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(54) **ROBOTICALLY SUPPORTED LAPAROSCOPIC ACCESS TOOLS**

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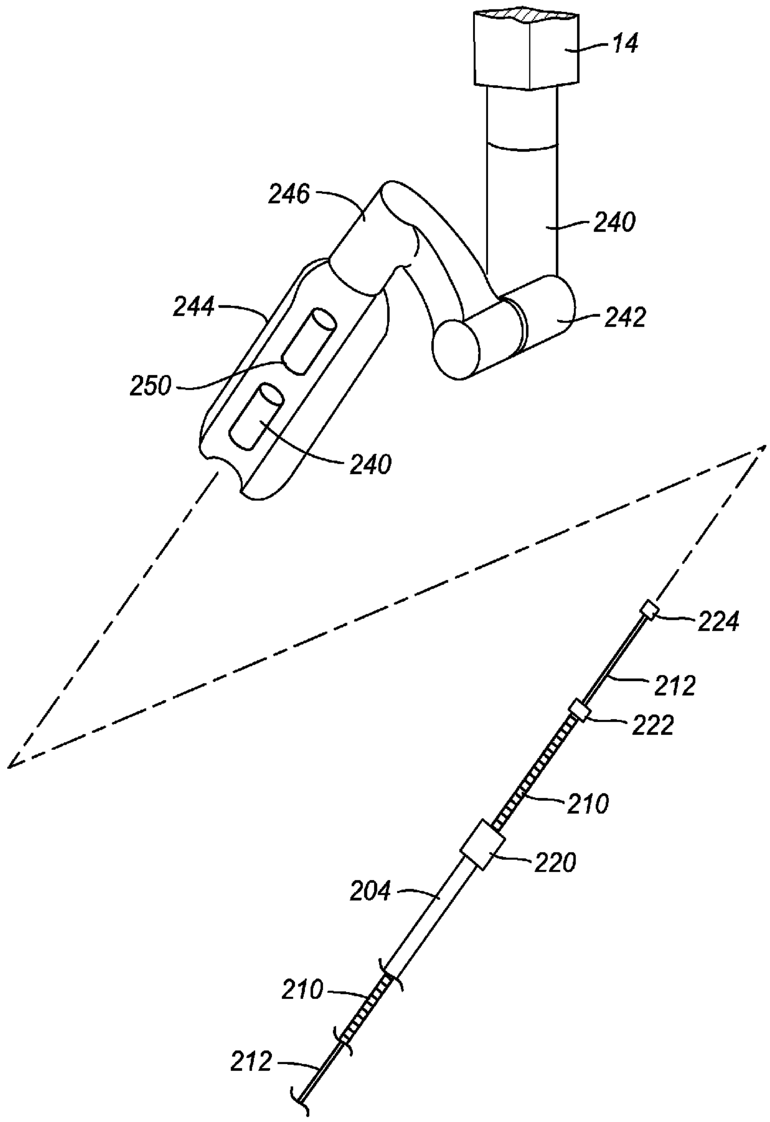
(57) **ABSTRACT**

Surgical tools intended for use with robotic system include a shaft having a distal effector end and a proximal attachment end. A flexible cable having a distal effector end and a proximal attachment end is slidably received in the central passage of the shaft, and a flexible cable wire assembly includes a pull/push wire having a distal effector end and a proximal attachment end slidably received in a lumen of the pull/push cable. An end effector is operably attached to the distal effector ends of the flexible cable and the distal effector end of the pull/push wire, and the end effector is disposed distally beyond the distal effector end of the shaft and is actuated by axially translating the pull/push wire relative to the flexible cable in the flexible cable wire assembly.



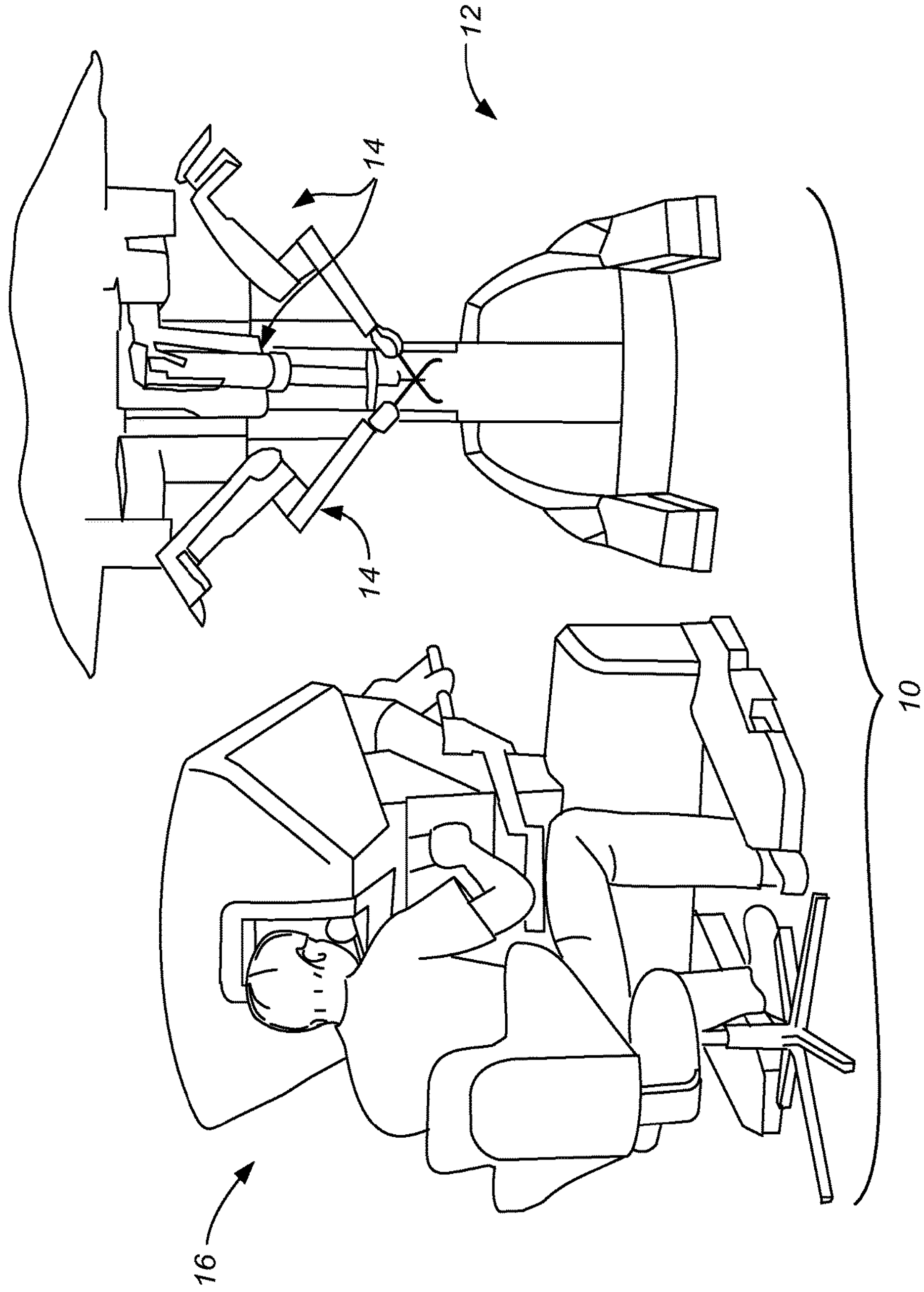


FIG. 1
(PRIOR ART)

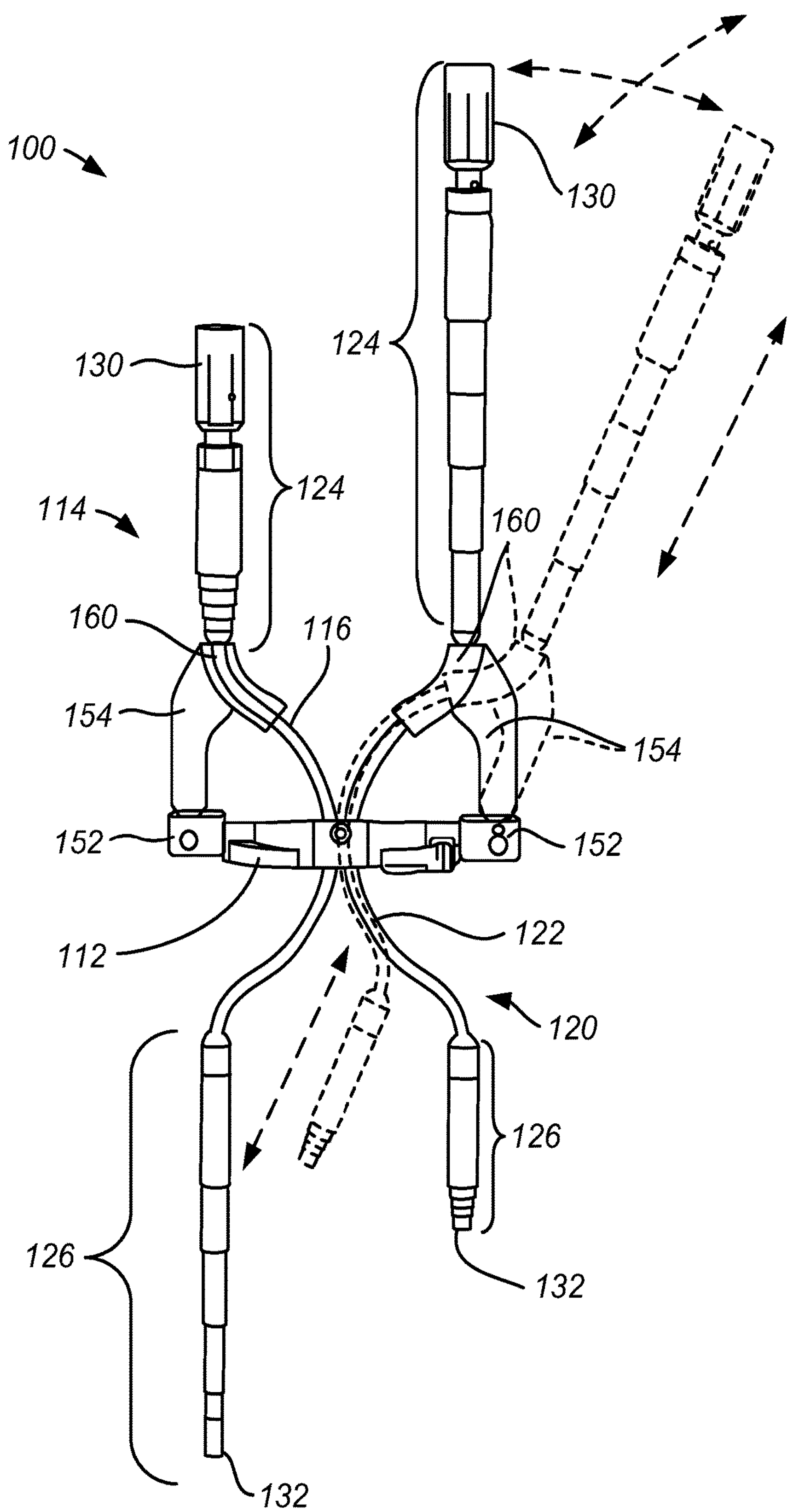


FIG. 2
(PRIOR ART)

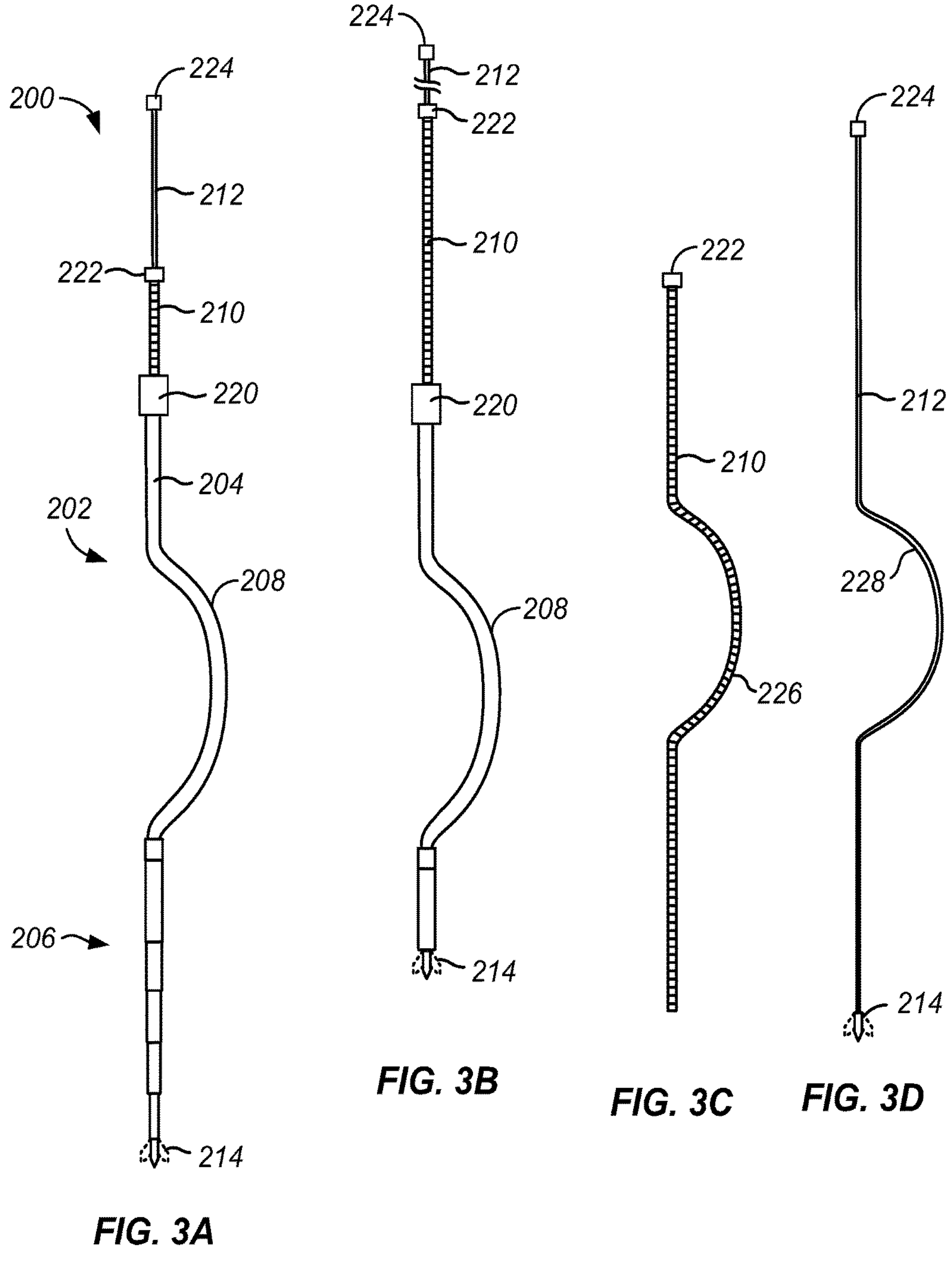


FIG. 3A

FIG. 3B

FIG. 3C

FIG. 3D

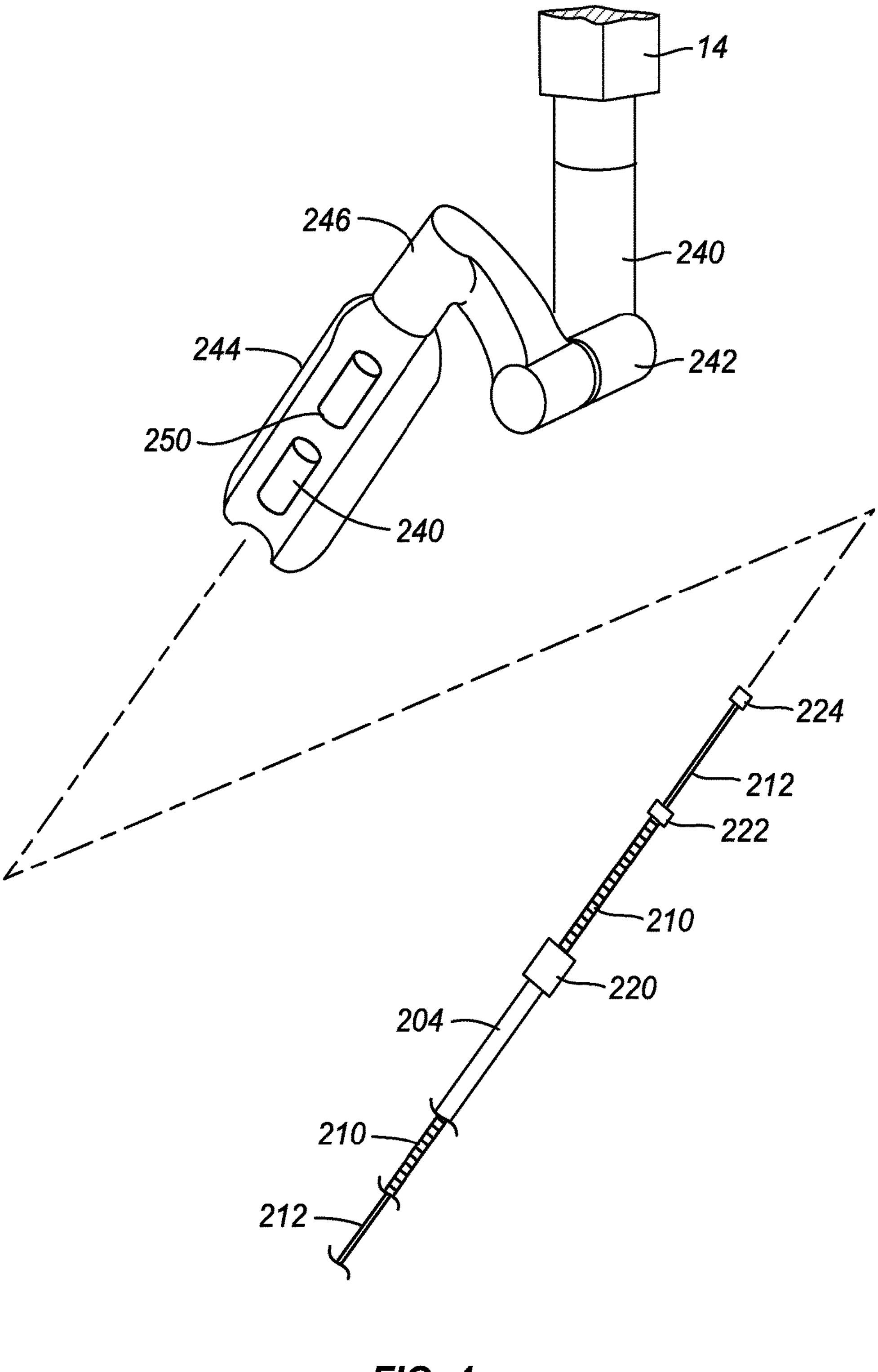


FIG. 4

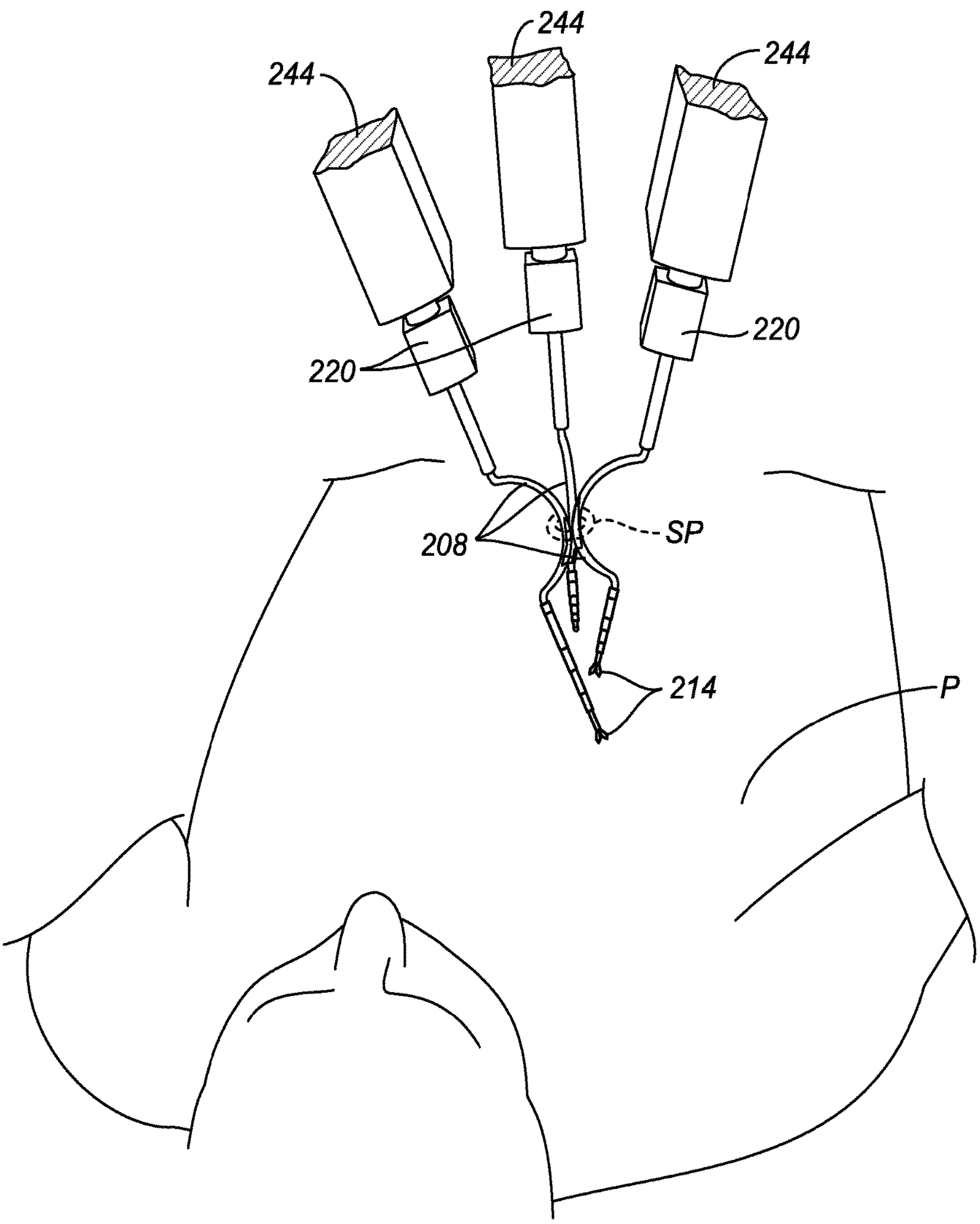


FIG. 5

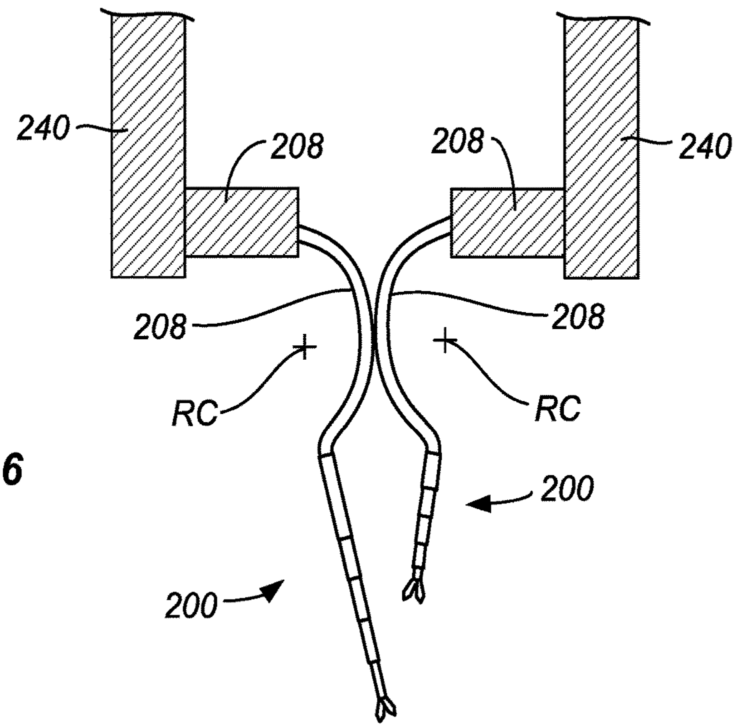

240
208
208
240
208
208
RC
RC
200
200

FIG. 6

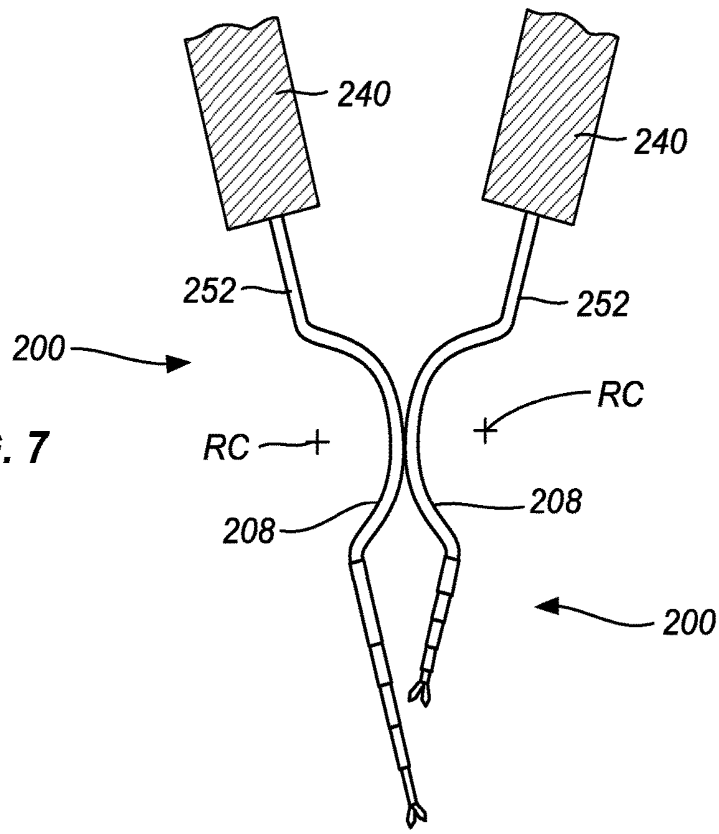

240
240
252
252
200
RC
RC
208
208
200

FIG. 7

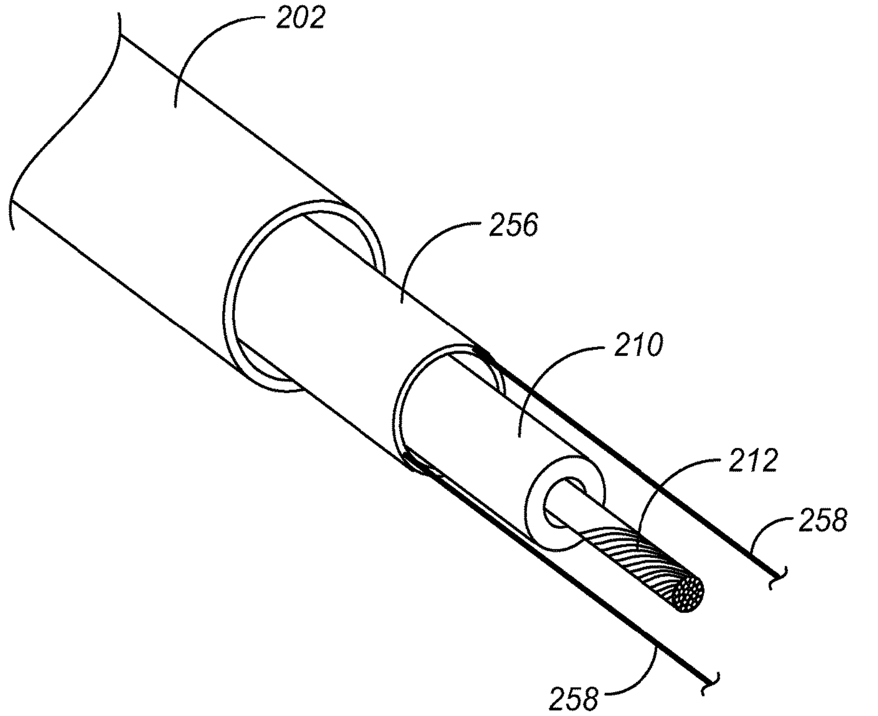

202
256
210
212
258
258

FIG. 8

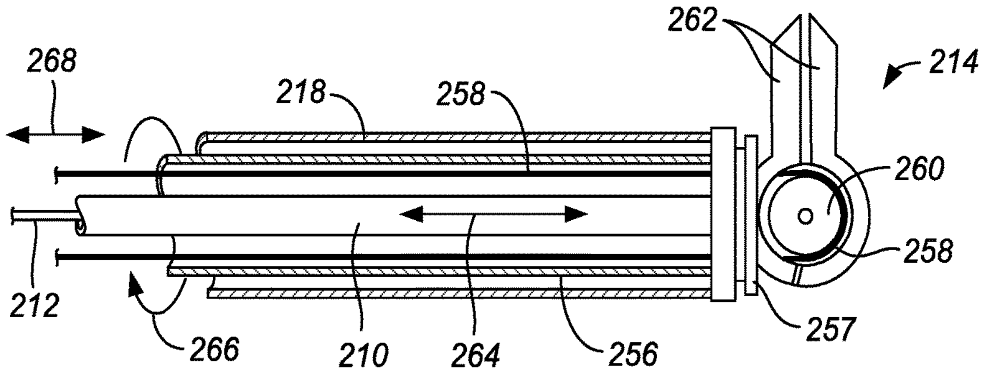

262
214
268
218
258
260
258
212
266
210
264
256
257

FIG. 9

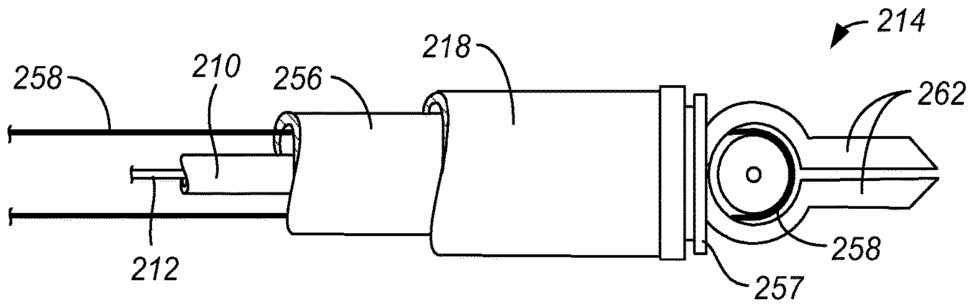


FIG. 10A

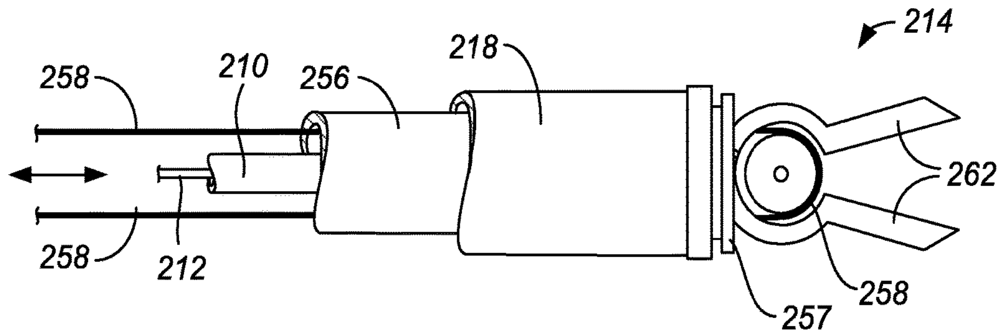


FIG. 10B

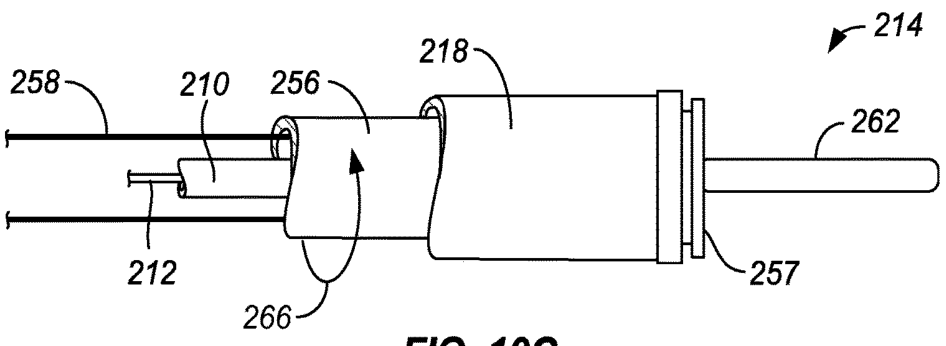


FIG. 10C

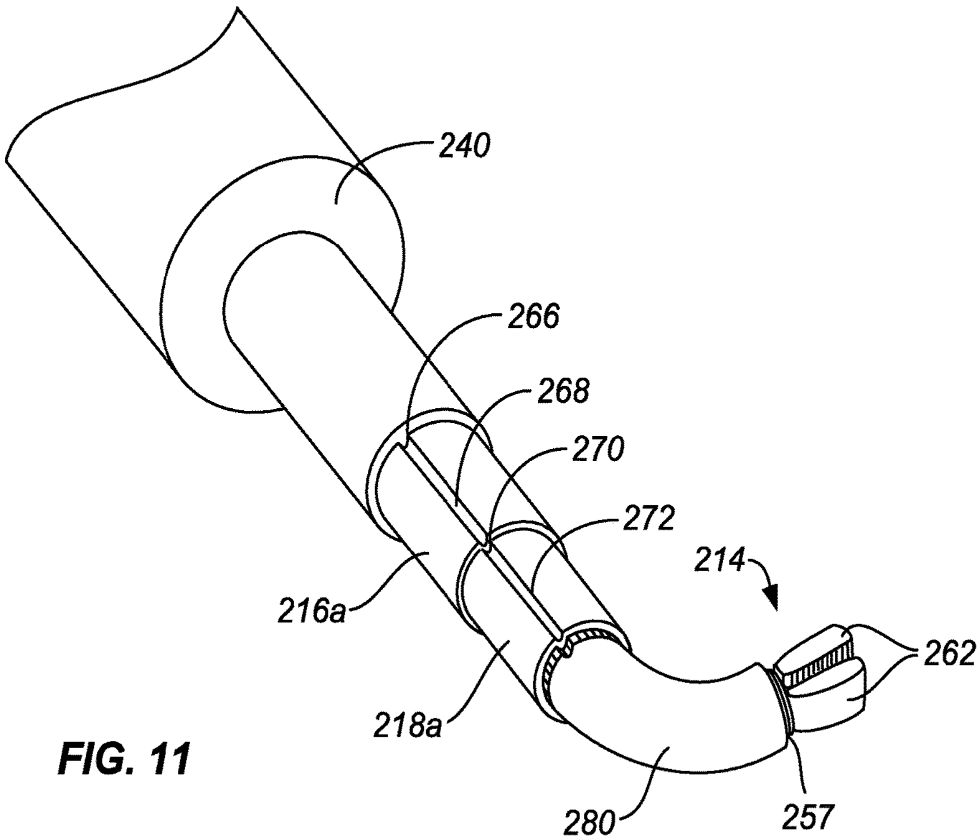

240
266
268
270
272
214
216a
262
218a
280
257

FIG. 11

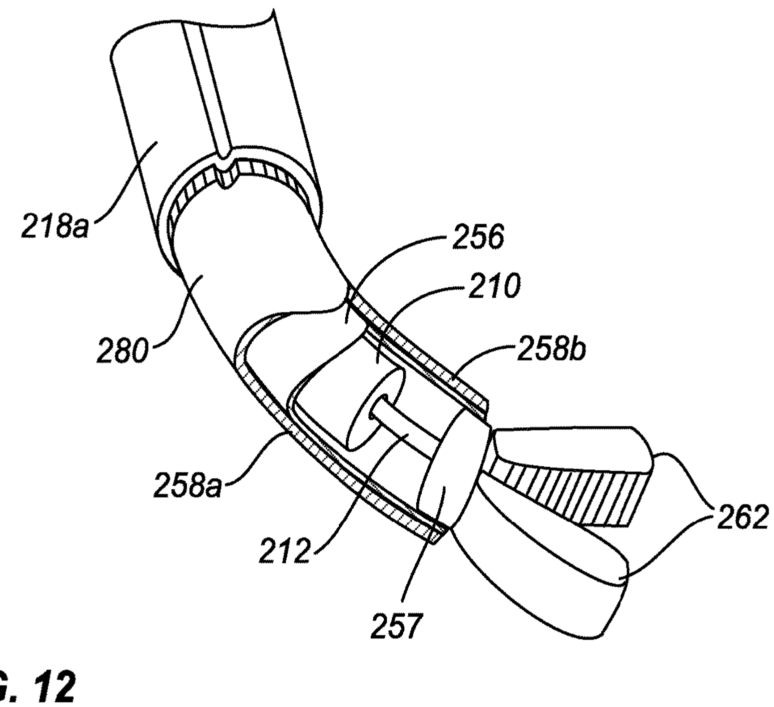

218a
256
210
280
258b
258a
262
212
257

FIG. 12

ROBOTICALLY SUPPORTED LAPAROSCOPIC ACCESS TOOLS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of Provisional Application No. 62/655,662 (Attorney Docket No. 41628-714.101), filed on Apr. 10, 2018, the full disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The present invention relates generally to medical systems, tools, and methods. More particularly, the present invention relates to systems and tools for robotically assisted laparoscopic access, typically for access of multiple robotically manipulated tools through a single incision in the umbilicus or other location.

[0003] In recent years, many open surgical procedures performed in the abdominal cavity have been replaced by minimally invasive procedures performed through several very small incisions using an endoscope, referred to as a laparoscope, inserted through one of the incisions. The other incisions are used for introducing surgical tools, and the abdominal cavity is inflated to create a space for performing the surgery. Such procedures are commonly called "laparoscopic", and can be used for gallbladder removal, hernia repair, hysterectomy, appendectomy, gastric fundoplication, and other procedures. Similar endoscopic, thoracoscopic and other procedures are performed in other body cavities with or without inflation.

[0004] While a great advance over open surgical procedures, which can require an incision of several inches or more through the abdominal wall, such laparoscopic procedures still require incisions through muscle or fascia in several separate sites. Each incision may increase the risk of infection, bleeding trocar site hernia, increased postoperative pain, compromised cosmetic result and other adverse events for the patient.

[0005] As an improvement over such laparoscopic procedures, "single port" laparoscopy has been proposed where a single access port is inserted through the umbilicus (the patient's navel). Access solely through the umbilicus is advantageous since it provides superior cosmetic and functional results. Introducing the laparoscope and all other tools necessary for the surgery through a single port, however, makes performance of the procedures more difficult. In particular, the use of conventional laparoscopic tools, which are typically straight, makes it difficult to approach a single target area in the treated tissue with two or more tools at the same time.

[0006] Further improvements in the field of single port laparoscopic surgery are described in U.S. Patent Publications 2012/0116362 and 2016/0081752, commonly assigned with the present application, the full disclosures of which are incorporated herein by reference. As generally described in these applications, systems for performing single port laparoscopic procedures include a transcutaneous seal and a plurality of tools. The tools comprise a substantially rigid tubular seal having a core which is translatably and rotatably disposed in the sleeve. The handle at the proximal end of the tool controls an end effector at the distal end of the tool. The sleeves of the tools are locked in the transcutaneous seals and remain in a fixed geometric relationship which prevents the tools from interfering with each other during laparoscopic procedures. Adjacent tools are held by a pivot structure in US2012/0116362 and by an external frame having a double pivot arm in US2016/0081752. While functional and a significant advance in the art, it would be desirable to incorporate certain design features of such manual single port access systems into robotically manipulated laparoscopic tool manipulation systems.

[0007] Thus, it would be a benefit to provide further improved systems and tools for laparoscopic access through single and individual ports for performing minimally invasive robotic surgical procedures. It would be particularly desirable if the robotically manipulated tools were configured to permit multiple tool access to abdominal and other surgical target sites through small single incisions or the umbilicus with a minimum interference between adjacent tools during the performance of a procedure. At least some of these objectives will be met by the inventions described hereinafter.

2. Description of the Background Art

[0008] U.S. Patent Publications 2012/0116362 and 2016/0081752 have been described above. Surgical robotic systems of the type suitable for use with the laparoscopic tools of the present invention are described in US20060167440; US20090163931; US20140188130; US20110118709; US20130116712; US20160235496; US20070021738; and US20030045778.

SUMMARY OF THE INVENTION

[0009] In a first aspect of the present invention, a laparoscopic tool is configured to be mounted on an arm of a surgical robotic system, such as a commercially available surgical robotic system of the type manufactured by Intuitive Surgical Systems, Inc., or any other commercial vendor. In particular, the laparoscopic tools of the present invention will be configured to be removably attached to the manipulable surgical robotic arms of the surgical robotic systems so that the robotic arms may freely move the laparoscopic tools in space, typically with six degrees of freedom, as well as manipulate components within the laparoscopic tools in order to move and actuate surgical effectors carried by the tools.

[0010] The tools described in this application are designed to work with the robotic systems, such as those which operate on the "remote center" principle. The robotic arms of such robots move in two planes rotated about the pivots which are positioned at the right angle to each other. A robotic cannula may be rotated by the arm in these two planes, e.g. up and down as well as laterally and medially or combination of these movements. These movements will change the position (angle) of the cannula in relation to the wall of the cavity maintaining the "remote center" of the cannula always in the point of insertion.

[0011] The laparoscopic tools of the present invention typically comprise a shaft, a flexible cable, a pull/push wire, and an end effector. The shaft has a distal effector end and a proximal attachment end. A central passage extends through the shaft between the ends and slidably receives the flexible cable which also has a distal effector end and a proximal attachment end. The pull/push wire, which also has a distal effector end and a proximal attachment end, is in turn slidably received in a lumen of the flexible cable to form a flexible cable wire assembly. The end effector is operably attached to both the distal effector end of the flexible cable and the distal effector end of the pull/push wire. The end effector will be disposed distally beyond the distal effector end of the shaft and may be actuated by axially translating the pull/push wire relative to the flexible cable wire assembly. In this way, the distal effector ends of each of the tool shaft, the flexible cable, and the pull/push wire are configured to be removably attached to the robotic arm of the surgical robotic system so that, in addition to moving the laparoscopic tool as a whole through free space, the robotic arm can also axially reposition the flexible cable wire assembly relative to the shaft, rotate the flexible cable wire assembly relative to the shaft, and axially translate the pull/push wire relative to the flexible cable of the flexible cable wire assembly to actuate the end effector.

[0012] In specific embodiments, the laparoscopic tool may further comprise a telescoping section extending distally of the distal effector end of the shaft. Such as telescoping section can accommodate extension and retraction of the flexible cable wire assembly which results from manipulation by the surgical robotic arm, while serving to support and protect the flexible cable wire assembly as it is being extended and retracted. The shaft of the laparoscopic tool may also further comprise (a) a semicircular mid-portion end (b) straight proximal and distal sections which lay along a common axis, where the flexible cable wire assembly can bend to accommodate the semicircular mid-portion as the flexible wire cable assembly is axially translated in the central passage of the shaft by the robotic arm.

[0013] In still further specific aspects, the distal end effector of the tool shaft may be configured to be attached to a robotic arm so that the robotic arm can reposition the entire tool with six degrees of motion. The flexible cable wire assembly may be configured to be rotatably and translatably attached to one or more driver(s) in the robotic arm so that these drivers can axially and rotationally reposition the flexible cable wire assembly relative to the shaft. Similarly, the pull/push wire will be configured to be translatably attached to one or more driver(s) in the arm to axially translate the pull/push wire relative to the flexible cable in the flexible cable wire assembly which in turn will actuate the end effector. In this configuration, the robotic arm and the tool are positioned in a configuration where an imaginary line connecting proximal and distal segments of the tool penetrates the cavity wall at the point of "remote center". The distance from this point of remote center to the point of true insertion would be equal to the radius of the semicircle of a mid-segment of the tool

[0014] In a second aspect of the present invention, a method for performing robotic surgery utilizes two or more laparoscopic or other tools which are configured to pass through a single percutaneous port or other passage in a patient, typically a laparoscopic or other minimally invasive port, and often a port configured to provide access to the abdomen through the umbilicus. The method comprises providing a surgical robotic system of the type having at least first and second robotic arms. At least first and second surgical tools are provided, where each tool includes a shaft, a flexible cable and wire assembly, and an end effector, generally as described above. The first tool is attached to the first robotic arm, and the second tool is attached to the second robotic arm. The first and second robotic arms may be individually and/or simultaneously manipulated to position the shafts of the tools in free space and through the port or other passage as well as to operate the end effectors on each of the surgical tools to surgically interact with tissue while a mid-portion of each shaft remains positioned within the port in a manner such that the mid-portions of the shafts avoid interference during all or at least a portion of the surgical procedure.

[0015] In exemplary embodiments of the methods of the present invention, the mid-portions of each tool are semi-circular and extend radially inwardly from a common axis of proximal and distal sections of the shaft. Such curved geometries allow the first and second arms to be manipulated to rotate the tools about a virtual center point of the semi-circular mid-portion while that semi-circular mid-portion remains within the single percutaneous passage. Such geometries are particularly beneficial since they allow the surgical tools to be triangulated at the target while avoid interference of the shafts above the surgical site.

[0016] In other preferred aspects of the methods, the distal portion of at least some of the tools will provide telescoping sections extending distally of the distal end effector to accommodate extension and retraction of the flexible cable wire assembly.

[0017] In still further specific aspects of the methods of the present invention, the first and second robotic arms are manipulated to cause each of the (a) repositioning the entire tool with six degrees of motion, (b) rotating and translating the flexible cable wire assembly to axially and rotationally reposition the flexible cable wire assembly relative to the shaft, (c) axially translate the pull/push wire relative to the flexible cable in the flexible cable wire assembly to actuate the end effector.

[0018] In further aspects, the flexible cable wire assemblies of the present invention may further include a bidirectional torque tube located coaxially over the flexible cable and having a proximal end coupled to the one or more driver(s) in the robotic arm. The bidirectional torque tube will typically be configured to transmit both torque (rotation about its axis) and axial translation (translation along its axis) from the one or more driver(s) in the robot arm to the end effector. Use of the bidirectional torque tube in addition to the flexible cable of the flexible assembly is advantageous as the torque tube can be made from a more robust material such as a braid or other reinforced polymer tube, a counterwound coiled tube, or the like, in order to enhance both the transmission of axial and rotational forces.

[0019] In still further exemplary and preferred embodiments, the flexible cable wire assembly may further comprise an angulation disc and an angulation cord coupled to the one or more driver(s). Use of the angulation disc and the angulation cord allows the end effector to be rotated about an axis normal to the axial direction of the bidirectional torque tube. In particular, such structure allows the end effector, which is typically an asymmetric jaw structure or similar asymmetric effector, to be rotated about an axis transverse to the shaft while maintaining the position of all other shaft components immobile.

INCORPORATION BY REFERENCE

[0020] All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

[0022] FIG. **1** illustrates a commercially available robotic surgical system of the type that can be used to manipulate the laparoscopic tools of the present invention.

[0023] FIG. **2** illustrates a pair of laparoscopic tools intended for manual manipulation in surgical procedures where said tools are intended for single port access and are pivotally mounted in a support frame, with a repositioned view of one of the tools shown in broken line.

[0024] FIGS. **3**A-**3**D illustrate a laparoscopic tool constructed in accordance with the principles of the present invention with FIGS. **3**A and **3**B showing the tool with an extended and a retracted telescopic distal extension, respectively, and FIGS. **3**C and **3**D showing internal component parts of the laparoscopic tool.

[0025] FIG. **4** illustrates mounting of a proximal attachment end of the laparoscopic tool onto an arm of a surgical robot.

[0026] FIG. **5** illustrates three laparoscopic tools constructed in accordance with the principles of the present invention attached to three arms (shown partially) of a surgical robotic system (not shown) performing a single port laparoscopic surgical procedure.

[0027] FIGS. **6** and **7** illustrate alternative attachments of the laparoscopic tools to the surgical robotic arms.

[0028] FIG. **8** illustrates the incorporation of a bidirectional torque cable coaxially over a Bowden cable with an end effector angulation cord between the bidirectional torque cable and the Bowden cable in a particular embodiment of the laparoscopic tool of the present invention.

[0029] FIG. **9** is a cross-sectional view of a distal portion of a laparoscopic tool of the present invention showing connections of the bidirectional torque cable, the Bowden cable, and the end effector angulation cord of FIG. **8** to an end effector.

[0030] FIGS. **10**A through **10**C illustrate how the bidirectional torque cable, the Bowden cable, and the end effector angulation cord of FIGS. **8** and **9** are used to manipulate the end effector in accordance with the present invention.

[0031] FIG. **11** illustrates an alternative embodiment of an end effector mounted on a steerable shaft segment.

[0032] FIG. **12** is a detailed view of the steerable shaft segment of FIG. **11** with portions broken away.

DETAILED DESCRIPTION OF THE INVENTION

[0033] Referring now to FIG. **1**, the laparoscopic tools and end effectors of the present invention are intended to be used with and manipulated by known and commercially available robotic systems, such as a da Vinci® Surgical System available from Intuitive Surgical, Inc., Sunnyvale, Calif. An exemplary robotic surgery system **10** includes a robotic station **12** that includes a plurality of robotic arms **14** (with three being illustrated) and a controller module **16** where a physician can view the procedure and control the surgical arms to manipulate the tools to perform a desired laparoscopic or other surgery.

[0034] Referring now to FIGS. **2**, a prior art laparoscopic tool system **100** of the type described in US2016/0081752, previously incorporated herein by reference, comprises a tool attachment frame **112** having a first tool **114** and a second tool **120** pivotally attached thereto. The first tool has a mid-portion **116** and the second tool has a mid-portion **122**, and both mid-portions extend generally inwardly from an axis **128** of the tool. Both mid-portions **116** and **122** are preferably circular and have a radius emanating from a virtual rotation point which is generally aligned with a pivot **152** of an assembly attached to an outer periphery of the tool attachment frame **112**. Having the virtual rotation points of each tool located outside the periphery of the ring in the location of double pivot allows the generally circular mid-portions **116** and **22** to pass and move through the central opening **118** of the frame **112** without interfering with each other. While the mid-portions **116** and **22** could alternatively have non-circular geometries which extend radially inward relative to the frame **112**, for example being oval or polyhedral, the circular shape causes the passage point of the mid-portion to remain fixed within the central opening **118** of the frame so long as the tool is constrained to move in to orthogonal planes by the pivot attachment as will be explained in more detail hereinafter. While in some instances, it would be possible to modify the arms of a surgical robot to manipulate these prior art tools, these tools are intended to be manually manipulated and any attempt to directly interface the look with a robotic arm would be suboptimum.

[0035] Referring now to FIGS. **3**A-**3**D, a laparoscopic tool **200** constructed in accordance with the principles of the present invention comprises a shaft **202** having a proximal section **204** and a distal section **206** separated by a mid-portion **208**. The shaft has a hollow central passage which receives a flexible cable **210**. The flexible cable **210** has a hollow lumen extending from a distal end to a proximal end thereof which receives a pull/push wire **212** having an end effector **214** at its distal end. The shaft **202** has a proximal attachment member **220** at its distal end. The flexible cable **210** has a proximal attachment member **222** at its proximal end, and the pull/push wire **212** has a proximal attachment member **224** at its proximal end. The distal section **206** of the shaft **202** is preferably joined as a telescoping structure having a plurality of segments **216** including a distal-most segment **218** that carries the end effector **214**. The telescoping distal section may be axially extended and retracted to accommodate full axial extension of the flexible cable **210**, as illustrated in FIG. **3**A, as well as full axial retraction of the flexible cable, as illustrated in FIG. **3**B. The flexible cable **210**, by nature of its flexibility, provides a conformable central region **226** to accommodate bending as the cable passes through a preferred C-shaped mid-portion **208** of the shaft. Similarly, the pull/push wire **212** will have a conforming region **228** to accommodate bending as it is extended and retracted through the conforming region **226** of the flexible cable **210**.

[0036] The laparoscopic tool **200** can thus allow manipulation of the end effector **214** using a surgical robotic arm in a number of ways. First, the entire laparoscopic tool **200** can be moved through free space, typically with up to six degrees of freedom, by grasping and moving the proximal attachment member **220** of the shaft. By "six degrees of freedom of movement, it is meant that the surgical arm can move the arm (1) forward/backward along the tool's axis, (2) laterally (side-to-side) in a first direction orthogonal to the axis, (3) laterally (side-to-side) in a second direction orthogonal to the axis and to the first direction, and (4-6) rotation about each of the three perpendicular axes, i.e. yaw (first lateral axis), pitch (second lateral axis), and roll (longitudinal tool axis).

[0037] In specific embodiments, the robot arm will move the laparoscopic tool **200** in at least three different directions including up and down (i.e. closer to the patient and away from). Such up and down movement may be used at the beginning of the procedure for example during the setup. Once the set-up is complete, the distance from a proximal portion of the laparoscopic tool held by the robotic arm to the single port or other entry point into the body cavity will typically remain the same. The initial distance is selected so a "remote center" **208** (FIGS. **7** and **8**) of the laparoscopic tool **200** is at the level of the entry point into the body cavity. From this time on, all movement of the robotic arm will maintain this distance so that the remote center remains the same location at the point of entry through the abdominal wall.

[0038] Axial translation of the cable and wire assembly (including the flexible cable **210** and pull/push wire **212**) relative to the shaft **202** can be achieved by grasping and manipulation of the proximal attachment member **222** at the proximal end of the flexible cable **210**. Similarly, rotation of the cable and wire assembly about the assembly's longitudinal axis can also be achieved by grasping and rotation of the proximal attachment member **222** at the proximal end of the flexible cable **210**. In addition, axial translation of the pull/push wire **212** relative to the flexible cable **210** to actuate an end effector may be achieved by manipulation of the proximal attachment **224** at the proximal end of the pull/push wire **212**.

[0039] Referring now to FIG. **4**, such manipulation of the proximal attachments members **220**, **222**, and **224** by a surgical arm **14** is schematically illustrated. The surgical arm **14** may include a first arm segment **240** and a second arm segment **246** connected to the first arm segment by a rotatable joint **242**. A tool connector **244** having at least a first driver **248** and a second driver **250** is connected to the distal or free end on the second arm segment **246**. The laparoscopic tool **200** may be attached to the tool connector **244** and operably coupled to the drivers **248** and **250** by connecting the proximal attachment member **220** of the shaft directly to the tool connector **244**. The proximal attachment member **222** of the flexible cable may be connected to the first driver **248** while the proximal attachment member **224** of the pull/push wire may be connected to the second driver **250** herein.

[0040] The first driver **248** will typically be configured to both axially translate and rotate the proximal attachment member **222** on the flexible cable **210** while the second driver **250** will typically be configured to at least axially translate and optionally rotate the proximal attachment member **224** on the pull/push wire **212**. In this way, the laparoscopic tool **200** can be attached to and be fully manipulated via the surgical arm **14** of the surgical robot during a surgical procedure.

[0041] Referring now to FIG. **5**, the tool connectors **244** of the three surgical robotic arms **14**, as illustrated previously in FIG. **1**, can be attached to the proximal attachment members **220** of three different laparoscopic tools as generally described previously. Instead of an end effector, however, one of the surgical tools may provide a laparoscope to allow viewing of the surgical site during performance of the procedure. The three laparoscopic tools **200** are typically introduced sequentially through a single port (SP) such that the C-shaped mid-portions **208** of each are clustered within the access passage provided by the port. The robotic arms **14** are able to move each of the laparoscopic tools **200** independently so that the C-shaped mid-portions **208** remain within the single port SP with minimal or no interference with each other. The end effectors **214**, however, can remain laterally separated as they are engaged with tissue to perform the desired procedure. Specific movements of the end effectors will be provided by manipulating the flexible cable and pull/push wires separately using the internal drivers shown in FIG. **4**.

[0042] FIGS. **6** and **7** illustrate alternative attachments of the laparoscopic tools **200** to the surgical robotic arms. In particular, FIG. **6** illustrates the C-shaped mid-portions **208** of the tools being attached by lateral extensions from the bottoms of each arm segment **240**. FIG. **7** illustrates straight proximal shaft portions **252** extending into the bottoms of each surgical arm segment **240**.

[0043] FIG. **8** illustrates an optional modification to the flexible cable assembly where a bidirectional torque tube **256** is located coaxially over the exterior of the flexible cable **210**. An end effector angulation cord **258** extends through an annular gap between the interior surface of the bidirectional torque tube **256** and an exterior surface of the flexible cable **210**. The pull wire **212** for actuating the end effector **214** is disposed in a central lumen of the flexible cable **210**, as in prior embodiments.

[0044] Referring now to FIG. **9**, the assembly of the flexible tube **210**, the pull wire **212**, the bidirectional torque tube **256**, and the end effector angulation cord **258** extends through a distal-most segment **218** of the telescoping distal section **206** of the device shaft **202**. The bidirectional torque tube **256** is typically attached to a rotating base **257** so that rotation of the torque tube will rotate the end effector **214** which is mounted on the base. The torque tube **256** may be rotated together with the flexible tube **210** in the same manner as the flexible tube is rotated by itself. The addition of the torque tube enhances the torsional stiffness as well as the axial pushability of the flexible tube assembly. Thus, pulling and pushing the torque tube **256** in the directions of arrow **264**. In addition, rotation of the torque tube **256** in the directions of arrow **266** will cause the end effector **214** to rotate about an axis of the flexible tube assembly and the distal-most segment of the shaft.

[0045] In addition, the end effector **214** may be rotated about an axis transverse to the axis of the shaft segment **218** by drawing on either end of the end effector angulation cord **258**, as shown by arrow **268**. The end effector angulation cord **258** is disposed around the periphery of an angulation disc **260** which in turn is coupled to the end effector **214**. The end effector angulation cord will cause the angulation disc **260** to turn and cause the end effector to turn as well. The annular space between the exterior of the flexible tube **210** and the inner wall of the bidirectional torque tube **256** also protects the end effector angulation cord **258**, and additional eyelets, channels, and other structure may be provided in the annular space to assure that the end effector angulation cord **258** can be pulled in either direction to rotate the end effector, for example from a laterally deflected orientation as shown in FIG. **9** to an axially aligned orientation as shown in FIG. **10**A.

[0046] Referring now to FIGS. **10**A through **10**C, use of the flexible cable assembly for manipulating the end effector **214** will be described. As shown in FIG. **10**A, the end effector **214** may comprise a pair of jaws pivotally mounted on a base **257** to open (FIG. **10**B) and close (FIGS. **9** and **10**A). Initially, the jaws **262** may be closed, as shown in FIG. **10**A. The jaws may then be opened, as shown in FIG. **10**B, by drawing on the pull wire **212** in the lumen of the flexible cable **210**, as described previously. The jaws or other end effectors may be rotated of deflected about an axis transverse to the longitudinal of axis of the distal-most shaft segment **218**, typically over ±180°, by causing a driver in the robot arm to draw on either end of the end effector angulation cord **258**. As shown in FIG. **10**C, the end effector **214** may be further rotated about the longitudinal axis of the distal-most segment **218** of the device shaft by rotating the bidirectional torque tube **256** in the direction of arrow **266**.

[0047] Referring now to FIGS. **11** and **12**, an alternative embodiment of an end effector assembly comprising a steerable shaft segment **280** is described. The steerable shaft segment **280** may comprise any type of flexible sleeve as is commonly known in the catheter and laparoscopic tool art, including reinforced and non-reinforced polymer tube, tubes formed from a plurality of ring segments, slotted metal and polymeric tubes, and the like. The steerable shaft segment **280** typically extends distally from a data-most shaft segment **218**a, and the angulation cord **258** will extend through lumens or other passages formed in a wall of the steerable shaft segment. The angulation cord will typically be formed in two separate lengths **258**a and **258**b so that tension on one of the lengths will bend the steerable segment in a first direction and tension on the other of the lengths will bend the segment in an opposed second direction. As shown in FIG. **12**, tension is applied to length **258**b, causing the steerable shaft segment to bend toward the right as illustrated.

[0048] In order to accommodate a twisting torque that may applied to the steerable shaft segment, the telescoping segments **216** and **218** segments of the tool shaft **202** will be provided with alignment features to prevent rotational misalignment. For example, each of the segments **216**a and **218**a as illustrated in FIGS. **11** and **12** may be provided with pins or tracks **266** and **270** which can slide in exterior grooves **268** and **272** as he segments telescope in and out to prevent relative rotation.

[0049] Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

[0050] All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

What is claimed is:

1. A laparoscopic tool for mounting on an arm of a surgical robotic system, said laparoscopic tool comprising:

a shaft having a distal effector end and a proximal attachment end, said shaft having a central passage extending between said ends;

a flexible cable wire assembly slidably received in the central passage of the shaft, said flexible cable wire assembly comprising a flexible cable having a distal effector end and a proximal attachment end and a pull/push wire having a distal effector end and a proximal attachment end slidably received in a lumen of the flexible cable; and

an end effector operably attached to the distal effector end of the flexible cable and the distal effector end of the pull/push wire, wherein the end effector is disposed distally beyond the distal effector end of the shaft and is actuated by axially translating the pull/push wire relative to the flexible cable in the flexible cable wire assembly;

wherein the distal effector ends of each of the tool shaft, the flexible cable, and the pull/push wire are configured to be removably attached to the arm of the surgical robotic system so that the arm can at least axially reposition the flexible cable wire assembly relative to the shaft, rotate the flexible cable wire assembly relative to the shaft, and axially translate the pull/push wire relative to the flexible cable of the flexible cable wire assembly to actuate the end effector.

2. A laparoscopic tool as in claim **1**, further comprising a telescoping section extending distally of the distal effector end of the shaft to accommodate extension and retraction of the flexible cable wire assembly.

3. A laparoscopic tool as in claim **1**, whirring segments of the telescoping section have alignment features that prevent relative rotation as the segments are extended and retracted.

4. A laparoscopic tool as in claim **1**, wherein the shaft comprises (a) a semicircular mid-portion and (b) straight proximal and distal sections which lay along a common axis, wherein the flexible cable wire assembly bends to accommodate the semicircular mid-portion as the flexible cable wire assembly is axially translated in the central passage of the shaft by the robot arm.

5. A laparoscopic tool as in claim **1**, wherein (a) the distal effector end of the tool shaft is configured to be attached the robotic arm so that the robot arm can reposition the entire tool with six degrees of motion, (b) the flexible cable wire assembly is configured to be rotatably and translatably attached to one or more driver(s) in the robot arm so that the driver(s) can axially and rotationally reposition the flexible cable wire assembly relative to the shaft, and (c) the pull/push wire is configured to be translatably attached to one or more drivers in the arm to axially translate the pull/push wire relative to the flexible cable in the flexible cable wire assembly to actuate the end effector.

6. A laparoscopic tool as in claim **1**, wherein the flexible cable wire assembly further comprises a bidirectional torque tube located coaxially over the flexible cable and having a proximal end coupled to the one or more driver(s) in the robot arm, wherein the bidirectional torque tube is configured to transmit torque and axial translation forces from the one or more driver(s) in the robot arm to the end effector.

7. A laparoscopic tool as in claim **5**, wherein the flexible cable wire assembly further comprises an angulation disc and an angulation cord coupled to the one or more driver(s) to rotate the end effector about an axis normal to a central axis of the bidirectional torque tube.

8. A laparoscopic tool as in claim **1**, wherein the shaft includes a steerable end segment at the distal effector end.

9. A method for performing robotic surgery with at least two tools passing through a single percutaneous passage, said method comprising:

providing a surgical robotic system having at least first and second robotic arms;

providing at least first and second surgical tools, wherein each tool includes:

(i) a shaft having a distal effector end and a proximal attachment end, said shaft having a central passage extending between said ends;

(ii) a flexible cable wire assembly slidably received in the central passage of the shaft, said flexible cable wire assembly comprising a flexible cable having a distal effector end and a proximal attachment end and a pull/push wire having a distal effector end and a proximal attachment end slidably received in a lumen of the flexible cable; and

(iii) an end effector operably attached to the distal effector end of the flexible cable and the distal effector end of the pull/push wire, wherein the end effector is disposed distally beyond the distal effector end of the shaft and is actuated by axially translating the pull/push wire relative to the flexible cable in the flexible cable wire assembly;

attaching the first tool to the first robotic arm;

attaching the second tool to the second robotic arm;

manipulating the first and second arms to operate the end effectors to surgically interact with tissue while a mid-portion of each shaft is positioned in the single percutaneous passage and said mid-portions avoid interference.

10. A method as in claim **9**, wherein the mid-portions of each tool are semi-circular and extend radially inwardly from a common axis of proximal and distal sections of the shaft and wherein the first and second arms are manipulated by the surgical robotic arms to rotate each of the tools about a virtual center point of the semi-circular mid-portion while the semi-circular mid-portion remains with the single percutaneous passage.

11. A method as in claim **9**, wherein each tool comprises a telescoping section extending distally of the distal effector end of the shaft to accommodate extension and retraction of the flexible cable wire assembly.

12. A method as in claim **9**, wherein manipulating the first and second robot arms effects each of (a) repositioning the entire tool with six degrees of motion, (b) rotating and translating the flexible cable wire assembly to axially and rotationally reposition the flexible cable wire assembly relative to the shaft, and (c) axially translating the pull/push wire relative to the flexible cable in the flexible cable wire assembly to actuate the end effector.

13. A method as in claim **9**, wherein the flexible cable wire assembly further comprises a bidirectional torque tube located coaxially over the flexible cable and having a proximal end coupled to the one or more driver(s) in the robot arm, wherein the bidirectional torque tube is configured to transmit torque and axial translation forces from the one or more driver(s) in the robot arm to the end effector.

14. A method as in claim **13**, wherein the flexible cable wire assembly further comprises an angulation disc and an angulation cord coupled to the one or more driver(s) to rotate the end effector about an axis normal to a central axis of the bidirectional torque tube.

15. A method as in claim **13**, further comprising tensioning an angulation wire to bend a steerable end segment on the shaft to laterally deflect the end effector.

* * * * *

专利名称(译)	机器人支持的腹腔镜检查工具		
公开(公告)号	US20190307474A1	公开(公告)日	2019-10-10
申请号	US16/378087	申请日	2019-04-08
[标]申请(专利权)人(译)	KIETURAKIS马切伊Ĵ		
申请(专利权)人(译)	KIETURAKIS，马切伊J.		
当前申请(专利权)人(译)	KIETURAKIS，马切伊J.		
[标]发明人	KIETURAKIS MACIEJ J		
发明人	KIETURAKIS, MACIEJ J.		
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摘要(译)

旨在与机器人系统一起使用的手术工具包括具有远端执行器端和近端附接端的轴。具有远端效应器端和近端附接端的柔性电缆可滑动地容纳在轴的中央通道中，并且柔性线缆线组件包括具有远端效应器端和近端附接端的可滑动地容纳在轴中的拉/推线。拉/推电缆的管腔。末端执行器可操作地附接到柔性电缆的末端执行器末端和拉/推线的末端执行器末端，并且末端执行器在远侧布置在轴的末端执行器末端之外，并且通过轴向平移拉动而被致动。 /相对于柔性电缆线组件中的柔性电缆推线。