whose stitches may be individually tensioned precisely and uniformly along the length of the suture similar to suturing done by hand in the conventional way. The user may employ a single suture which would extend the entire length of the incision or multiple sutures.

(77) The device **50** starts with the needle **120** in the home position and the handle **60** fully open (see FIG. **8**). In an embodiment, the handle **60** is made up of a grip which rests in the user's palm and is squeezed in order to actuate the device **50**. To drive the needle **120** through the tissue to be sutured, the user squeezes the handle **60** moving the needle **120** from the home position to the rotation position. The handle **60** contains linkages **144** to both the upper drive rod **142** and the lower drive rod **140**. Squeezing the handle **60** (see FIG. **9**) causes the two drive rods **140** and **142** to move in opposite directions. The upper drive rod **142**, moves forward while the lower drive rod **140** moves backward. The drive rods are connected to the suture head assembly **56** with cables **84** and **86** and idler pulleys **80**. The upper rod **142** is connected to pulley **78** with cable **84**. The lower rod **140** is connected to pulley **76** with cable **86**.

(78) FIGS. **10** and **11** in conjunction with FIG. **8**, show the connections and positions of cables **84** and **86** and the drive pulleys **72**, **74**, **76** and **78** when the handle **60** is in the open position. FIGS. **12** and **13** in conjunction with FIG. **9**, show the connections and positions of cables **84** and **86** and the drive pulleys **72**, **74**, **76** and **78** when the handle **60** is in the closed position. The force to move needle **120** from the home position to the rotation position comes from the lower rod **140** pulling backward on the drive cable **86**. The lower rod **140** extends nearly the full length of the elongated barrel **54**, connecting to drive cable **86**, at the proximal end of the elongated barrel **54**. As shown in FIG. **11**, cable **86** exits the elongated barrel **54** and enters the suture head assembly **56**, passing over

an idler pulley **80** located in the spherical portion **58**, then wrapping clockwise (as viewed from the bottom) around pulley **76** and is secured to pulley **76** located in the suture head assembly **56**. The pulling action of cable **86** causes pulley **76** to rotate through an arc of approximately 190 degrees. As lower rod **140** pulls backward, the upper rod **142** moves forward. The upper rod **142** also extends nearly the full length of the elongated barrel **54**, connecting to drive cable **84**, at the proximal end of the elongated barrel **54**. As shown in FIG. **10**, cable **84** also exits the elongated barrel **54** and enters suture head assembly **56**, passing over a second idler pulley **80** located in the spherical portion **58**, then wrapping (clockwise as viewed from the top) around pulley **78** and is secured to pulley **78** located in the suture head assembly **56**. Pulley **78** is directly linked to pulley **76** through the actuator arm **102**, and cables **84** and **86** are wrapped in opposing directions, so that as cable **86** unwinds from pulley **76**, cable **84** winds onto pulley **78**.

(79) The needle **120** is held in a path of rotation by a combination of three components. The cartridge **88**, the C-brace **106** and the cartridge holder assembly **90** interact to constrain the needle **120** to the path of rotation (see FIG. **5**). The cartridge **88** is a semicircular shaped component that is held into the device **50** by a plurality of extensions **94** located on each end of the cartridge **88** (see FIGS. **14** and **15**). In an embodiment, the plurality of extensions **94** takes the form of tabs. In an embodiment, the cartridge **88** is made from a sterilizable medical grade metallic material such as stainless steel. The cartridge **88** provides some of the support structure for keeping the needle **120** in a rotational path and therefore should be constructed from a material with structural integrity. Those skilled in the art will recognize that any high-strength medical grade material may be used to fabricate the cartridge **88**, such as a high-strength plastic. In an embodiment, the plurality of extensions are tabs extending from the cartridge housing **88**. The plurality of extensions **94** lock into mating grooves **96** located along on the distal edge of the cartridge holder assembly **90** that are located diametrically opposite to one another, and are capable of engaging the plurality of extensions **94** correspondingly located in the needle cartridge housing **88** as shown in FIG. **16**.

(80) The proximal end of cartridge **88** is held in place by a cartridge holder assembly **90**, as shown in FIG. **17**A. The cartridge holder assembly **90** also includes a latch **110**, a lever **112**, associated pins **114** and **116**, a shoulder screw **108**, an anti-rotate spring **136** and at least one groove **96** that can engage with the plurality of extensions **94** located on the cartridge **88**. It is the interaction of all of the elements of the cartridge holder assembly **90** that hold and lock the cartridge **88** in place. The latch **110** slides back to release the cartridge **88** and forward to lock the cartridge **88** in place. The latch **110** also has a built into ejector feature, as shown in FIG. **17**B. A lever **112** is located distal and below the needle **120** and the cartridge **88**. The lever **112** pivots on a pin **114**. A second pin **116** located above the pivot pin **114**, engages with a slot in the latch **110**. To release the needle **120** and the cartridge **88**, the latch **110** is pulled back and the lever **112** is rotated up and back, causing pin **116** to move back with the latch **110** and to rotate about pin **114** thus pushing the needle **120** and the cartridge **88** from the cartridge holder assembly **90**. The needle **120** and the cartridge **88** are then removed from the device **50** by a slight proximal motion to disengage the plurality of extensions **94** from their mating grooves **96** in the cartridge holder assembly **90**. FIG. **17**C shows the needle **120** as it is driven through a first semi circular arc (the handle **60** has partially completed a first full squeeze). As the pawl **98** drives the needle **120** through a first semi circular arc, the anti-rotate spring **136** slips out of the notch **134** and slides over the outer surface of the needle **120**.

(81) Loading of the needle **120** and the cartridge **88** is accomplished by engaging the plurality of extensions **94** into both grooves **96** on the cartridge holder assembly **90** and then pressing the proximal ends down against the sloped distal surface of the latch **110**. The latch **110** is spring loaded at the proximal end, thus can slide back as the needle **120** and the cartridge **88** are pressed into place and then snap closed to the locked position, retaining the needle **120** and the cartridge **88**. The lever **112** is down and out of the way of the operation of the needle **120** and the cartridge **88**.

(82) FIG. **18** shows a close-up view of the needle **120**. The two notches **132** are located about 180

degrees apart on the inner surface and assist in driving the needle **120**. The pawl **98** engages the notches **132** when driving the needle **120** through the circular motion. A third notch **134** is located on the outer surface of the needle **120**. The notch **134** assists in preventing rotation of the needle **120** and provides an anti-rotation feature. In an embodiment (see FIGS. **19**A and **19**B), the needle **120** is formed as a circular split ring with a gap **122**, a sharp, pointed end **124**, and a blunt end **126**. The needle **120** further comprises an opening **130** to accommodate the leading end of the suturing material or thread **146**. In one embodiment, the opening **130** is the form of an eye though which the leading end of the suturing material or thread **146** may be passed through for attachment to the needle **120**. In the illustrated needle **120** (FIG. **19**A), the opening **130** is located adjacent to the blunt end **126**. The opening **130** however, can be positioned anywhere along the arc or the needle **120** between the apex **128** and the blunt end **126**. In another embodiment (FIG. **19**B), the needle **120** comprises an opening **130** in the form of a cylindrical bore aligned axially with respect to the needle **120**, located at the blunt end **126** (FIG. **19**B). The leading end of the suturing material or thread **146** is inserted into the opening **130** and restrained by mechanically crimping. To enable the needle **120** to penetrate tissue to a required depth, the arc length of the needle **120** is preferably about 240 degrees to about 300 degrees. The needle **120** comprises two symmetric notches **132** along the radially inner edge ("inner notches") that are positioned proximally to the sharp, pointed end **124** and the blunt end **126** of the needle **120**. The notches **132** are located directly opposite to each other, each having a perpendicular (about 90 degree) segment and an angular segment that makes an angle of about 60 degrees with the perpendicular segment. The inner notches **132** are engaged by the needle driver **98** of the drive mechanism **70** and enable the needle **120** to undergo a rotary movement upon actuation of the drive mechanism **70**, thereby causing the needle **120** to penetrate into and advance through tissue. A similar triangular notch **134** is located on the radially outer edge ("outer notch") of the needle **120** proximally to the inner notch **132** closer to the sharp, pointed end **124**. The outer notch **134** engages with the anti-rotate spring **136** located on the cartridge holder assembly **90**, whereby rotation of the needle **120** in a direction opposite to the advancing direction or "needle backing-up" is prevented. The positive engagement of the needle outer notch **134** during operation of the suturing device precludes needle **120** from straying out of sequence during the suturing process.

(83) The suture head assembly **56** of the device **50** can be laterally articulated to the left of center and also to the right of center. In one embodiment, the suture head assembly **56** can be laterally articulated through an arc of about 22.5 degrees to the left of center and also to the right of center, for a total of about 45 degrees or more. In addition, the suture head assembly can be articulated up and down. In one embodiment, the suture head assembly **56** can be articulated up and down. The ability of the suture head assembly **56** to be articulated to the left and right of center, as well as up and down, permits the user to position the suture head assembly **56** for many different types of suturing applications. The articulation lever **66**, just distal of the top of the handle **60**, is pushed or pulled to cause the suture head assembly **56** to rotate. Viewed from above, moving the articulation lever **66** clockwise moves suture head assembly **56** to the right and moving the articulation lever **66** counterclockwise moves suture head assembly **56** to the left. The suture head assembly **56** is locked in place with the locking lever **64** located on the bottom of the device **50**, below the articulation lever **66**. Movement is accomplished using the solid articulation rod **68** to link the articulation lever **66** to the suture head assembly **56**. The articulation rod **68** is pinned to the articulation lever **66** and to one side of the most proximal section of the suture head assembly **56** so that the articulation rod **68** pushes or pulls the suture head assembly **56** through a full range of motion (see FIGS. **20**-**23**).

(84) FIGS. **20**-**23** show the articulation rod **68** in the elongated barrel **54** and the connection to the suture head assembly **56**. The suture head assembly **56** is shown moving from left articulation, to straight to right articulation (some components are not shown to allow clear viewing of the linkage). FIG. **20** shows a side view of the suture head assembly **56**. FIG. **21** shows a bottom view of the suture head assembly **56** with no articulation. FIG. **22** shows a bottom view of the suture

head assembly **56** articulated to the left. FIG. **23** shows a bottom view of the suture head assembly **56** articulated to the right. FIGS. **20-23** show a number of items. The articulation rod **68** runs down the center of the elongated barrel **54** and is attached to one side of the spherical portion **58**. The function of the articulation rod **68** is to push and pull the suture head assembly **56** through an articulation. The two idler pulleys **80**, which drive cables **84** and **86** are located in the spherical portion **58**. Looking at FIG. **20**, the two idler pulleys **80** seem to be one on top of the other. Instead however, they are located in plane with either pulley **76** and lower rod **140** or pulley **78** and upper rod **142**.

(85) In accordance with one embodiment, the entire suturing device **50** can be designed as a single unit which may be either reusable or disposed after a single use. If desired, the entire suturing device **50** can be designed from a number of units which, each unit may be either reusable or disposed after a single use.

(86) The suturing device **50** is preferably configured to provide a “pistol like” grip for the user that includes an elongated barrel **54** and a handle **60** that extends from the proximal end of the elongated barrel **54**. The elongated barrel **54** has either a linear or non-linear configuration, including but not limited to, straight, curved and angled configurations. A suture head assembly **56** is removably attached to the distal end of the elongated barrel **54**. The suture head assembly **56** contains a portion of the drive mechanism **70** of the device **50**. The working end of the suture head assembly **56** has a cartridge holder assembly **90** to which a disposable cartridge **88** that is capable of accommodating a suturing needle **120** may reside.

(87) The disposable cartridge **88** preferably has a generally cylindrical housing with an opening or aperture **118** in the sidewall of the housing at the distal or working end thereof. An arcuate suturing needle **120** having a sharp, pointed end **124** is slidably mounted in a circular track **92** of the cartridge **88**. A blunt end of the needle **126** is connected to a suturing material or thread **146**. The radius of the arc defining the arcuate suturing needle **120** is approximately equal to the circumference to the cartridge housing **88** at the aperture **118** therein. The needle **120** normally resides in a “home” position in the track **92** such that the gap in the arcuate suturing needle **122** is in alignment with the aperture **118** in the cartridge **88**. The sharp, pointed end of the needle **124** is situated on one side and entirely within the confines of the housing aperture **118**; the pointed end of the needle **124** is, therefore, shielded by the cartridge housing **88**. The blunt end of the suturing needle **126** that is attached to the suturing material or thread **146** is located at the opposite side of the aperture **118**. The sharp, pointed end of the needle **124** is, therefore, wholly contained within the cartridge **88** and does not protrude beyond the housing of the cartridge **88**. Thus, the sharp pointed end of the needle **124** is not exposed to the user.

(88) In accordance with the presently disclosed embodiments, the needle **120** may be releasably engaged by a needle driver **98** that is rotatably mounted within the suture head assembly **56** so that the needle **120** can be rotated from the home position by about 360 degrees about the central vertical axis of the cartridge **88**. Such a rotary action of the needle **120** causes the sharp point **124** to advance across the cartridge housing **88** so as to span the aperture **118**. Thus, when the device **50** is positioned such that the incised tissue segments to be sutured are situated at the housing aperture **118**, the needle **120** penetrates the tissue segments and spans the incision between them. A continued rotary movement of the needle **120** causes the needle **120** to return to the home position, and thereby causes the suturing material or thread **146** attached to the needle **120** to be pulled into and through the tissue in an inward direction on one side of the tissue incision, and upwards and out through the tissue on the opposite side of the incision. Thus, the suture material or thread **146** follows the curved path of the needle **120** to bind the tissues together with a stitch of material or thread **146** across the incision in a manner similar to manual suturing, wherein the needle **120** is “pushed” from the blunt end **126** and then “pulled” from the pointed end **124** by the pawl **98**. Preferably, an anchoring mechanism is provided at the trailing terminal end of the suturing material or thread **146** to prevent the material **146** from being pulled completely through and out of the

tissue segments. For example, the anchoring mechanism can be a pre-tied or a welded loop, a knot wherein the suture material or thread **146** is simply tied, or a double-stranded, looped suture is that attached to the suturing needle **120**. The rotary movement of the needle **120** within the needle cartridge **88** is accomplished by a pawl **98** that may be operated by the user by holding the suturing device **50** with one hand in a pistol-like grip around the handle **60**, and using at least one finger of that hand to activate.

(89) The suturing device **50** of the presently disclosed embodiments can be used for a laparoscopic procedure, including but not limited to laparoscopic colostomy, colectomy, adrenalectomy, splenectomy, repair of paraesophageal hernia, inguinal hernia repair, ventral hernia repair, Nissen fundoplication, liver lobectomy, gastrectomy, small bowel resection, treatment of small bowel obstruction, distal pancreatectomy, nephrectomy and gastric bypass. Those skilled in the art will recognize that the presently disclosed embodiments can be used in other laparoscopic procedures.

(90) In using the device **50** of the presently disclosed embodiments, the abdomen is insufflated with gas to create a working space for the user. Any gas known to those skilled in the art including, but not limited to, nitrogen or carbon dioxide, can be used. Access portals are established using trocars in locations to suit the particular surgical procedure. A variety of surgical instruments may then be inserted into the body through these access ports/cannulas. The user then introduces the distal end portion of suturing device **50** into a cannula, and then laterally articulates the suture head assembly **56** using the articulation lever **66** located just distal to the top of the handle **60**. The suture head assembly **56** is then positioned relative to the tissue/vessel to be sutured together, and the user locks the suture head assembly **56** in place using the locking lever **64**. The user then, through manipulation of suturing device **50**, positions a plurality of separated tissue segments into the opening defined at the distal end portion of the suture head assembly **56** and within the aperture **118** of the cartridge **88**. The user, using only one hand, may manipulate the device **50** while actuating the handle **60** to close an incision with a continuous suture whose stitches may be individually tensioned precisely and uniformly along the length of the suture similar to suturing done by hand in the conventional way. The user may employ a single suture which would extend the entire length of the incision or multiple sutures. Thus, by placement of the device **50** with the needle cartridge aperture **118** spanning the incised tissue segments and actuating the handle **60**, the suturing device **50** enables the user to lay down a running stitch or interrupted stitch to close the tissue incision in a time efficient manner. Those skilled in the art will recognize that any conventional procedure for conducting laparoscopic surgery can be used with the device **50**.

(91) The needle cartridge **88** is disposably mounted on a cartridge holder assembly **90** at the distal end of the suture head assembly **56**. The minimalized structural design of the suture head assembly **56** enables the user to have a clear, unobstructed view of the suturing needle **120** during advancement through the tissue segments during the course of a suturing operation, thereby enabling precise placement of the suturing device **50** to provide uniform sutures and precluding the risk of tearing tissue by placement too close to the edge of the incision. The suturing device **50** is then advanced a short distance along the incision and the aforementioned operation is repeated to produce another stitch comprising the suturing material or thread **146**.

(92) The user may continue to manipulate the suturing device **50**, alternately advancing and actuating rotation of the needle **120** about an axis that is generally parallel to the direction of advancement to create a continuous suture which may extend through the entire length of the incision or a series of interrupted stitches. After each individual stitch is laid down, the stitch is tightened by exerting a pull on the suturing material or thread **146** so that the resultant suture is tensioned uniformly along the length of the incised tissue segments. Therefore, a tight closure of the segments is accomplished and bleeding and tearing of tissue are minimized. Once the appropriate amount of suture material or thread **146** has been placed, the user can use a needle grasper to tighten and knot the formed stitches.

(93) The presently disclosed embodiments provide a method for suturing tissue during minimally

invasive surgery including engaging a cartridge **88** to a suture head assembly **56** at a distal end of a suturing device **50**, the cartridge **88** having a protective housing and a suturing needle **120** with a pointed end **124** and a blunt end **126**; introducing the distal end of the suturing device **50** into a body cavity; positioning an opening **118** in the cartridge **88** to span a plurality of separated tissue segments; activating an actuator **52** coupled to a drive mechanism **70** that engages the suturing needle **120** to cause rotational movement of the suturing needle **120** about an axis approximately perpendicular to a longitudinal axis of the suturing device **50** and advance the suturing needle **120** through the plurality of separated tissue segments; and pulling a suturing material **146** attached to the suturing needle **120** through the plurality of separated tissue segments forming a stitch.

(94) The presently disclosed embodiments provide a method for suturing tissue during minimally invasive surgery including (a) engaging a cartridge **88** to a suture head assembly **56** at a distal end of a suturing device **50**, the cartridge **88** having a protective housing and a suturing needle **120** with a pointed end **124** and a blunt end **126**; (b) introducing the distal end of the suturing device **50** into a body cavity; (c) positioning an opening **118** in the cartridge **88** to span a plurality of separated tissue segments; (d) activating an actuator **52** coupled to a drive mechanism **70** that engages the suturing needle **120** to cause rotational movement of the suturing needle **120** about an axis approximately perpendicular to a longitudinal axis of the suturing device **50** and advance the suturing needle **120** through the plurality of separated tissue segments; (e) pulling a suturing material **146** attached to the suturing needle **120** through the plurality of separated tissue segments forming a stitch and repeating steps (c) through (e) to cause a plurality of stitches to be placed through the separated tissue segments.

(95) The presently disclosed embodiments provide a method for suturing tissue during minimally invasive surgery including inserting a distal end of a suturing device **50** having a suturing needle **120** with a pointed end **124** into a body; positioning the suturing needle **120** to span a plurality of separated tissue segments; activating an actuator **52** a first time causing the pointed end **124** of the suturing needle **120** to extend beyond a protective housing of a cartridge **88** to engage the plurality of separated tissue segments; activating the actuator **52** a second time to cause the suturing needle **120** to complete a revolution and pull a suture **146** extending from the suturing needle **120** through the plurality of separated tissue segments to form a stitch.

(96) The suturing device **50** may be configured in different ways with respect to length and angle of the suture head assembly **56**. The size of the needle **120**, the needle cartridge **88**, the cartridge aperture **118** and the aperture position may also be varied for use in open surgery to perform procedures such as closing of the fascia, skin closure, soft tissue attachment, anastomosis, fixation of mesh, grafts and other artificial materials.

(97) FIGS. **24** and **25** show an alternative embodiment of a suturing device shown generally at **150**. Referring to FIGS. **24** and **25**, the suturing device **150** can be used to produce a continuous or interrupted stitch or suture so as to enable closure of openings internal to a patient's body. The suturing device **150** can be utilized to suture any type of anatomical tissue in any type of anatomical cavity; and, accordingly, while the device **150** is described hereinafter for use with a cannula in endoscopic procedures, such as laparoscopy, the device **150** can be used in open surgery and with catheters and other small and large diameter tubular or hollow, cylindrical members providing access to small cavities, such as veins and arteries, as well as large cavities, such as the abdomen.

(98) In an embodiment, the suturing device **150** includes an actuator mechanism shown generally at **152** which comprises an elongated barrel **154** and a handle **160** that extends from the undersides at a proximal end of the elongated barrel **154**. Located within the elongated barrel **154** are mechanical parts including cables which run from the elongated barrel **154** through a spherical portion **158** and then engages with the drive mechanism in a suture head assembly **156**. The spherical portion **158** resides within the distal portion of the elongated barrel **154** and rotates with low friction. In an embodiment, a drive mechanism **170** includes a pulley system and cables that extend from the

distal end of the suture head assembly **156** to the proximal end of the elongated barrel **154**.
(99) The suture head assembly **156** houses the mechanism for driving a curved needle **220** in a complete 360 degree circular arc. The orientation of the suture head assembly **156** is such that when the needle **220** is attached to the suture head assembly **156** the needle **220** is driven in a curved path about an axis approximately perpendicular to the longitudinal axis of the device **150**. In this way, the needle **220** may be optimally visualized as the needle **220** is driven in a circular arc. Also, as shown in FIGS. **24** and **25**, the needle **220** is in a plane parallel to the drive mechanism and fits into the same space in the suture head assembly **156**.
(100) The improved visibility offered by the shape and configuration of the suture head assembly **156** enables precise device placement over the incision, and uniform advancement of the suturing device **150** after every stitch to provide a uniform and symmetric suture, thereby minimizing the risk of tearing tissue and bleeding due to a stitch being positioned too close to the edge of the incised tissue. In one embodiment, the entire device **150** or parts of the device **150**, such as the suture head assembly **156**, the elongated barrel **154**, the handle **160**, and the needle **220**, are composed of a sterilizable medical grade plastic material, in which case, the entire device **150** or parts of the device **150** may discarded and disposed after a single use. In an embodiment, the device **150** is composed of a sterilizable medical grade metallic material such as stainless steel to enable reuse subsequent to sterilization following a prior use. In another embodiment, the device **150** is composed of a sterilizable medical grade metallic material such as titanium to enable reuse subsequent to sterilization following a prior use. The use of titanium is beneficial for certain procedures including Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) because they are X-Ray radiolucent and do not interfere with MRI and CT scans.
(101) FIG. **24** shows the handle **160** in an open position. FIG. **25** shows the handle **160** in the closed position. The suture head assembly **156** is attached to the distal end of the elongated barrel **154**. In one embodiment, the suture head assembly **156** is removably attached to the distal end of the elongated barrel **154**. The length of the suture head assembly **156** can range from about 10 mm to about 100 mm. In a particular embodiment, the length of the suture head assembly **156** is about 40 mm. The length of the elongated barrel **154** can range from about 50 mm to about 400 mm. Those skilled in the art will recognize that the elongated barrel **154** can be made shorter or longer depending on the intended use of the device **150**. In one embodiment, the elongated barrel **154** is about 300 mm in length. In another embodiment, the elongated barrel **154** is about 350 mm in length. An articulation lever **166**, just distal to the top of the handle **160** is pushed or pulled to cause the suture head assembly **156** to rotate. Moving the articulation lever **166** clockwise moves the suture head assembly **156** to the right and moving the articulation lever **166** counterclockwise moves the suture head assembly **156** to the left. The articulation lever **166** can also be moved to articulate the suture head assembly **156** up and down, as desired. The suture head assembly **156** is locked in place with a locking lever **164** located on an underside of the device **150**, below the articulation lever **166**. The suture head assembly **156** may be articulated, and the elongated barrel **154** may be any length appropriate for the intended clinical application of the device **150**. The diameter of the device **150** can range from about 3 mm to about 20 mm. In one embodiment, the diameter of the device **150** is about 12 mm. In another embodiment, the diameter of the device **150** is about 3 mm.
(102) The handle **160** may be a grip that is squeezed in order to actuate the suturing device **150**. The suturing device **150** is actuated by the actuator mechanism **152** coupled to a drive mechanism **170**. The actuator mechanism **152** of the suturing device **150** may comprise a triggering mechanism that is known in the art, such as for example, the triggering mechanisms disclosed in U.S. Pat. Nos. 6,053,908 and 5,344,061, both of which are hereby incorporated by reference. Alternatively, the actuator mechanism **152** can be either a manually operable button or switch, or mechanically operable by an automated electrical or a fuel driven device, such as for example, an electrical, electromagnetic or pneumatic motor powered by electrical, electromagnetic, compressed air,

compressed gas, hydraulic, vacuum or hydrocarbon fuels. Those skilled in the art will recognize that any actuator mechanism of any type known in the art can be within the spirit and scope of the presently disclosed embodiments.

(103) FIG. **26** provides an assembly view of the suture head assembly **156**. The suture head assembly **156** is fabricated from multiple pieces including a holder assembly **190**, a needle holder assembly **188**, a latch **210**, and parts of the drive mechanism **170** including a plurality of pulleys, **172**, **174** and **176** and two idler pulleys **180** involved in driving a needle driver **198** through a semicircular path. Pulleys **172** and **174** may include a set of four pulleys, or two sets of pulleys, labeled **178**. In one embodiment, the needle driver is a pawl **198**. A shoulder screw **208** and a plurality of needle assembly extensions **194** may be used to keep the latch **210** locked in place over the needle holder assembly **188** and the suturing needle **220**. The needle holder assembly **188** includes a curved track **192** where the needle **220** rides. Pulleys **172**, **174** and **176** are engaged with an actuator arm **202**, which is attached to the pawl **198**. The pawl **198** interfits with two notches **232** located on the face of the needle **220** at about 180 degrees apart which drives the curved needle **220** in a circular arc. The suture head assembly **156** is configured so that the pawl **198** or other needle driver known in the art, does not intrude into or obstruct the area within the curve of the needle **220**. The area within the circular arc of the needle **220** is unobstructed; there is not a hub at the center of the circular arc so that the device **150** can encompass the maximum volume of tissue within the circular arc of the curved needle **220**. In this way, the needle **220** may be rotated through a relatively large arc, allowing the needle **220** to obtain a sufficient “bite” into the tissue. Preferably, the needle **220** will have a radius of curvature of about 3 mm to about 40 mm. In one embodiment, the device **150** sutures within the limit of the diameter of the suture head assembly **156**, which is advantageous to suturing through small cannulas during minimally invasive surgery. In one embodiment, the diameter of the curved needle **220** does not exceed the diameter of the suture head assembly **156**.

(104) FIGS. **27**A and **27**B show detailed views of the drive mechanism **170** located in the suture head assembly **156** with respect to driving the needle **220** during use of the device **150** (the needle holder assembly **188** and the holder assembly **190** have been removed to show the drive mechanism **170** in detail). The drive mechanism **170** includes the actuator arm **202** that engages pulleys **172**, **174**, and **176** and the pawl **198** that drives the needle **220** through a curved path. The pawl **198** is located in the distal end of the actuator arm **202** and is capable of engaging the notches **232** located along the face of the needle **220**. A flat spring **200** keeps the pawl **198** engaged into the notches **232** of the needle **220**. When the needle **220** is pushed around, the pawl **198** will be pushed back up against the flat spring **200** and allow the needle **220** to cycle. As the handle **160** is closed and opened, the pawl **198** moves through the same arc as the pulleys. The actuator arm **202** is activated by the user upon squeezing of the handle **160**, and is capable of sweeping back and forth in an arc spanning about 190 degrees or more.

(105) FIG. **28** shows a close-up view of the needle holder assembly **188** showing the curved track **192** where the needle **220** resides as well as the needle holder assembly extensions **194** that help keep the latch **210** in place. The suturing needle **220** follows a curved path along the track **192** during rotation of the suturing needle **220**. The curved track **192** for the needle **220** may be machined into the needle assembly **188** and provides a captive curved track **192** so that the needle **220** can be driven around with precision. The curved track **192** includes an inside slot and a larger slot surrounding the inside slot. The larger outside slot provides clearance for the pawl **198**, so that the pawl **198** can maneuver around without hitting anything, and the smaller inside slot provides clearance for a pawl tip **199**, which goes through the smaller inside slot and then into the needle **220** so that the pawl tip **199** can drive the needle **220**.

(106) FIG. **29** shows a close-up view of the suture head assembly **156** with the needle holder assembly **188**, the holder assembly **190**, the latch **210** and the needle **220** in view as well as the relationship between the pawl **198** and the actuator arm **202** with respect to the needle **220**.

(107) The needle **220** is enclosed within the needle holder assembly **188**, so the sharp pointed end **224** of the needle **220** is not exposed. This needle **220** position, as loaded, is referred to as the "home" position. In the home position, the needle **220** is fully contained within the needle holder assembly **188** to eliminate needle-pricks during handling of the suture head assembly **156**. The needle assembly extensions **194** form a "tongue-in-groove" connection with the latch **210**, which keeps the forces from the needle **220** from opening the thin members of the latch **210**. The needle assembly extensions **194** cause an entrapment at a distal end of the suturing device, thus locking the latch **210** in place. Squeezing the device handle **160** fully operates the device **150** through one full cycle. The first full actuation of the handle **160** drives the needle **220** through about a 190-degree arc. The pointed end **224** of the needle **220** exits the protective enclosure of the needle holder assembly **188**, drives through the tissue to be sutured, and re-enters the protection of the needle holder assembly **188** of the device **150**. This position, after the first squeeze of the handle **160**, is referred to as the "rotation" position. The handle **160** is then released, and the needle **220** remains in the rotation position while the pawl **198** and the actuator arm **220** return to their start position. The handle **160** is then squeezed again driving the needle **220** through about a 190-degree arc returning the needle **220** to the home position. A flat pawl spring **200** keeps the pawl **198** engaged into the pawl notches **232** on the needle **220**. When the needle **220** is pushed around the pawl **198** will be pushed back up against the flat pawl spring **200** and allow the needle **220** to cycle.
(108) FIGS. **30** and **31** show top views of the suture head assembly **156**. Needle holder assembly **188** forms a connection with the latch **210**. The latch **210** forms a top cover over the suturing needle **220** which is in the curved track **192** of the needle holder assembly **188**. FIG. **30** shows the latch **210** in the open position, which is for needle **220** removal and insertion into the needle holder assembly **188**. To insert and/or remove the needle **220** a user may turn the needle **220** 180 degrees in its curved track **192** from the as-drawn position. A user may grab the needle **220** by hand or with a surgical tool to either install the needle **220** or remove the needle **220**. By grabbing and lifting the needle **220** out, the needle **220** is removed. By grabbing the needle **220** the needle can be inserted when the latch **210** in the open position. FIG. **31** shows the latch **210** in the locked position, also known as the forward position.
(109) FIG. **32** shows the suturing needle **220**. The two notches **232** are located about 180 degrees apart on the face of the needle **220** and assist in driving the needle **220**. The pawl **198** engages the notches **232** when driving the needle **220** through the circular motion. A third notch **234** is located on the outer surface of the needle **220**. The notch **234** provides an anti-rotation feature by preventing rotation of the needle **220**. The needle **220** is formed as a circular split ring with a gap **222**, a sharp, pointed end **224**, and a blunt end **226**. The needle **220** further comprises an opening **230** to accommodate the leading end of the suturing material or thread **246**. In an embodiment, the opening **230** is the form of an eye though which the leading end of the suturing material or thread **246** may be passed through for attachment to the needle **220**. In the illustrated needle **220**, the needle **220** comprises an opening **230** in the form of a cylindrical bore aligned axially with respect to the needle **220**, located at the blunt end **226**. The opening **230**, can be positioned anywhere along the arc or the needle **220** between the apex **228** and the blunt end **226**. The leading end of the suturing material or thread **246** is inserted into the opening **230** and restrained by mechanically crimping or other connection methods known in the art. To enable the needle **220** to penetrate tissue to a required depth, the arc length of the needle **220** is preferably about 240 degrees to about 300 degrees. The needle **220** comprises two symmetric notches **232** along the face ("drive notches"). The notches **232** are located directly opposite to each other. A similar notch **234** is located on the radially outer edge ("outer notch") of the needle **220** proximally to the inner notch **232** closer to the sharp, pointed end **224**. The outer notch **234** engages with an anti-rotate spring, whereby rotation of the needle **220** in a direction opposite to the advancing direction or "needle backing-up" is prevented. The positive engagement of the needle outer notch **234** during operation of the suturing device precludes the needle **220** from straying out of sequence during the suturing

process.
(110) FIG. **33** shows a close-up view of the pawl tip **199** engaging the drive notches **232** of the needle **220**. The drive notches **232** are engaged by the pawl tip **199** of the drive mechanism **170** and enable the needle **220** to undergo a rotary movement upon actuation of the drive mechanism **170**, thereby causing the needle **220** to penetrate into and advance through tissue.
(111) FIGS. **34** and **35** show parts of the drive mechanism **170** including return pulleys **172** and **174**. Pulleys **172** and **174** are connected to each other using wires **175**. As can be seen in FIG. **27**A and FIG. **27**B, pulleys **172** and **174** are made up of four pulleys **178** that are connected together by laser welding or other methods known in the art. The four pulleys **178** produce an over-rotation, of about 190 degrees. The over-rotation leads to the wire **175** design where there is a wire **175** on each set of pulleys **178**. As shown in FIG. **34** and FIG. **35**, there are two wires **175** with four pulleys **178**, resulting in the four pulleys **178** being in synch with one another, even under load. The four pulleys **178** are rotationally in sync, i.e., one pulley **178** will follow the other pulley **178**, because the wires **175** are configured to be pulling against one another. The wire **175** may be attached to the pulleys **178** via a hole that the wires **175** are soldered into. FIG. **35** shows a side view of the suture head assembly **156** which shows the two wires **175** connecting the four pulleys **178** together for synchronized rotation.
(112) FIGS. **36** and **37** in conjunction with FIG. **38**, show the connections and positions of cables **184** and **186** to the drive pulley **176** and to the return pulleys **172** and **174**, respectively, and to the when the handle **160** is in the open position. The cables **184** and **186** may be made from stainless steel. Connected at the proximal end of the suture head assembly **156** there is the spherical portion **158** that contains part of the drive mechanism **170** including two idler pulleys **180** and cables **184** and **186**. FIG. **36** shows a top view of the suture head assembly **156** with the cable **184** running through two idler pulleys **180** and wrapped around drive pulley **176**. FIG. **37** shows a top view of the suture head assembly **156** with the cable **186** running through two idler pulleys **180** and wrapped around return pulley **174**. The cable **186** runs from return pulley **174** through the elongated barrel **154** and to the very proximal end of the handle **160**. The force to move the needle **220** from the home position (shown in FIGS. **36** and **37**) to a rotation position comes from a return spring **240** that is connected to the cable **184**, resulting in a pre-load (shown in FIG. **38**). When the trigger of the handle **160** is squeezed closed, the handle **160** moves to the closed position and the drive pulley **176** turns counterclockwise, driving the needle **220**. At the same time, the cable **186** drives the return pulley **174** counterclockwise and cycles the actuator arm **202** to drive the needle **220** forward through the tissue. The needle **220** is driven through a circular motion, through a cycle, and the cable **184** is compressing the return spring **240** on the other end. When the handle **160** closes more, the actuator arm **202** drives the needle. When the trigger of the handle **160** is released, the front pulley **178**, which is now fully charged with the return spring **240**, will return the needle **220** to the home position. The return spring **240** pulls cable **184**, returning the pulleys to their starting positions, and returning the actuator arm **202** to a position to engage the second drive notch of needle **220**. A second compression-release cycle returns the needle **220** to the home position. Relaxing the trigger of handle **160** takes no power.
(113) FIG. **38** shows a side elevational view of the suturing device **150**. The handle **160** includes a number of internal parts—a cable connector **182** has a hole and a shoulder. The shoulder rides against the end of the return spring **240**, and the hole provides an opening for the cable **184**. The return spring **240** is compressed and the cable **184** is soldered or locked to the connector **182**, so that the cable **184** provides a preload onto the return spring **240**. The cable **184** runs from the connector **182** through the return spring **240** over pulley **244**, through the elongated barrel **154**, through the spherical portion **158**, between the idler pulleys **180** and fixed to the drive pulley **176**. The cable **186** is connected at the very proximal end of the handle **160** and lies under pulley **245**, over pulley **242**, through the elongated barrel **154**, through the spherical portion **158**, between the idler pulleys **180** and fixed to the return pulley **174**.

(114) When the handle **160** is translated from the open position to the closed position the needle **220** is driven through the tissue. A user has a tactile feel as the needle **220** moves. If the needle **220** runs across something that is impenetrable, the handle **160** will stop moving and the user could feel this in their hand holding the handle. When the handle **160** is in a closed position, the return spring **240** takes on a charge, the return spring **240** has shortened in length. When the handle **160** is released, the return spring **240** pulls the cable **184** and brings the needle **220** back to the home position and also brings the handle **160** back to the open position. The return spring **240** provides a load on the cable **184**. A loop is formed throughout the suturing device **150** that includes the cables **184** and **186** and the pulleys **172**, **174** and **176** such that cable **184** is attached at one end to the return spring **240**, at the other end to the drive pulley **176**. The cable **186** is attached to the return pulley **174** and then cable **186** attaches to the very proximal end of the handle **160**, thus forming a loop. The return spring **240** can be set to a desired spring-rate so that the return spring **240** performs as desired by the user. The return spring **240** should have a small amount of preload to make sure that the handle **160** opens all the way, which provides that the driving mechanism **170** would return the needle **220** to the home position.
(115) The cables **184** and **186** extend through the elongated barrel **154** and connect to the drive mechanism **170** in the suture head assembly **156**. The long length of the cables **184** and **186** provides a small amount of a spring buffer. If the suturing device **150** were to become bound or something locked up at the suture head assembly **156** this would not translate. If the user continued to pull on the handle **160** to close the handle **160**, the cables **184** and **186** would stretch and should not break. The two idler pulleys **180**, which drive the cables **184** and **186** are located in the spherical portion **158**. As shown in FIG. **34**, the two idler pulleys **180** appear to be one on top of the other, but they are located in a plane with either pulleys **174** and **176** or pulley **178** (see FIG. **26**).
(116) FIG. **39** shows an alternative embodiment of a suture head assembly **356**. The actuator arm **102** (FIGS. **3**A, **4**A and **4**B) of the suture head assembly **56** is replaced by a tendon or band filament **302** (FIG. **39**). The cables **84** and **86**, and drive rods **140** and **142** (FIG. **8**) can be replaced by an actuator that can move fore and aft with compression and release of the handle **60** (FIG. **8**) or **160** (FIG. **24**). The actuator can be a drive rod (not shown), and can be constructed of a tensile material that permits lateral elastic flexibility but minimal longitudinal compressibility, such as steel or other metal alloys with spring-like qualities, shape memory alloys, such as NITINOL® or a flexible hardened polymer or plastic such as high density polyethylene or polypropylene. The drive rod can be encased within a passageway inside the elongated barrel **54**, the walls of which can include a sufficiently lubricious material to minimize the friction of the fore and aft movement of the drive rod. For example, the passageway may be made from or include a coating of a fluoropolymer or other lubricious material, such as silicone oil and the like. The drive rod can be connected on its distal end to the tendon or filament **302** by any suitable means (including, for example, the use of a screw, a bolt, adhesive, a weld joint, a hinge joint, or a snap-lock connection).
(117) The suture head assembly **356** can be attached rigidly to the elongated barrel **54**. Alternatively, the suture head assembly **356** can be attached moveably to the elongated barrel **54** by an articulating joint as shown in FIG. **2**A and FIGS. **20-23**. For example, the proximal end of the suture head assembly **356** (FIG. **39**) can be modified to form a partially spherical portion similar to spherical portion **58** (FIG. **2**A), which can permit superior-inferior motion of the suture head assembly **356** with respect to the elongated barrel **54**. An articulation rod **68** can be used as shown in FIGS. **20-23** to push and pull the suture head assembly **356** through an arc within the limits of the articulation. Those skilled in the art will recognize there are many possible means of connecting an embodiment exemplified by the suture head assembly **356** to a handle and actuating mechanism to achieve the push-pull motion of the tendon or filament **302**.
(118) As shown in FIG. **39**A, in this embodiment the suture head assembly **356** is comprised of two mating components **356**A and **356**B. A needle track **332** is located in the needle track component **356**B. A drive track (not shown) is located in the drive track component **356**A next to the needle

track **332**. In this embodiment, the suturing needle **220** exits the suture head assembly **356** from the distal end of aperture **318**, and re-enters the device at the proximal end of aperture **318**. Therefore, in its 'home' position, the blunt end **226** of needle **220**, and its attached suture material **246** are situated more proximally in the suture head assembly **356** than the pointed end **224** (not shown).
(119) By way of further example, as depicted in FIG. **39**B, device **300** equipped with a suture head assembly **356** may be provided with a flexible proximal segment **354** and include a steering mechanism for controlling curvature of the shaft. The steering mechanism may achieve steering in any suitable manner, such as steering wires. For example, two, four or any other suitable number of steering wires **371** may be used to control movement of device **300**. Steering may be controlled accordingly by way of a steering control mechanism **372**, which may be made in any way known in the art. Similar to the embodiments of FIGS. **1**-**38**, an actuator **373** is also provided for activating the suturing head. As will be appreciated by those of skill in the art, the embodiments of FIGS. **1**-**38** may similarly be modified to include a flexible barrel (**54**, **154**), as desired.
(120) As embodied herein, the tendon **302** may include an elongated flexible member that can slide fore and aft within a track in the suture head assembly **356**. It can have any cross-sectional shape, including for example, round, oval, square, or rectangular. In a preferred embodiment, it is relatively flat, forming a band, which has the advantage of limiting the flexibility of the tendon **302** to one lateral dimension (e.g., superior-inferior and not side-to-side). It is preferably constructed of material that is minimally compressible, allowing for the longitudinal transmission of a pushing as well as a pulling force. In one embodiment, the material from which a tendon is constructed has sufficient tensile properties to exert a spring-like force that opposes lateral flexion. Examples of material with such properties can include, for example, shape memory alloys such as NITINOL®, steel or other metal alloys with spring-like qualities, or a flexible hardened polymer or plastic such as high density polyethylene or polypropylene. In other embodiments, spring-like properties on lateral flexion are not required, where, for example, the lateral movement of the tendon is urged by a spring located with the suture head assembly **356** that exerts a force against the external surface of the tendon.
(121) As shown in FIG. **40**, the tendon **302** is situated in a drive track **333** within the drive track component **356**A of the suture head assembly **356**. The drive track **333** is substantially straight until it reaches the distal portion of the suture head assembly **356**, which at this point is shaped to define an aperture **318**. At this location the drive track **333** in one embodiment divides into an engagement track **334**, and disengagement track **335**, which each follow a curved path conforming to the contour of the suturing needle **220**. As shown in FIG. **41**, tendon **302** flexes to conform to the shape of the engagement and disengagement tracks **334** and **335**. FIG. **41** shows a perspective view of the distal flexed end of tendon **302**, to which is attached a cylindrical pawl **308**. The pawl **308** consists of a pawl body **308**A and a pawl tip **308**B. The cylindrical shape of the pawl body **308**A and pawl tip **308**B reduce the frictional resistance to movement of the tip of tendon **302** within engagement and disengagement tracks **334** and **335**. Other cross-sectional shapes of the pawl assembly **308**A and **308**B are also possible, including, for example, an oval, a square a rectangle, or other more complex shapes. Moreover, the pawl body can also be constructed as a roller bearing, further reducing frictional resistance to the fore and aft motion of the tendon **302**. FIG. **42**A shows how the pawl tip **308**B engages a trailing notch **232**B or leading notch **232**A on needle **220** to allow the tendon **302** to advance the needle **220** within its track **332**. FIG. **42**B shows the needle **220** in isolation, in which the drive notches **232**A and **232**B are located on the side of the needle **220**, and the anti-rotate notch **234** is located on the outer circumference of the needle **220**. A pointed end **224** pierces the target tissue during forward rotation of the needle **220**, and suture material **246** is attached to the blunt end **226** of needle **220**.
(122) In one embodiment, notches **232**A and **232**B have a substantially perpendicular leading wall **232**A**1** and **232**B**1** against which the pawl tip **308**B can engage and move the needle forward in its track **332**; whereas the angled trailing walls **232**A**2** and **232**B**2** allow the pawl tip **308**B to slide

smoothly into position in the notches **232** and **233** as it advances within the engagement track **334**. The leading walls **232**A**1** and **232**B**1** of notches **232**A and **232**B can also be inclined away from the pointed end of the needle, the angle of inclination being in the range of about 91 degrees to about 160 degrees with respect to the surface of the needle. The trailing walls **232**A**2** and **23**B**2** of notches **232**A and **232**B can also be inclined away from the pointed end of the needle, the angle of inclination being in the range of about 91 degrees to about 160 degrees with respect to the surface of the needle.

(123) Alternatively, the trailing wall **232**B**2** of trailing notch **232**B can also be made substantially perpendicular to the surface of the needle, with a gap between the leading wall **232**B**1** and the trailing wall **232**B**2** large enough to accommodate the pawl tip **308**B. This embodiment allows the user either to advance the needle **220** by pushing the tendon **302** distally, or move the needle backwards by pulling the tendon **302** proximally when the pawl tip **308**B is engaged in the trailing notch **232**B. The surgeon can thus 'back out' the needle from the tissue being sutured when an obstacle is encountered that prevents complete penetration of the needle **220**, or when repositioning of the needle in tissue is desired for other reasons. Under these circumstances, the leading wall **233**A**1** of leading notch **232**A is preferably not angled away from the pointed end in order to avoid a 'barb-like' structure that would impede reversal of the needle path in tissue. In addition, the leading wall **233**A**1** can have a chamfered or rounded corner at the junction with the surface of needle **220** to facilitate backing the needle out of tissue. For the same reasons, the anti-rotate notch **234** can have a leading wall that does not angle away from the pointed end **224** of the needle **220**, and it can have a chamfered or rounded corner at the junction with the surface of the needle **220**. The trailing wall **232**B**2** of trailing notch **232**B can also be constructed with a chamfered or rounded corner to facilitate forward movement of the needle through tissue.

(124) As shown in FIG. **43**, in one embodiment, the track **333** divides into engagement track **334** and disengagement track **335**. Engagement track **334** is adjacent to and side-by-side with the needle track **332**. Disengagement track **335** is adjacent to the outside circumference of engagement track **334**. Pawl body guides **336**A (FIG. **43**) and **336**B (FIG. **44**) separate engagement track **334** from disengagement track **335**, except for a gap between the pawl body guides **336**A and **336**B running the length of the tracks **334** and **335**. (best shown in FIG. **46**A) The base of pawl body guide **336**A is either formed or attached along the inside wall of the drive track side **356**A of suture head assembly **356**. The base of pawl body guide **336**B is either formed or attached along the inside wall of the needle track side **356**B of suture head assembly **356**. The pawl body guides **336**A and **336**B terminate short of the ends of the tracks **334** and **335**, both at their proximal and distal ends, at proximal chamber **380** and distal chamber **390**. This allows engagement track **334** to be in full communication with disengagement track **335** at both the proximal chamber **380** and the distal chamber **390** of the tracks. Tendon **302** moves only within engagement track **334**, whereas the distal end **302**A of tendon **302** and pawl **308** can move in engagement track **334** when driving needle **220**, and move in disengagement track **305** when returning to proximal chamber **380**. At the proximal end **308** of the engagement and disengagement tracks **334** and **335** (i.e. at the proximal chamber **380**), the spring force caused by tendon **302** being flexed in a downward direction causes the pawl **308** to move up into the proximal end of engagement track **334**. As the tendon moves distally in the engagement track **334**, it engages the trailing notch **232**B or leading notch **232**A of needle **220**, moving the needle **220** forward in its track **332**. When the pawl **308** reaches the distal end of the track **334** at the distal chamber **390**, the tendon **302** is flexed in an upward direction, and the spring force of tendon **302** now exerts a downward force on the pawl **308**. The pawl **308** drops down into the distal end of disengagement track **335**. The distal end of tendon **302** comprises a narrowed segment **302**A, allowing this distal segment to travel within the disengagement track **335** as tendon **302** is pulled proximally, because the narrower dimension of the distal end of tendon **302** clears the pawl body guides **336**A and **336**B. The more proximal portion of tendon **302**, at full width, continues to travel in engagement track **334**, being held in place by the pawl body guides

336A and **336**B.
(125) FIG. **45** shows a top perspective view of the suture head assembly **356**. The drive track side **356**A is mated to the needle track side **356**B. The needle track **332** is formed on the outside surface of the needle track side **356**B of the suture head assembly **356**. In this embodiment, a second opening **357**, located at the distal end of aperture **318**, is where the pointed end **224** of needle **220** exits the device. A first opening **358**, located at the proximal end of aperture **318**, is where the pointed end **224** of needle **220** re-enters the suture head assembly **356** after penetrating the target tissue. FIG. **46**A shows a cutaway top perspective view of suture head assembly **356**, in which the roof of track **333**, the proximal chamber **380**, and the distal chamber **390** have been cut away. The pawl **308** can be seen in cross-section within the proximal end of engagement track **334**, adjacent to the cross-section of needle **220** at trailing notch **232**B. Pawl tip **308**B is engaged in trailing notch **232**B of needle **220**. The pawl **308** is held within the track by pawl body guides **336** A and **336**B. The narrow segment **302**A of tendon **302** can pass through the gap between pawl body guides **336**A and **336**B. Thus while the main portion of tendon **302** remains within engagement track **334**, the pawl **308** and narrow segment **302**A of tendon **302** can travel either in engagement track **334** or engagement track **335**. A thrust collar **360**, shown in FIG. **46**A (and in isolation in FIG. **46**B) snaps over the outside of needle **220** into suture head assembly **356** to hold needle **220** within its needle track **332**. Alternatively, a cartridge **88**, as shown in FIG. **2**A and FIG. **2**B, can be used, which can then be attached to a cartridge holder assembly **90**. A cartridge **88** can provide operating room personnel with the added safety of avoiding inadvertent puncture from handling an exposed needle **220**.
(126) A further enhancement of suture head assembly **356** is shown in FIG. **47**. An anti-rotate spring **346** (shown in isolation in FIG. **48**), anchored inside suture head assembly **356** can engage a notch on the outer circumference of needle **220** to prevent backward migration of needle **220** in its track **332**. As shown in FIG. **44**, the anti-rotate spring **346** contacts the surface of needle **220** through an aperture **347** lateral to the disengagement track **335** so as not to interfere with movement of the distal end of tendon **302** and pawl **308**. In a preferred embodiment, the anti-rotate notch **234** is located on the outer circumference of needle **220**, and sufficiently distally along the needle to cause engagement of the anti-rotate spring **346** only when the pointed end of needle **220** is within the confines of suture head assembly **356**.
(127) An additional feature to coax pawl **308** to engage the notch **232**A or **232**B of needle **220** is shown in FIG. **47**. A flat spring **348** (shown in isolation in FIG. **49**) is situated within proximal chamber **380** of the drive track side **356**A of suture head assembly **356**. The flat spring **348** urges the pawl **308** against the side of needle **220** to engage the pawl tip **308**B with either the trailing notch **232**B or leading notch **232**A. The force exerted by flat spring **348** is substantially weaker than the spring force exerted by the downwardly flexed tendon **302**, allowing the distal end of tendon **302** and the pawl **308** to move into position at the proximal end of engagement track **334**, compressing flat spring **348** if necessary. Thus it is possible for pawl **308** to engage the notch **232**A or **232**B of needle **220** even if the pawl **308** and notch **232**A or **232**B are not exactly adjacent to one another. FIG. **50**A is a cross-sectional view of suture head assembly **356** showing pawl **308** positioned immediately proximal to trailing notch **232**B of needle **220**. FIG. **50**B is a view of FIG. **50**A through section B-B. Pawl tip **308**B is pressed against the side of needle **220** immediately proximal to notch **232**B by compressed flat spring **348**. FIG. **50**C is a view of FIG. **50**A through section C-C. Flat spring **348** deflected by pawl **308**, maintaining pressure of pawl tip **308**B against the side of needle **220**. FIG. **51**A is a cross-sectional view of suture head assembly **356** showing pawl **308** positioned within trailing notch **232**B of needle **220**. FIG. **51**B is a view of FIG. **51**A through section B-B. At this point, pawl tip **308**B is engaged with notch **232**B of needle **220**, spring **348** is in a relaxed position, and pawl **308** is aligned with the side wall of engagement track **334**, allowing it to proceed distally to drive the needle **220** within its needle track **332**. FIG. **51**C is a view of FIG. **51**A through section C-C. Flat spring **348** is now in a relaxed position, and pawl tip

308B is situated within notch **232**B of needle **220**. Once the pawl **308** moves distally within engagement track **334**, the confines of the track wall itself keep the pawl tip **308**B engaged with notches **232**B or **232**A.

(128) FIGS. **52**-**59** are sectional views through the length of suture head assembly **356** showing the progression of a complete four stroke movement (two push-pull cycles) that causes needle **220** to undergo a 360 degree rotation within its track **332**, penetrating the target tissue in the first stroke of the first cycle. In FIG. **52**, the pawl **308** is situated at the proximal end of engagement track **334**, and is engaged with notch **232**B of needle **220**. Anti-rotate spring **346** is engaged with the anti-rotate notch **234** on the outer circumference of needle **220**, preventing it from moving in a reverse direction. In FIG. **53**, the tendon **302** has been pushed distally in a first stroke, and has driven pawl **308** to the distal end of engagement track **334**. When the ends of pawl guides **336**A and **336**B have been cleared, the distal end of tendon **302** and pawl **308** snap by spring force into the distal end of disengagement track **335**. In this embodiment, movement of needle **220** by pawl **308** in this stroke has caused the pointed end of needle **220** to exit the second opening **357** of suture head assembly **356**, traverse the aperture **318**, penetrated the target tissue, and re-entered the first opening **358** of suture head assembly **356**. In FIG. **54**, the pawl **308** and the distal end of tendon **302** have dropped into the distal end of the disengagement track **335** by spring force of the upwardly deflected tendon **302**. The pull stroke in the first suturing cycle is shown in FIG. **55**. The pawl **308** is being pulled by tendon **302**, which is being retracted proximally by the surgeon via the handle **60** or **160**. Backward migration of the needle **220** is prevented by the engagement of anti-rotate spring **346** against the hub or blunt end **226** of needle **220**. This helps to keep the leading notch **232**A of needle **220** aligned with the proximal chamber **380**, where the pawl **308** can engage it. In FIG. **56**, the pawl **308** has reached the end of the pull stroke at the proximal end of disengagement track **335**. At this point the tendon **302** is significantly deflected downward, generating a spring force to drive pawl **308** upward into the proximal end of engagement track **334**, after it has cleared the pawl body guide **336**A and **336**B. In FIG. **57**, the pawl **308** has been driven by spring force into engagement with the leading notch **232**A of needle **220**. The push stroke of the second suturing cycle involves pushing the tendon **302** distally, driving the pawl **308** and pointed end **224** of needle **220** toward the distal end of needle track **332** (visually indistinguishable from engagement track **334** in this view). This is shown in FIG. **58**, where the pointed end **224** of needle **220** has advanced half-way through needle track **332**. In FIG. **59**, the push stroke of the second suturing cycle has been completed, with the pawl having dropped into the distal end of disengagement track **335** by spring force from the upward deflection of tendon **302**. The needle **220** has returned to its home position. Backward movement of the needle **220** is prevented by anti-rotate spring **346** engagement with the anti-rotate notch **234** of needle **220**. The trailing notch **232**B of needle **220** is in position to be engaged by pawl **308** at the proximal end of engagement track **334**. As shown in FIG. **60**, the pull stroke of the second suturing cycle is a retraction of tendon **302** proximally, pulling the pawl **308** proximally within disengagement track **335** and bringing it into position in the proximal chamber **380** to re-engage the trailing notch **232**B of needle **220**. Backward migration of needle **220** is prevented by anti-rotation spring **346** engaging the anti-rotation notch **234** of needle **220**. The suturing cycle is ready to resume if desired at this point.

(129) Those skilled in the art will recognize that the movement of the distal end **302**B of tendon **302** and pawl **308** into and out of notches **232**A and **232**B can be effected by springs situated within the suture head assembly **356** at the beginning of disengagement track **335** and at the end of engagement track **334**. Externally applied spring force, or even the placement of ramps in the engagement and disengagement tracks can cause the pawl **308** to be re-directed into the proximal end of engagement track **334**, and into the distal end of disengagement track **335**.

(130) It will also be apparent to those skilled in the art that the direction of travel of needle **220** can be reversed by having the home position for the trailing notch situated in the distal end of needle track **332**. In this case, the pawl and tendon are situated at the distal end of engagement track **334** at

the start of the first stroke of the first suturing cycle. The first (pull) stroke of the cycle would cause the pointed end of needle **220** to exit the first opening **358**, pass through the target tissue, and re-enter the suture head assembly at the second opening **357**. Structured in this way, the disengagement track **335** would be equipped with a spring or ramp to press the pawl **308** into the notch **232**A or **232**B at the distal end of the track, and with a spring or ramp to disengage the pawl **308** from the notch **232**A or **232**B at the proximal end of the track. Alternatively, the disengagement track **335** can be constructed so that it lies within the inner circumference of the engagement track **334** and needle track **332**. Under this circumstance, the spring-like property of tendon **302** will naturally drive the pawl **308** into notch **232**A or **232**B at the distal end, and out of notch **232**A and **232**B at the proximal end.

(131) In an embodiment, the entire suturing device **150** can be designed as a single unit which may be either reusable or disposed after a single use. In one embodiment, the entire suturing device **150** can be designed from a number of separable parts where each unit may be either reusable or disposed after a single use.

(132) The suturing device **150** is configured to provide a “pistol like” grip for the user that includes an elongated barrel **154** and a handle **160** that extends from the proximal end of the elongated barrel **154**. The elongated barrel **154** has either a linear or non-linear configuration, including but not limited to, straight, curved and angled configurations. A suture head assembly **156** is removably attached to the distal end of the elongated barrel **154**. The suture head assembly **156** contains a portion of the drive mechanism **170** of the device **150**. The working end of the suture head assembly **156** has a needle holder assembly **188** to which a suturing needle **220** may reside. A latch **210** forms a cover over the needle **220**.

(133) An arcuate suturing needle **220** having a sharp, pointed end **224** is slidably mounted in a circular track **192** of the needle holder assembly **188**. The blunt end of the needle **226** is connected to the suturing material or thread **246**. The needle **220** normally resides in a “home” position in the track **192** such that the gap in the arcuate suturing needle **222** is in alignment with an aperture **218** in the needle holder assembly **188**. The sharp, pointed end of the needle **224** is situated on one side and entirely within the confines of the needle holder aperture **218**; the pointed end of the needle **224** is, therefore, shielded by the needle holder assembly **188**. The blunt end of the suturing needle **226** that is attached to the suturing material or thread **246** is located at the opposite side of the aperture **218**. The sharp, pointed end of the needle **224** is, therefore, wholly contained within the needle holder assembly **188** and does not protrude beyond the housing of the needle holder assembly **188**. Thus, the sharp pointed end of the needle **224** is not exposed to the user.

(134) In accordance with the presently disclosed embodiments, the needle **220** may be releasably engaged by the needle driver **198** that is rotatably mounted within the suture head assembly **156** so that the needle **220** can be rotated from the home position by about 360 degrees about the central vertical axis of the needle holder assembly **188**. Such a rotary action of the needle **220** causes the sharp point **224** to advance across the needle holder assembly **188** so as to span the aperture **218**. Thus, when the device **150** is positioned such that the incised tissue segments to be sutured are situated at the needle holder assembly aperture **218**, the needle **220** penetrates the tissue segments and spans the incision between them. A continued rotary movement of the needle **220** causes the needle **220** to return to the home position, and thereby causes the suturing material or thread **246** attached to the needle **220** to be pulled into and through the tissue in an inward direction on one side of the tissue incision, and upwards and out through the tissue on the opposite side of the incision. Thus, the suture material or thread **246** follows the curved path of the needle **220** to bind the tissues together with a stitch of material or thread **246** across the incision in a manner similar to manual suturing, wherein the needle **220** is “pushed” from the blunt end **226** and then “pulled” from the pointed end **224** by the pawl **198**. Preferably, an anchoring mechanism is provided at the trailing terminal end of the suturing material or thread **246** to prevent the material **246** from being pulled completely through and out of the tissue segments. For example, the anchoring mechanism

can be a pre-tied or a welded loop, a knot wherein the suture material or thread **246** is simply tied, or a double-stranded, looped suture is that attached to the suturing needle **220**. The rotary movement of the needle **220** within the needle holder assembly **188** is accomplished by a pawl **198** that may be operated by the user by holding the suturing device **150** with one hand in a pistol-like grip around the handle **160**, and using at least one finger of that hand to activate.

(135) In accordance with further aspects of the invention, for purposes of illustration and not limitation, FIGS. **61**-**71** depict a further embodiment of a suturing head **500** for a suturing instrument.

(136) FIGS. **61**-**62** illustrate perspective views of this embodiment, both in plain view and showing hidden features, respectively. As illustrated, suturing head **500** is comprised of two main housing components, **502** and **504**. Housing component **502** defines a portion of a needle track **506** that is complete when components **502**, **504** are assembled. This embodiment is similar to that of FIG. **39**, but with certain differences. Significantly, in contrast to the embodiment of FIG. **39**, this embodiment operates by moving needle **520** through needle track **506** during a pull stroke of filament **530**, rather than during a push stroke. Distal end **534** of filament **530** is attached to an engagement mechanism **550** that selectively engages notches formed in the needle **520** in a manner similar to other embodiments described herein. As depicted in FIG. **63**, engagement mechanism rides in an arcuate track **505** formed in housing component **504** that is generally concentric with the needle track **506**. Suturing head **500** includes a tissue capture gap **540**, similar to the embodiment of FIG. **39**.

(137) FIG. **65** depicts the engagement mechanism that rides in track **505**. As depicted, engagement mechanism **550** includes four main components: cap **552**, sleeve **554**, piston **556** and a chamber **558** housing a compression spring **559** (spring **559** is depicted in FIG. **67**(B)). In operation, sleeve **554** is affixed to distal end **534** of filament **530**, piston **556** is received within sleeve **554**. Next spring **559** is inserted into cap **552**, which in turn is attached to sleeve **554**. Reduced diameter portion **556***a* of piston **556** is urged through bore **554***a* of sleeve **554**. Portion **556***a* of piston **556** mates with notches **526**, **528** in needle **520**. The operation of suturing head **500** through a complete cycle will now be described.

(138) As depicted in FIG. **66**, needle **520** having a first pointed end **522** and a second end **524** is in the home position prior to a rotation cycle, and engagement mechanism **550** is engaged with notch **528** in needle **520**. As depicted, needle includes a hollow **529** in second end **524** of needle **520** for receiving a suture (not shown). Filament **530** further includes an enlarged portion **535** for riding against needle track **506** to reduce friction and ease operation of the suturing head. As further depicted, tip **562** of pawl **560** is biased to engage with antirotate notch **527** formed into the outer circumferential surface of needle **527**.

(139) As depicted in FIG. **67**(A), filament **530** is pulled proximally through the suturing instrument, causing engagement mechanism **550** to urge against notch **528** in needle, resulting in needle **520** being drawn through track **506**, across gap **540**, and back into track **506**. Tip **562** of pawl **560** slides out of antirotate notch **527** of needle **520** and drags along the needle **520** as needle **520** moves through needle track **506**. As can be seen in side cross-sectional view FIG. **67**(B), end **556***a* of piston **556** is urged against notch **528** of needle **520** by spring **559**. FIG. **68** depicts needle **520** after having been moved through a 180 degree rotation. As can be seen in FIG. **68**, second end **524** of needle has moved past tip **562** of pawl **560**, and tip **562** of pawl snaps into the needle track **506** to prevent the needle **520** from reversing direction. At this point, filament **530** is once again advanced distally, causing tip **556***a* of piston **556** to urge against the distal inclined surface **528***a* of notch **528**. Inclined surface **528***a* acts as a ramp to push piston **556** into chamber **558** against the force of spring **559** until surface **556***a* rides up out of notch **528**, and over the outer surface of needle **520** through track **505** until it passes over needle **520** and pops back out. As engagement mechanism **550** continues to be guided by arcuate notch **505**, it encounters first end **522** of needle **520**. The pointed end **522** of needle **520** once again acts as a ramp, compressing spring **559** as surface **556***a*

rides up and over the needle **520** until surface **556***a* reaches notch **526**. Upon reaching the notch **526**, the piston snaps down into the notch. At this position, engagement mechanism is as depicted in FIG. **69**.

(140) Next, filament **530** is once again pulled proximally through device causing the needle **520** to move through another 180 degree rotation, returning the needle **520** to the home position as depicted in FIGS. **70**(A)-**70**(B). While antirotate notch **527** can move past tip **562** of pawl **560**, when filament **530** is moved distally once again to pick up the needle at notch **528**, needle **520** will move backward slightly until notch **527** engages with pawl tip **562**. At that point, surface **556***a* of engagement mechanism **550** rides up inclined surface **526***a* and travels over the outer lateral surface of the needle **520** until the piston snaps into notch **528**, preparing the suturing head **500** for another cycle as depicted in FIGS. **71**(A)-**71**(B).

(141) Suturing head **520** can be constructed using any desired techniques and any desired materials as described herein, for example, with reference to suturing head **356**. Preferably, suturing head **500** is made from a polymeric material to permit manufacture of a low-cost, disposable device. Suturing head **500** can be mounted on a flexible shaft as depicted in FIG. **39**(B).

(142) In accordance with still further aspects of the invention, for purposes of further illustration and not limitation, FIGS. **72-85** depict further variations of the device generally depicted at FIGS. **1-38**.

(143) As depicted in FIG. **72**, device **600** is provided with a handle **660** that has been found to be particularly user-friendly and comfortable. Device **600** also includes a suturing head **610**, an elongate tubular body **640**, and a roticulation region **650**.

(144) The roticulation region **650** is illustrated in FIG. **73**. Roticulation section includes a hub **652** that is attached to tubular body **640**. Hub **652** is rotatably mounted on a cylindrical bearing surface **658**, having a plurality of elongate detents **659** surrounding the bearing surface **658**. A detent ball **654** is contained within a detent housing **655**, wherein a spring **656** urges detent ball **656** into a detent **659**, preventing the hub from rotating freely, but also permitting hub to be rotated ("roticulated") about the axis of device **600**, thereby permitting roticulation of the suturing head **610**.

(145) As with the suturing head depicted, for example, in FIGS. **30-31**, a latch **612** is also provided in the embodiment of FIG. **72** to cover the suturing needle. Specifically, as depicted in FIGS. **74-76**, latch **612** is provided, and is preferably biased (e.g., by a spring) to the closed position. While latch **612** can be retracted proximally by pushing on the latch **612** itself, during a procedure latch **612** may not be easily accessible. Thus, if the device **600** should jam, to avoid the difficulty in moving the latch backward to permit the needle to fall out of device, a pull wire **616** is provided that is attached at its distal end to the latch **612** (inside of a bore **614**), and at its proximal end to a release trigger **618** that pivots about a point **618***a*. Thus, if it is desired to retract the latch **612** to permit the needle to fall out in the event of a jam, it can be released, the device **600** can be withdrawn, and the needle can be removed with forceps. The device **600** can then be reused with a new needle.

(146) FIGS. **77-83** depict an alternative drive mechanism for the suturing head **610**. Specifically, all components of the drive mechanism are fitted to one side of the suturing head **610***a*, rather than being anchored to both sides of the suturing head **610**. This is very advantageous in assembly. Specifically, all drive components (pulleys and the like) are attached to side **610***a* of the suturing head. This prevents any inconvenience in needing to align the pulleys and other drive components with two opposing housing sections, and facilitates assembly generally as this design permits the drive components to be stacked and attached to a single member. As will be noted, the drive components bear some similarity to those depicted in FIGS. **34-35**. A drive cable **634** is routed around a drive idler **624**, and into the drive pulley **620***a*. Drive pulley **620***a*, in turn, drives an idler pulley **621** by way of an actuator arm **628** when advancing the suturing needle. A link or strut **622** is provided that acts as a stop for rotation of pulley **621** by engaging a bearing surface **621***b* in

groove **621***a*. A needle engagement mechanism/needle assembly extension **628***a* is provided for driving the suturing needle (not depicted). In addition, a return cable **636** is routed around a return idler **626**, and into the return pulley **620***b*, which is concentric with the drive pulley **620***a*. Return pulley **620***b*, in turn, drives idler pulley **621** by way of actuator arm **628** in a direction opposite from the drive pulley **620***a*, causing engagement mechanism **628** a to return to the home position to repeat the half cycle. FIGS. **84-85** depict cross sectional and three dimensional wireframe views of the handle portion **660** of device **600**, respectively, depicting, for example, actuator handle **662** as well as the arrangement of interior passages through which drive and return cables are routed. The return cable **636** is preferably spring-loaded so as to cause the needle engagement mechanism **628***a* to return to its home position.

(147) In further accordance with the disclosure, embodiments of a suturing device are provided that includes an arced needle having a leading end, a second end, and a length of suture, a housing defining a track therein that receives the needle and defines a path for the needle to traverse, a needle driver operable to advance the needle along the circular path in a circular orbit, and a needle position detector including a needle position detection circuit. The needle position detection circuit is preferably configured and arranged to indicate when a portion of the needle is positioned at a predetermined location along the circular needle path.

(148) For purposes of illustration, and not limitation, FIGS. **86-93** depict aspects of a suturing device having a needle position detector that in turn includes a needle position detection circuit configured to determine the position of the suturing needle relative to the needle track of the suturing device. It will be appreciated that any of the presently disclosed embodiments can be modified to have such a needle position detection circuit, and that the present teachings concerning needle position detection circuits are applicable to other devices having circular needle drivers. In some embodiments, the needle can be configured to close an electrical circuit when it is present at the predetermined location, thereby revealing the location of the needle. For example, electrical current can flow through or along a portion of the needle in order to close the electrical circuit. In some implementations, the needle can be configured to actuate a mechanical switch that closes the electrical circuit. For example, the suturing device could be provided with discrete switches along the needle track that could be engaged and displaced by the needle pressing against them. Such switches could close or open circuits when pressure of the needle is applied to them. In a related embodiment, the needle can open an electrical circuit when the needle is present at the predetermined location in order for the position of the needle to be detected. For example, the needle can actuate a mechanical switch that opens the electrical circuit. In some embodiments, the needle position detection circuit can be configured to activate an indicator when the needle is positioned in the predetermined location. The indicator can include, for example, at least one light emitting diode, or other lighting device, vibratory device (e.g., piezoelectric element), or sound emitting device. In further implementations, the circuit can be operably coupled to a computing device or wireless device to transmit needle position information to a computing device so that the needle position can be indicated on a screen of a user device, operating room monitor, or the like.

(149) In some implementations, the at least one light emitting diode can be located in or on a handle of the suturing device. If desired, the indicator can include a plurality of light emitting diodes. For example, the plurality of light emitting diodes can be arranged in an arc shape and are spaced to indicate the needle location in the suturing device.

(150) With reference to FIG. **86**, an alternative embodiment of a latch **712** can be provided to cover the suturing needle within the suturing head of the suturing device. Specifically, as depicted in FIGS. **86-89**, latch **712** is provided, and is preferably biased (e.g., by a spring) to the closed position. While latch **712** can be retracted proximally by pushing on the latch **712** itself, during a procedure latch **712** may not be easily accessible. Thus, if the device should jam, to avoid the difficulty in moving the latch backward to permit the needle to fall out of device, a pull wire **716** is provided that is attached at its distal end to the latch **712** (inside of a bore **714**), and at its proximal

end to a release trigger, as with the embodiment of FIG. **72**.
(151) As illustrated, however, a second bore **715** is also provided in latch **712** alongside bore **714**. Bore **715** is connected to a channel **720** that is cut into the underside of the latch **712**. Bore **720** extends from a junction at a distal end of bore **715** and extends through the length of latch **712**, terminating at an arcuate end of latch **712** that is located immediately next to the needle of the device when the latch is closed, holding the needle in place in the needle track. Disposed within channel **720** is a conductor **722** that includes a conductive inner member **724**, such as a wire, surrounded by an insulating layer **726**. A distal tip portion of conductive inner member **724** is exposed, at least on an underside thereof, and is arranged to contact the arcuate suturing needle when a portion of the suturing needle is coincident with wire **724**. In some implementations, holder assembly **190**, which receives latch **712**, is electrically coupled to the handle **760** of the suturing device (such as by a separate conductor or through electrically conductive portions of the suturing device), which is in turn electrically coupled to a LED and power supply **780**, such as a battery or capacitor. Accordingly, when the needle is contacting the conductive inner member **724**, and also contacting holder assembly **190**, a circuit can be completed, which causes LED **770** to illuminate. This can be facilitated by fabricating component **190** from metal or other conductive material, as well as other components of the suturing device. Alternatively, a second conductor or conductive pad can be placed on the needle track and/or the needle track itself could be metal, or be provided with a conductive coating. Likewise, a second insulated conductor could be routed from the suturing head proximally to the handle with conductor **722** to permit a needle position detection circuit extend into the handle of the suturing device. As will be appreciated, when the needle is out of contact with the conductor **724**, the circuit is open, rather than closed, and the presence of the needle is not detected.
(152) With further reference to FIG. **90**, a handle **760** of the suturing device is presented. One or more conductors **774** extend proximally into the handle that carry electrical signals indicative of the closing of one or more needle position detection circuits as described herein. Conductor(s) **774** extend through handle **760** to complete a needle position detection circuit by coupling to a power supply **780** and LED. If desired, the circuit can further include a wireless transmitter **792** as known in the art to transmit the needle position information wirelessly. Also, if desired, a portion of the needle position detection circuit, including the battery and/or wireless transmitter can be provided in a removable module **790** that is sterile, and can be attached to the suturing device in the operating room prior to use. In another embodiment, all of the components of the needle position detection circuit can be integrally formed into the handle or other desired portion of the suturing device.
(153) In further implementations, it is possible to provide a plurality of conductors (two or more) that are disposed at spaced locations along the needle track. If desired, conductors can be placed every 15, 30, 45, 60 or 90 degrees along the needle track, as with the embodiment of FIGS. **91-92**. FIG. **91** illustrates an embodiment that places eleven contact pads **728** along the arcuate distal edge of the latch **712**, wherein each pad is connected to a separate insulated conductor **729** that carries back to the handle, passing through the channel **720** of latch **712**. As the suturing needle advances along the needle track, each successive contact pad **728** is contacted by the needle, completing a circuit with respect to each pad **728** through conductor **729**. This information can be used to illuminate a corresponding LED on the handle of the device. If desired, as illustrated in FIG. **92**, the LEDs **802** can be arranged circumferentially such that the circumferential location of each contact pad **728** along the needle track corresponds with the circumferential location of each LED on the display **800** on the handle, providing continuous feedback as to the position of the needle. If desired, the relative position of the gap **810** in the needle track can be provided in the indicia by providing a gap at a location that is in registration with the contact pads and gap of the actual suturing device. It will be appreciated that positional confirmation by way of electrical contact can be very effective in confirming needle location when the suturing device is located inside of a

patient's body and visibility is no available.
(154) FIG. **93** is a schematic representation of a surgical robot **900** including a robotic manipulator **920** that may be releasably attached to a suturing head (e.g., **156**) and controlled by a computer **930** that can in turn be provided with a display **940**. The rotational joints of the suturing head/robot can be provided with linear or rotational potentiometers, for example, to confirm angular displacement of various components of the robotic manipulator **920**. Computer **930** can be specially adapted to operate the robotic manipulator, and can be configured to display desired images on display **940**. In some implementations, signals from the needle position detection circuit described herein can be used by the computer **930** to determine the position of the needle in the needle track of the suturing head **156**. The needle position information can then be used to display the position of the needle on the display **940** with respect to the needle track. In various implementations, the needle position detection circuit is configured to be operably coupled to an electrical power supply, such as a battery, as mentioned above. Alternatively, the suturing device can be provided with a power and/or data port (e.g., **794**) to facilitate sterilization and transmission of needle position information.
(155) In some implementations, the needle position detection circuit can be configured to be electrically coupled to an anti-rotate spring of the suturing device of the suturing device, to a drive pawl of the suturing device, or to another portion of the suturing device. For example, the needle position detection circuit is configured to be electrically coupled to a needle track of the suturing device that defines the path for the needle to traverse. It will be further appreciated that various components of the suturing device described herein could be configured to conduct a low voltage signal to confirm when certain physical contacts occur with respect to the needle. For example, the anti-rotate spring **116**, pawl **98** or driving pin **198**/spring **200** can be provided with electrical current that can complete a circuit through needle when they are contacting needle. In some embodiments, the surface of the needle can be coated with an insulating material but the engagement surfaces of the notches of the needle/trailing edge of the needle can be exposed. This can be used to confirm, for example, when the drive notch of the needle is engaged by the needle driver, and when the anti-rotate notch has engaged the needle.
(156) The suturing devices of the presently disclosed embodiments can be used for laparoscopic procedures, including but not limited to laparoscopic colostomy, colectomy, adrenalectomy, splenectomy, repair of paraesophageal hernia, inguinal hernia repair, ventral hernia repair, Nissen fundoplication, liver lobectomy, gastrectomy, small bowel resection, treatment of small bowel obstruction, distal pancreatectomy, nephrectomy and gastric bypass. Those skilled in the art will recognize that the presently disclosed embodiments can be used in other laparoscopic procedures.
(157) In using the device **150** of the presently disclosed embodiments, the abdomen is insufflated with gas to create a working space for the user. Any gas known to those skilled in the art including, but not limited to, nitrogen or carbon dioxide, can be used. Access portals are established using trocars in locations to suit the particular surgical procedure. A variety of surgical instruments may then be inserted into the body through these access ports/cannulas. The user then introduces the distal end portion of suturing device **150** into a cannula, and then laterally articulates the suture head assembly **156** using the articulation lever **166** located just distal to the top of the handle **160**. The suture head assembly **156** is then positioned relative to the tissue/vessel to be sutured together, and the user locks the suture head assembly **156** in place using the locking lever **164**. The user then, through manipulation of the suturing device **150**, positions a plurality of separated tissue segments into the opening defined at the distal end portion of the suture head assembly **156** and within the aperture **218** of the needle holder assembly **188**. The user, using only one hand, may manipulate the device **150** while actuating the handle **160** to close an incision with a continuous suture whose stitches may be individually tensioned precisely and uniformly along the length of the suture similar to suturing done by hand in the conventional way. The user may employ a single suture which would extend the entire length of the incision or multiple sutures. Thus, by placement of the device **150** with the needle holder assembly aperture **218** spanning the incised tissue segments and

actuating the handle **160**, the suturing device **150** enables the user to lay down a running stitch or interrupted stitch to close the tissue incision in a time efficient manner. Those skilled in the art will recognize that any conventional procedure for conducting laparoscopic surgery can be used with the device **150**.

(158) The minimalized structural design of the suture head assembly **156** enables the user to have a clear, unobstructed view of the suturing needle **220** during advancement through the tissue segments during the course of a suturing operation, thereby enabling precise placement of the suturing device **150** to provide uniform sutures and precluding the risk of tearing tissue by placement too close to the edge of the incision. The suturing device **150** is then advanced a short distance along the incision and the aforementioned operation is repeated to produce another stitch comprising the suturing material or thread **246**.

(159) The user may continue to manipulate the suturing device **150**, alternately advancing and actuating rotation of the needle **220** about an axis that is generally parallel to the direction of advancement to create a continuous suture which may extend through the entire length of the incision or a series of interrupted stitches. After each individual stitch is laid down, the stitch is tightened by exerting a pull on the suturing material or thread **246** so that the resultant suture is tensioned uniformly along the length of the incised tissue segments. Therefore, a tight closure of the segments is accomplished and bleeding and tearing of tissue are minimized. Once the appropriate amount of suture material or thread **246** has been placed, the user can use a needle grasper to tighten and knot the formed stitches.

(160) The suturing device **150** may be configured in different ways with respect to length and angle of the suture head assembly **156**. The size of the needle **220**, the needle holder assembly **188**, the needle holder aperture **218** and the aperture position may also be varied for use in open surgery to perform procedures such as closing of the fascia, skin closure, soft tissue attachment, anastomosis, fixation of mesh, grafts and other artificial materials. Moreover, devices made in accordance with the teachings herein can be used in combination with needle loader devices described, for example, in U.S. patent application Ser. No. 12/175,442, filed Jul. 17, 2008.

(161) All patents, patent applications, and published references cited herein are hereby incorporated by reference in their entirety. It will be appreciated that one or more of the above-disclosed and other features and functions, or alternatives thereof, may be desirably combined into many other different systems or applications. Various presently unforeseen or unanticipated alternatives, modifications, variations, or improvements therein may be subsequently made by those skilled in the art which are also intended to be encompassed by the present disclosure.

Claims

1. A suturing device comprising: a housing defining an arcuate needle track therein, the arcuate needle track being configured to receive an arced suturing needle therein, the arcuate needle track having a first end and a second end and defining a first plane, wherein the housing defines a tissue capture gap between the first end and the second end of the arcuate needle track; a needle advancement drive that reciprocates between a driven position and a returned position, the needle advancement drive being configured and arranged to advance the arced suturing needle along the arcuate needle track from the returned position to the driven position, wherein the needle advancement drive comprises a laterally deflectable pawl that is configured to move into and out of engagement with an engagement surface of the arced suturing needle along a direction that is perpendicular to the first plane, and further wherein the laterally deflectable pawl is configured to contact an outer toroidal surface of the arced suturing needle when the needle advancement drive moves from the driven position to the returned position; and a needle position detection circuit configured to indicate when a portion of the arced suturing needle is positioned at a predetermined location along the arcuate needle track, the needle position detection circuit being configured to

complete an electrical circuit through the laterally deflectable pawl and the arced suturing needle.
2. The suturing device of claim 1, wherein the needle position detection circuit is configured to activate an indicator when the arced suturing needle reaches the predetermined location.
3. The suturing device of claim 2, wherein the indicator includes a light emitting device that is illuminated by the needle position detection circuit when the arced suturing needle reaches the predetermined location.
4. The suturing device of claim 2, wherein the indicator includes a vibration emitting device that is caused to emit vibration by the needle position detection circuit when the arced suturing needle reaches the predetermined location.
5. The suturing device of claim 2, wherein the indicator includes a sound emitting device that is caused to emit sound by the needle position detection circuit when the arced suturing needle reaches the predetermined location.
6. The suturing device of claim 1, further comprising a display screen configured to display a position of the arced suturing needle.
7. The suturing device of claim 1, wherein at least a portion of an outer surface of the arced suturing needle includes an electrically insulating coating, and further wherein the electrically insulating coating does not cover at least a portion of the engagement surface of the arced suturing needle to permit electrical continuity between the laterally deflectable pawl and the engagement surface of the arced suturing needle.
8. The suturing device of claim 7, wherein the engagement surface of the arced suturing needle comprises a notch formed into the arced suturing needle.
9. The suturing device of claim 7, wherein the engagement surface of the arced suturing needle comprises a trailing edge of the arced suturing needle.
10. A robotic surgical system, comprising: a robotic manipulator; the suturing device of claim 1, wherein the suturing device is configured to be driven by the robotic manipulator; and a computer operably coupled to the robotic manipulator and the needle position detection circuit, the computer being configured to display an indicia on a display based on an electrical signal received from the needle position detection circuit, wherein the indicia indicates a relative location of the arced suturing needle with respect to the arcuate needle track of the suturing device.
11. The robotic surgical system of claim 10, further comprising the display, the display being operably coupled to the computer to display the indicia illustrating the relative location of the arced suturing needle with respect to the arcuate needle track of the suturing device.
12. A suturing device comprising: a housing defining an arcuate needle track therein, the arcuate needle track being configured to receive an arced suturing needle therein, the arcuate needle track having a first end and a second end and defining a first plane, wherein the housing defines a tissue capture gap between the first end and the second end of the arcuate needle track; a needle advancement drive that reciprocates between a driven position and a returned position, the needle advancement drive being configured and arranged to advance the arced suturing needle along the arcuate needle track from the returned position to the driven position along a first direction; an anti-rotate spring that is biased to extend into the arcuate needle track to contact an engagement surface of the arced suturing needle to prevent movement of the arced needle along the needle track along a second direction that is opposite the first direction; and a needle position detection circuit configured to indicate when a portion of the arced suturing needle is positioned at a predetermined location along the arcuate needle track, the needle position detection circuit being configured to complete an electrical circuit through the anti-rotate spring and the engagement surface of the arced suturing needle.
13. The suturing device of claim 12, wherein the needle position detection circuit is configured to activate an indicator when the arced suturing needle reaches the predetermined location.
14. The suturing device of claim 13, wherein the indicator includes a light emitting device that is illuminated by the needle position detection circuit when the arced suturing needle reaches the

predetermined location.
15. The suturing device of claim 13, wherein the indicator includes a vibration emitting device that is caused to emit vibration by the needle position detection circuit when the arced suturing needle reaches the predetermined location.
16. The suturing device of claim 13, wherein the indicator includes a sound emitting device that is caused to emit sound by the needle position detection circuit when the arced suturing needle reaches the predetermined location.
17. The suturing device of claim 12, further comprising a display screen configured to display a position of the arced suturing needle.
18. The suturing device of claim 12, wherein at least a portion of an outer surface of the arced suturing needle includes an electrically insulating coating, and further wherein the electrically insulating coating does not cover at least a portion of the engagement surface of the arced needle to permit electrical continuity between the anti-rotate spring and the engagement surface of the arced needle.
19. The suturing device of claim 18, wherein the engagement surface of the arced suturing needle comprises at least one of a notch formed into the arced suturing needle or a trailing edge of the arced suturing needle.
20. A robotic surgical system, comprising: a robotic manipulator; the suturing of claim 12, wherein the suturing device is configured to be driven by the robotic manipulator; and a computer operably coupled to the robotic manipulator and the needle position detection circuit, the computer being configured to display an indicia on a display based on an electrical signal received from the needle position detection circuit, wherein the indicia indicates a relative location of the arced suturing needle with respect to the arcuate needle track of the suturing device.
21. The robotic surgical system of claim 20, further comprising the display, the display being operably coupled to the computer to display the indicia illustrating the relative location of the arced suturing needle with respect to the arcuate needle track of the suturing device.