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(54) **MEDICAL INSTRUMENT WITH ARTICULABLE SEGMENT**

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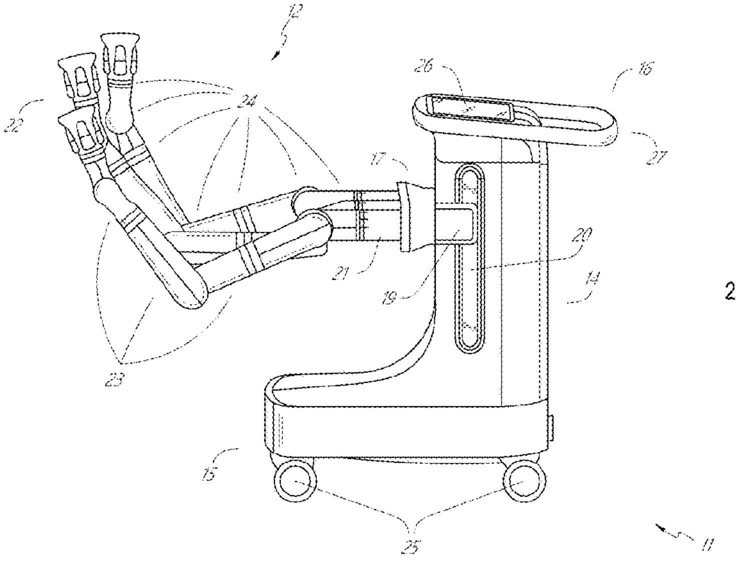
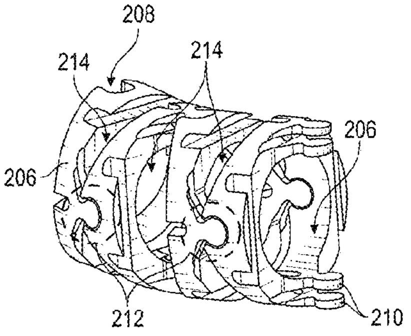
(57) **ABSTRACT**

Certain aspects relate to systems and techniques for a medical device. The medical device can include an elongated shaft having a proximal end, a distal end, and a bendable section between the proximal end and the distal end. The medical device can include a tip assembly at the distal end of the elongated shaft. The tip assembly include a control member and a distal tip component attached to the control member. At least one cable can extend through the elongated shaft and be anchored to the control member. The at least one cable can be configured to bend the bendable section based on a force applied thereto. At least one electronic component can be embedded in the distal tip component.

7 Claims, 30 Drawing Sheets





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See application file for complete search history.

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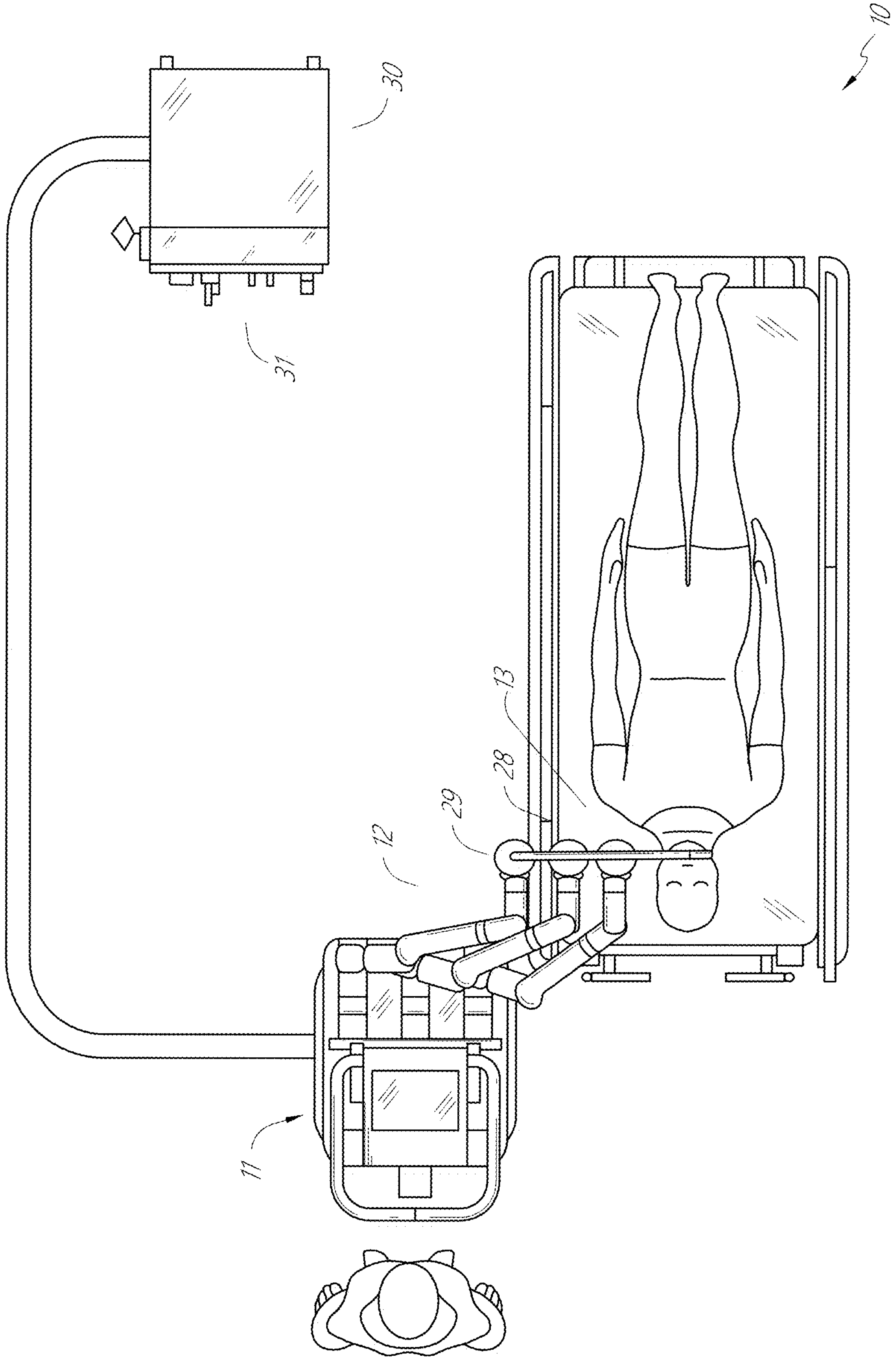


FIG. 1

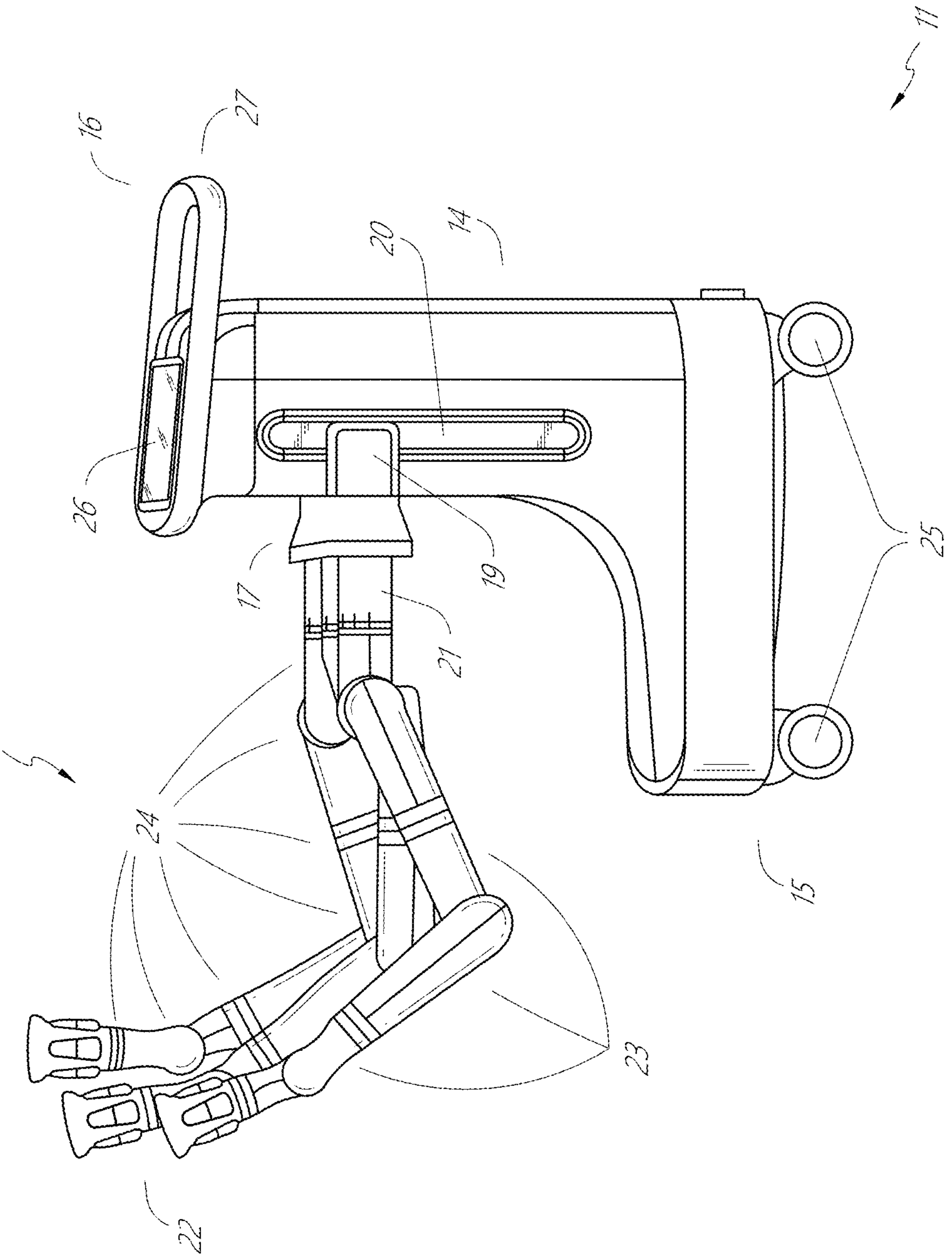


FIG. 2

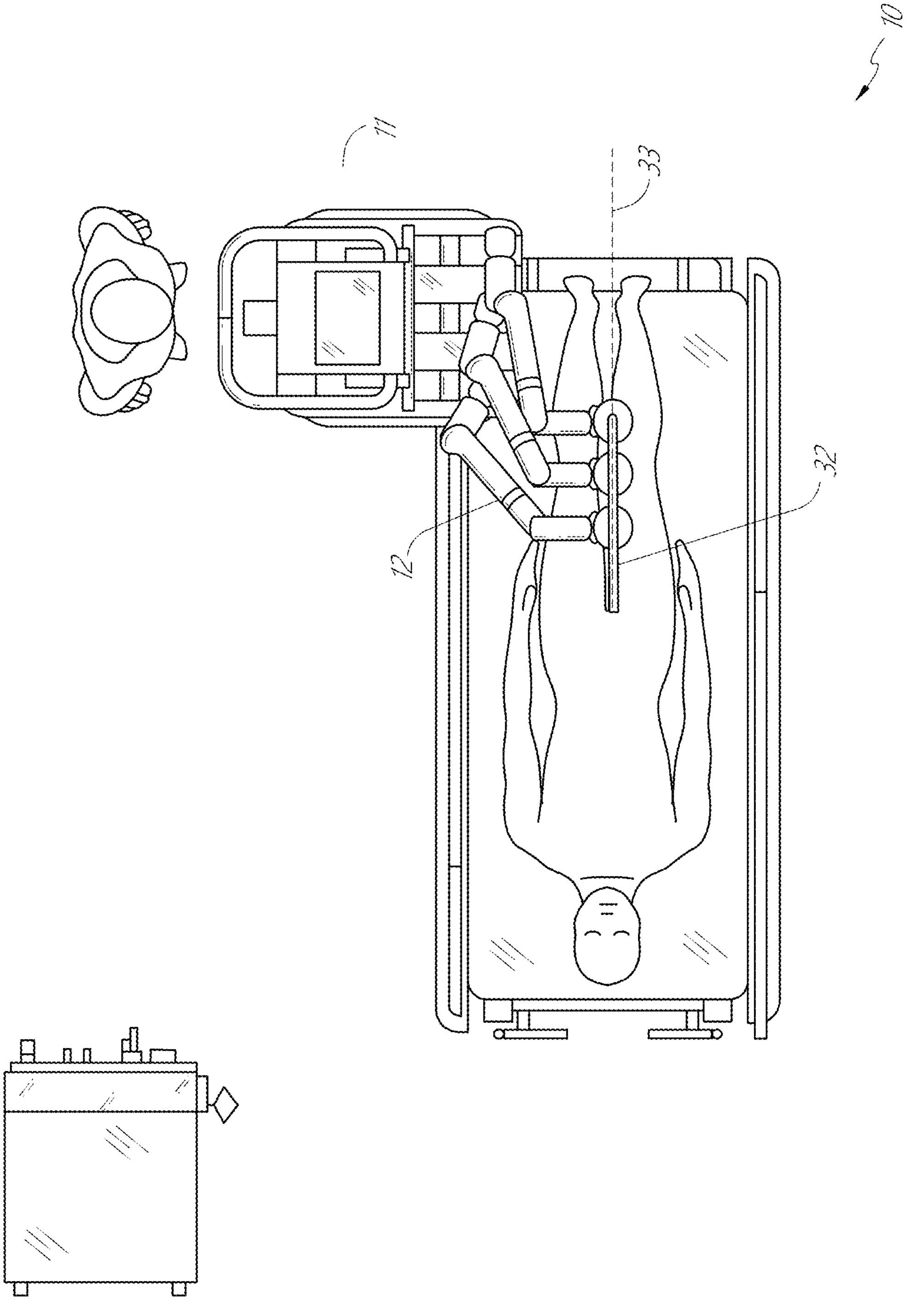


FIG. 3

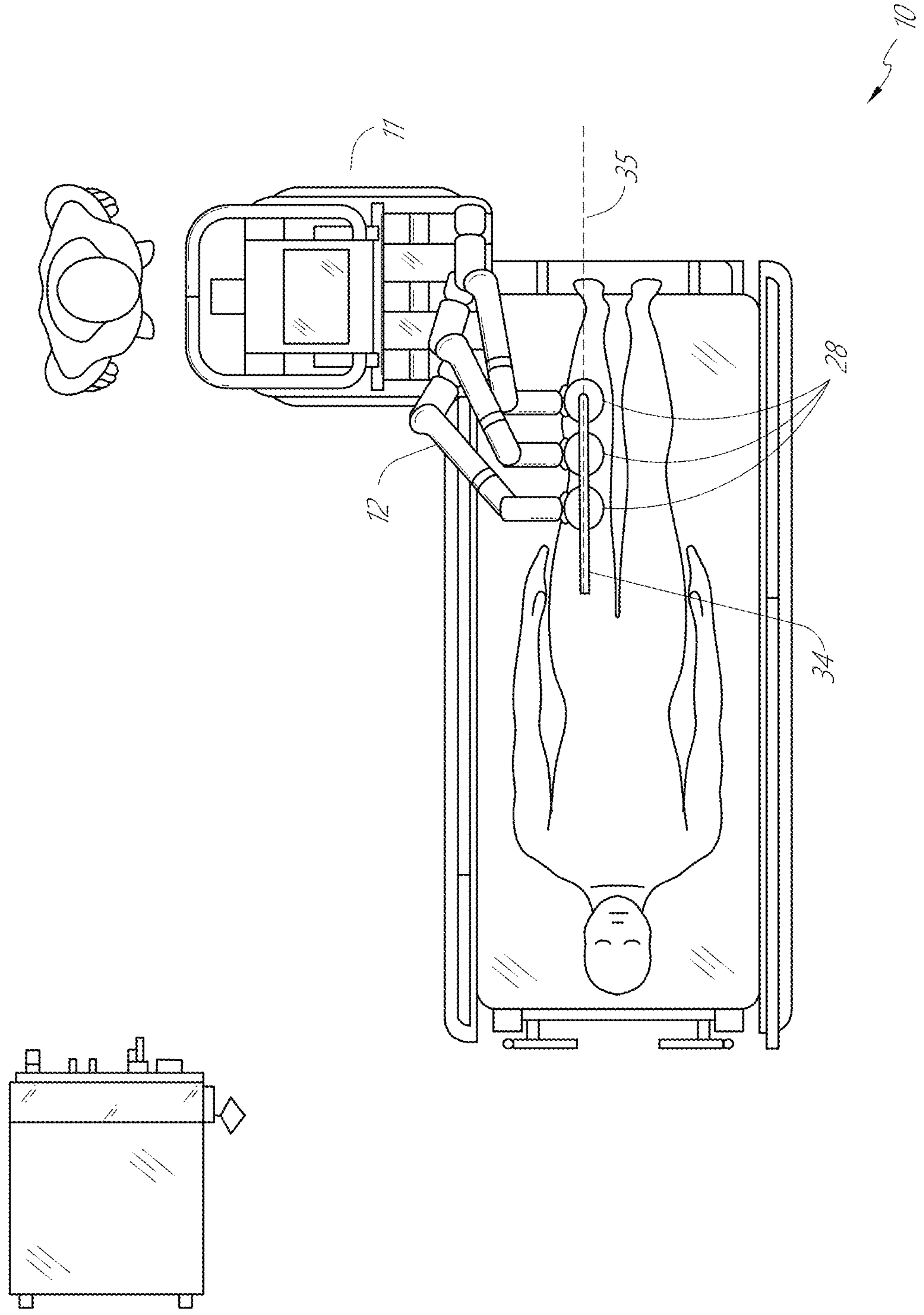


FIG. 4

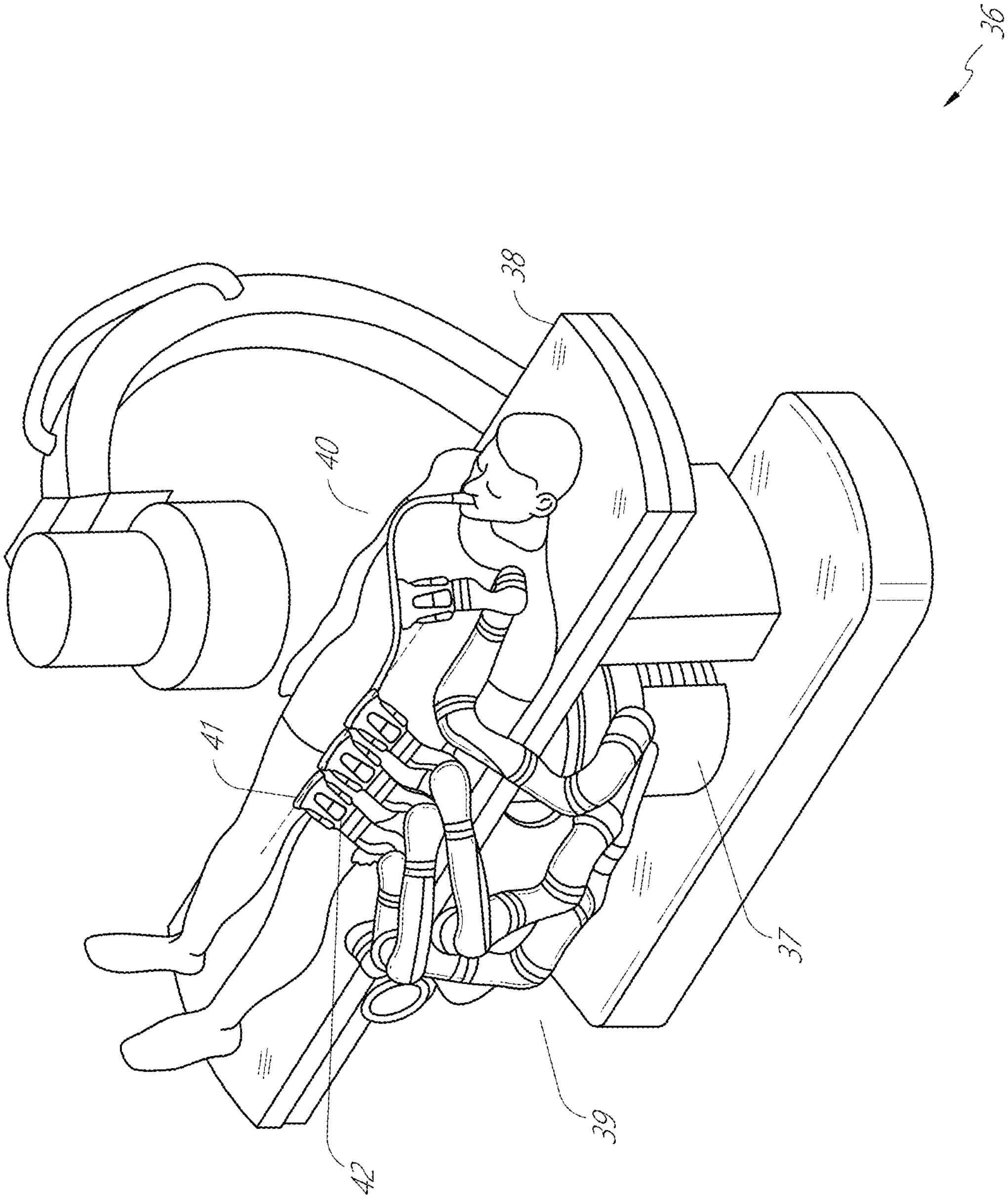


FIG. 5

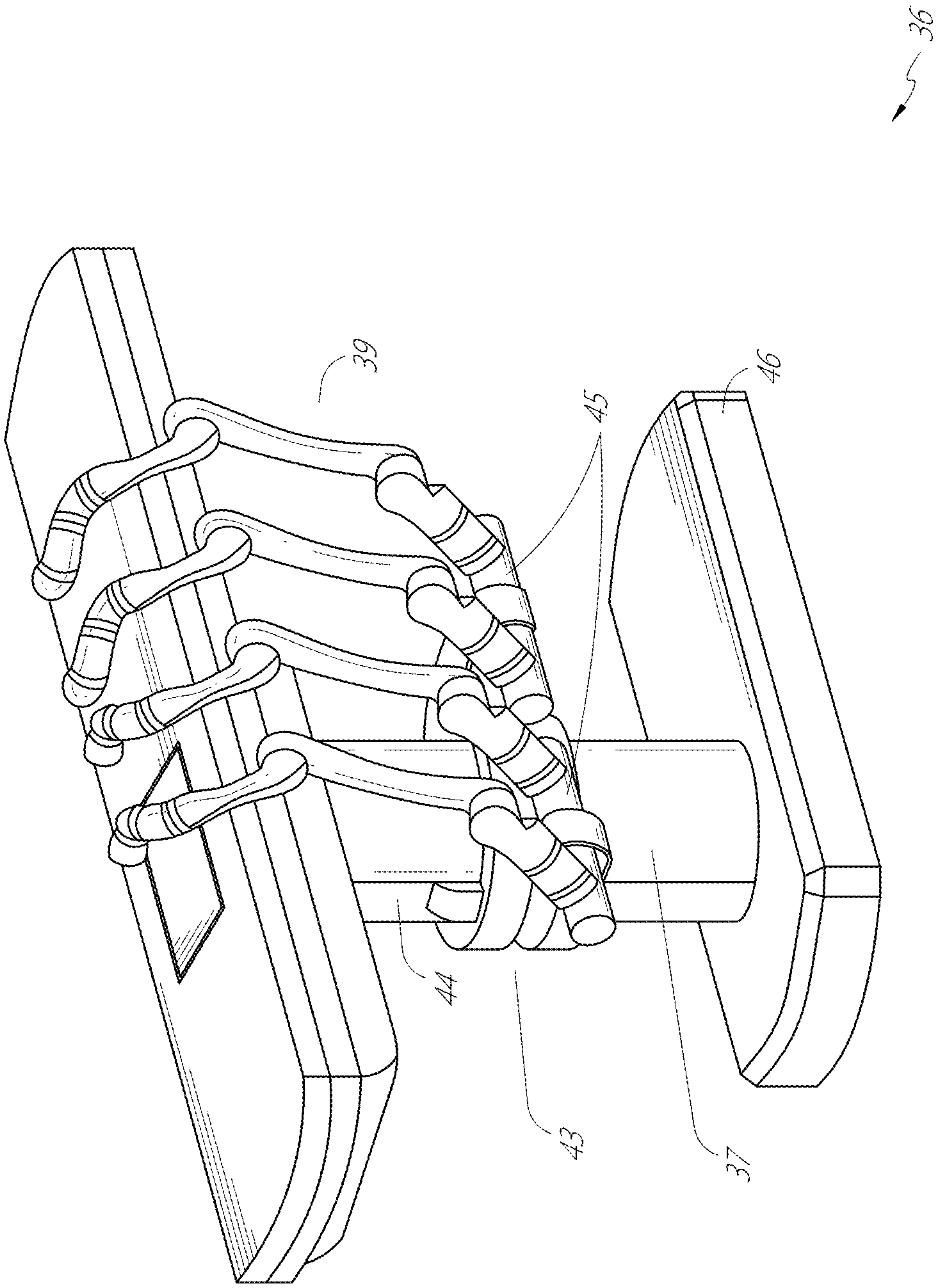


FIG. 6

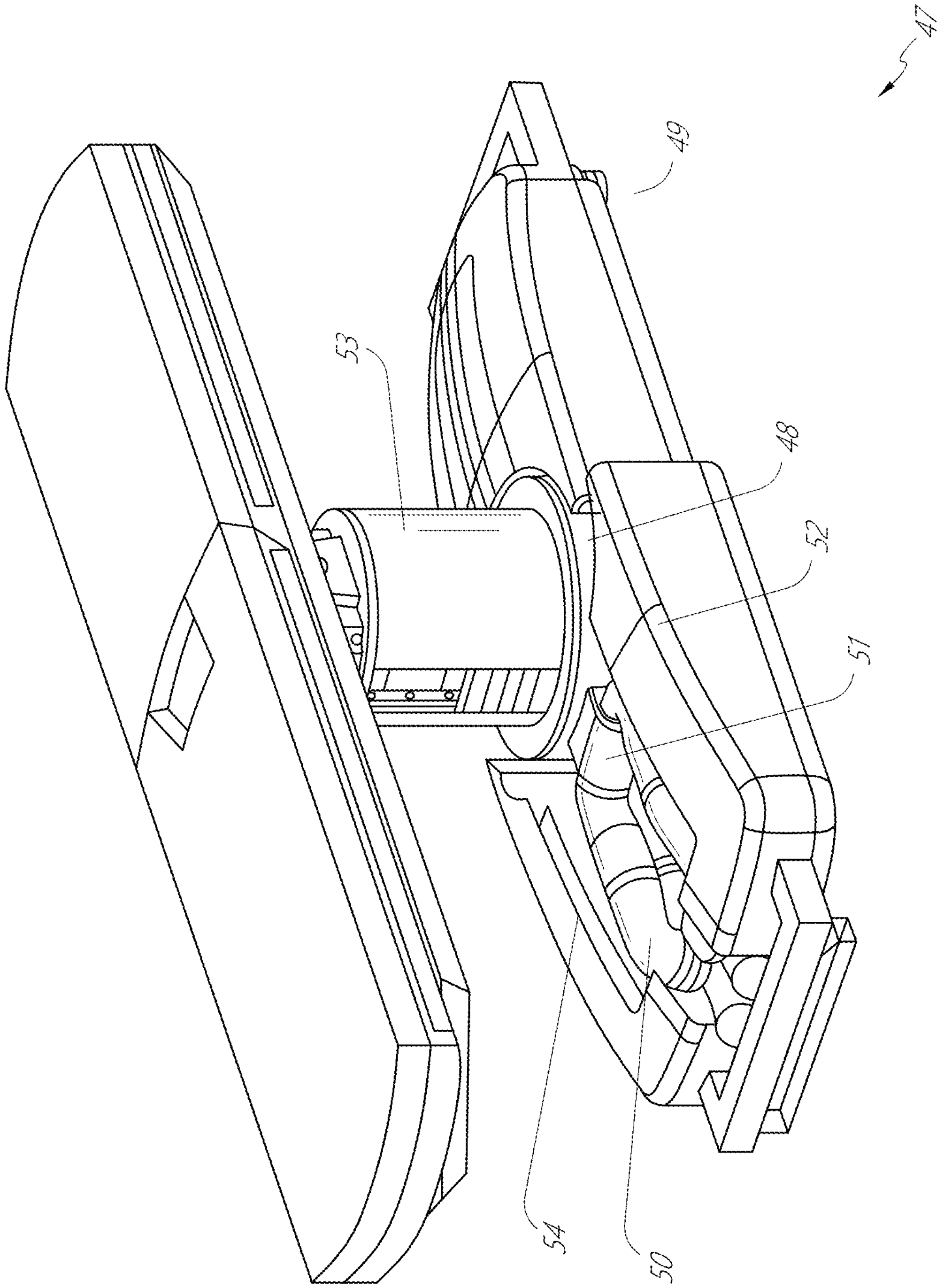


FIG. 7

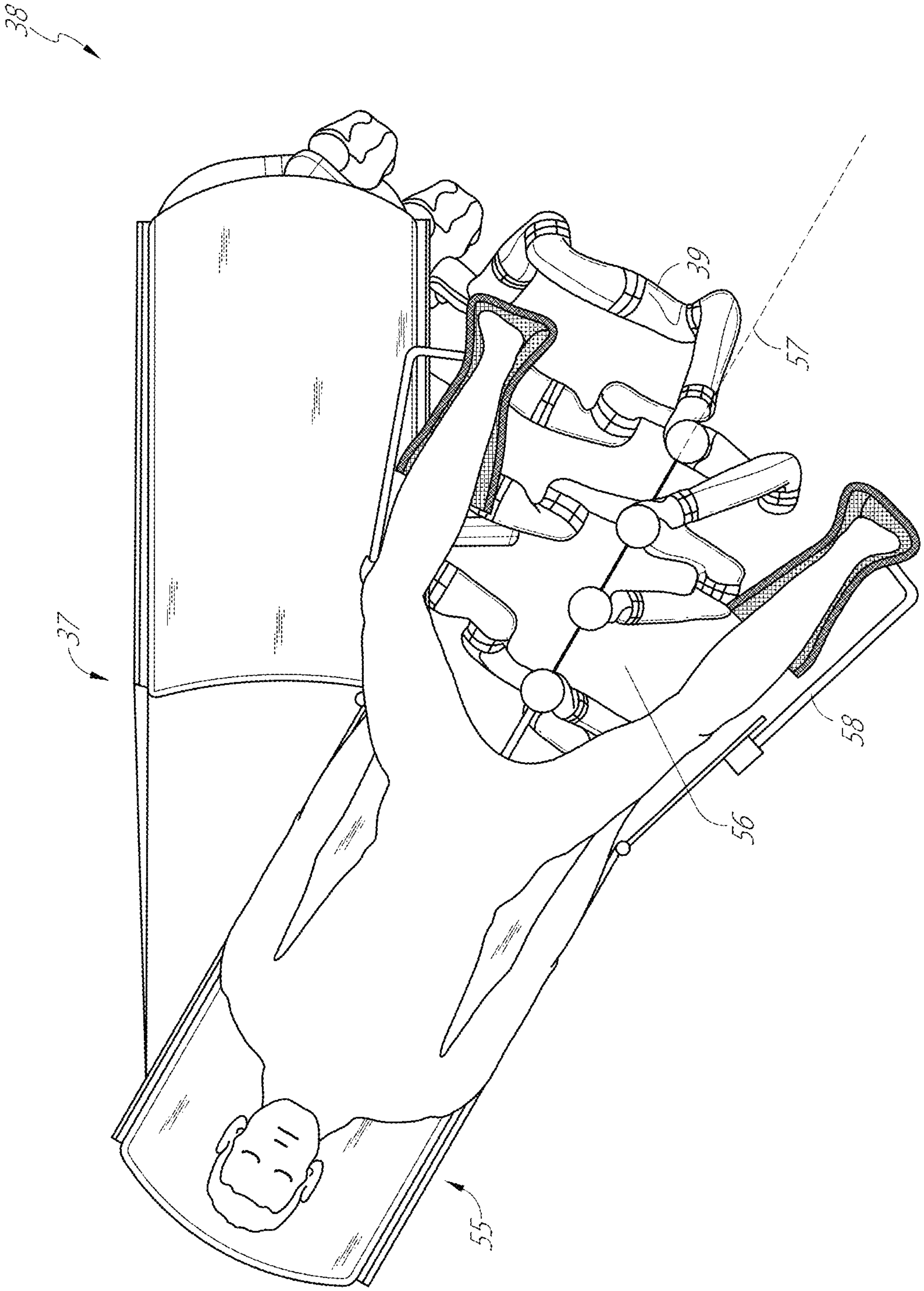


FIG. 8

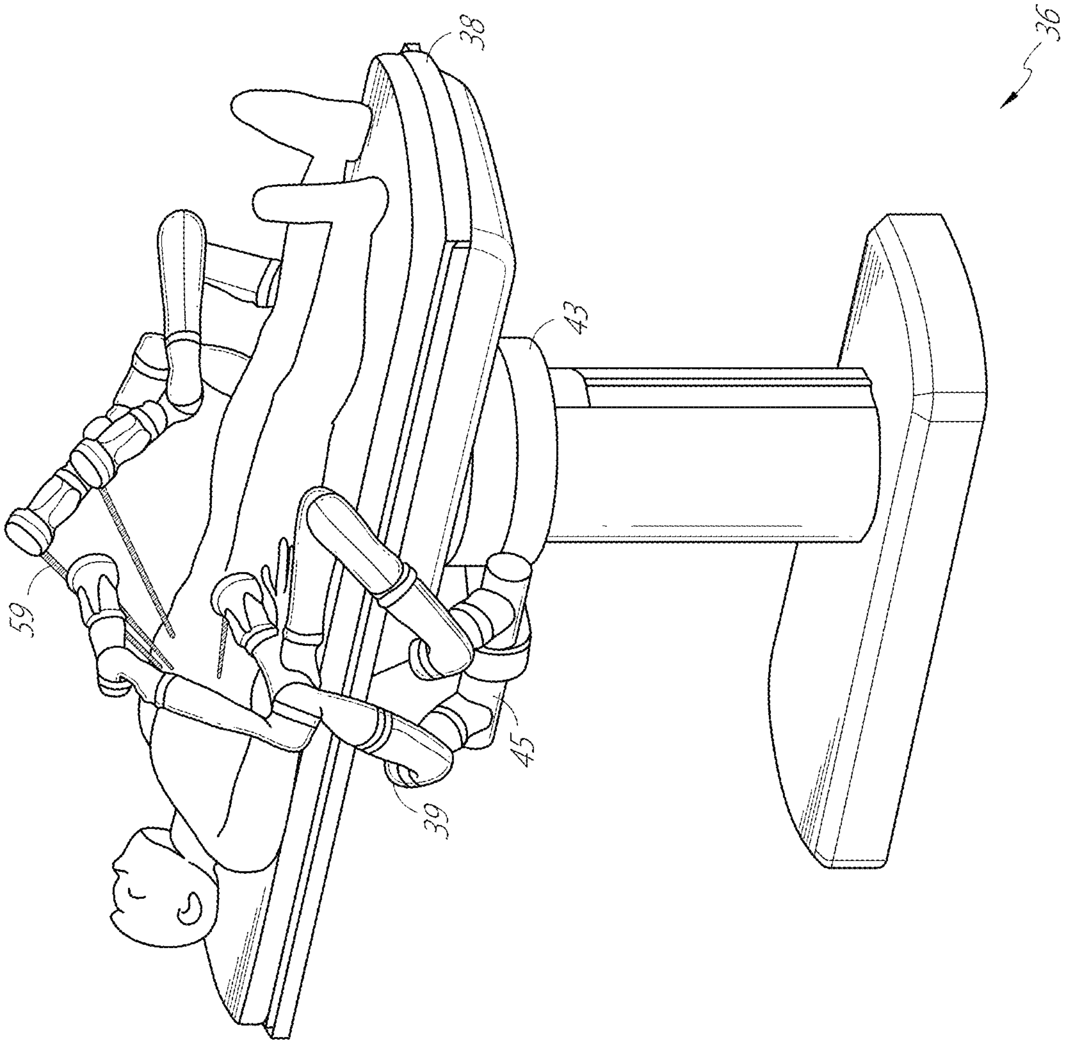


FIG. 9

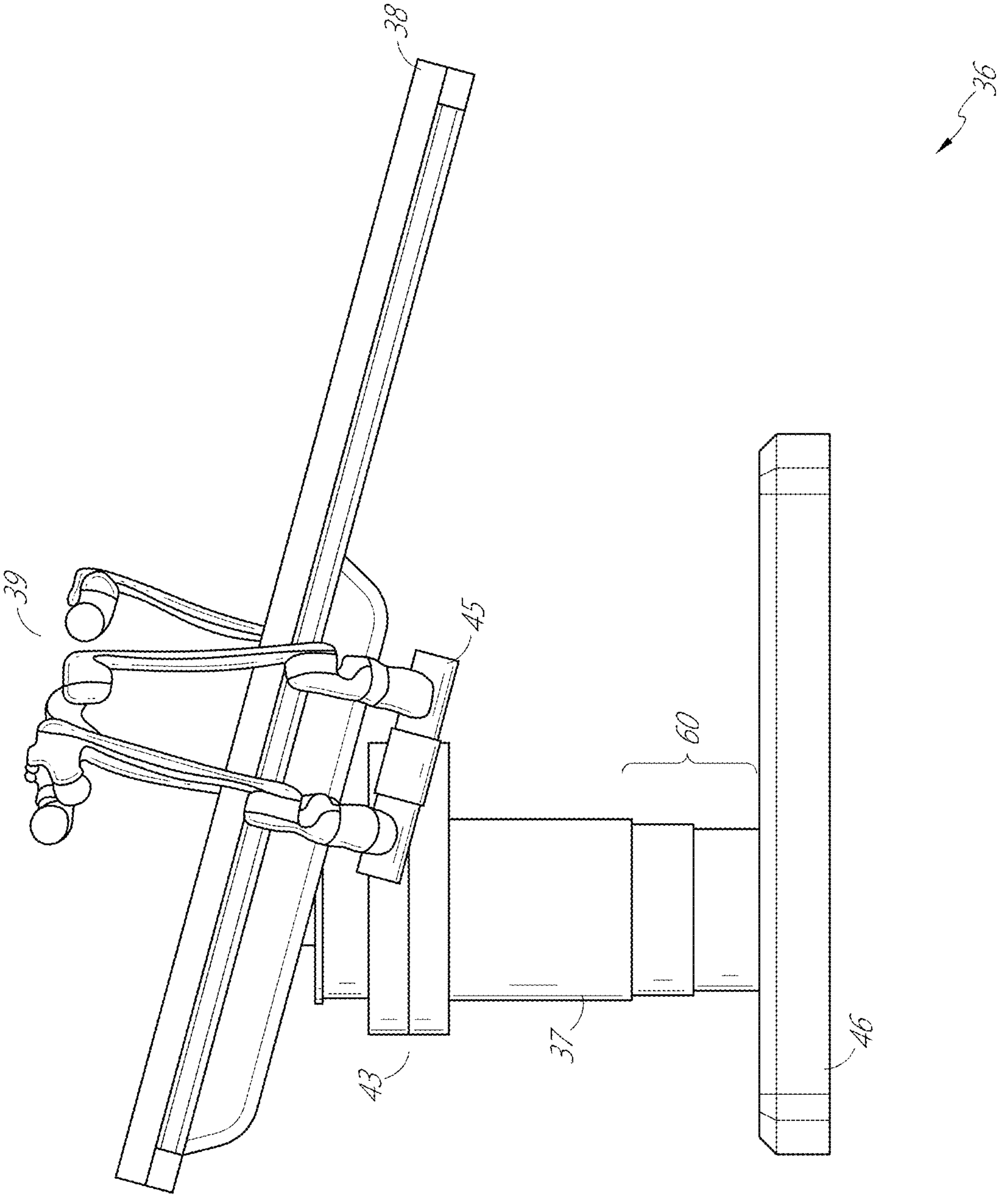


FIG. 10

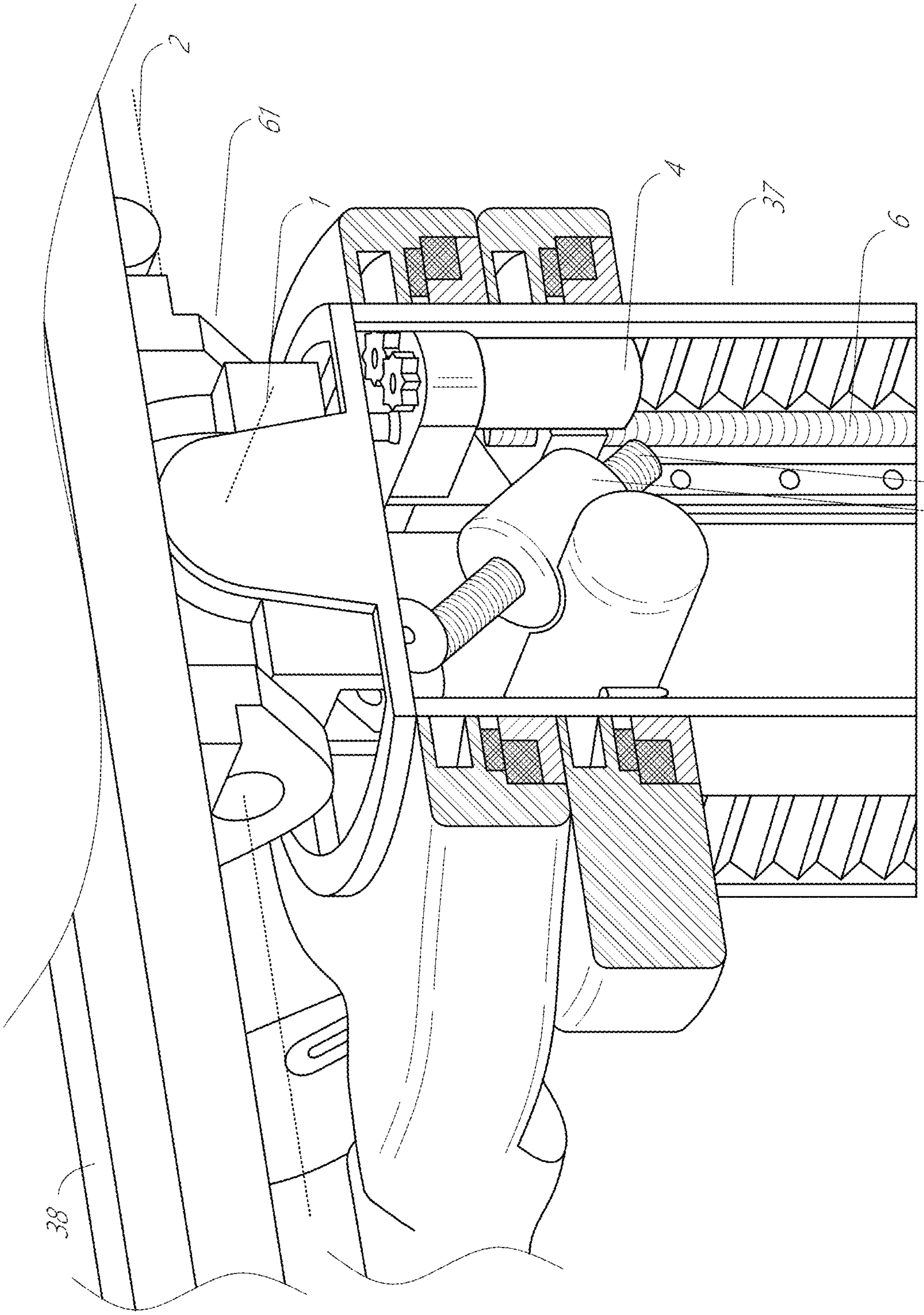
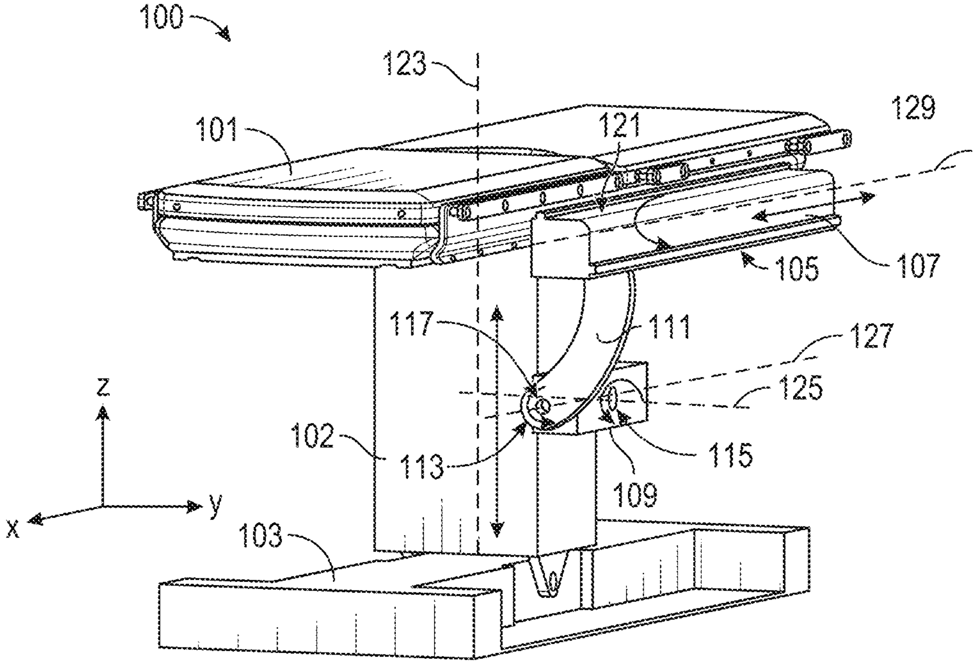


FIG. 11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105
107
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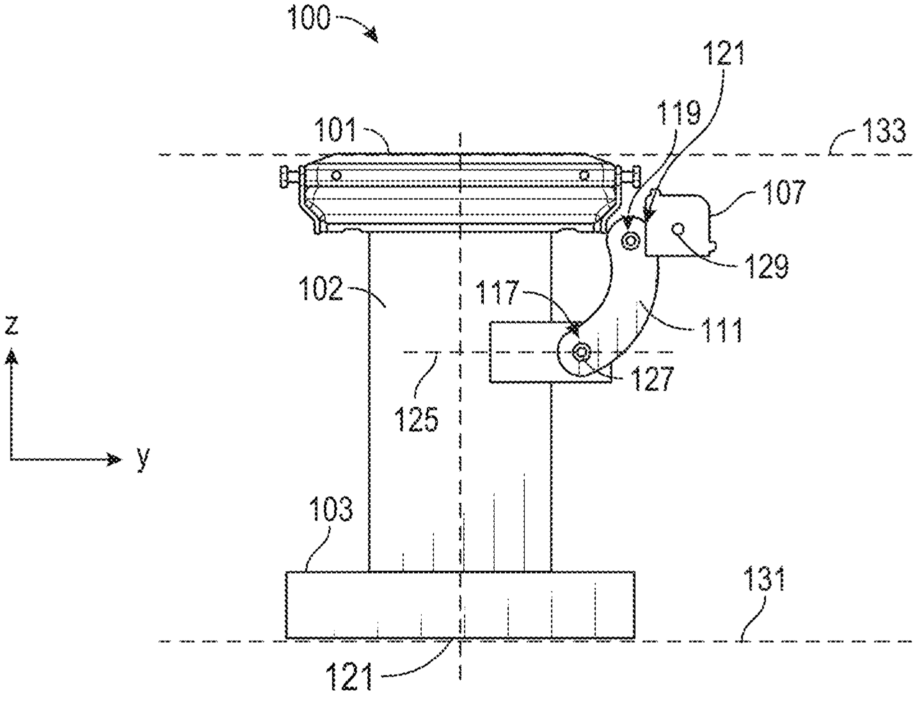
111
127
125
z
102
113
115
109
x
y
103

FIG. 12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133
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129
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117
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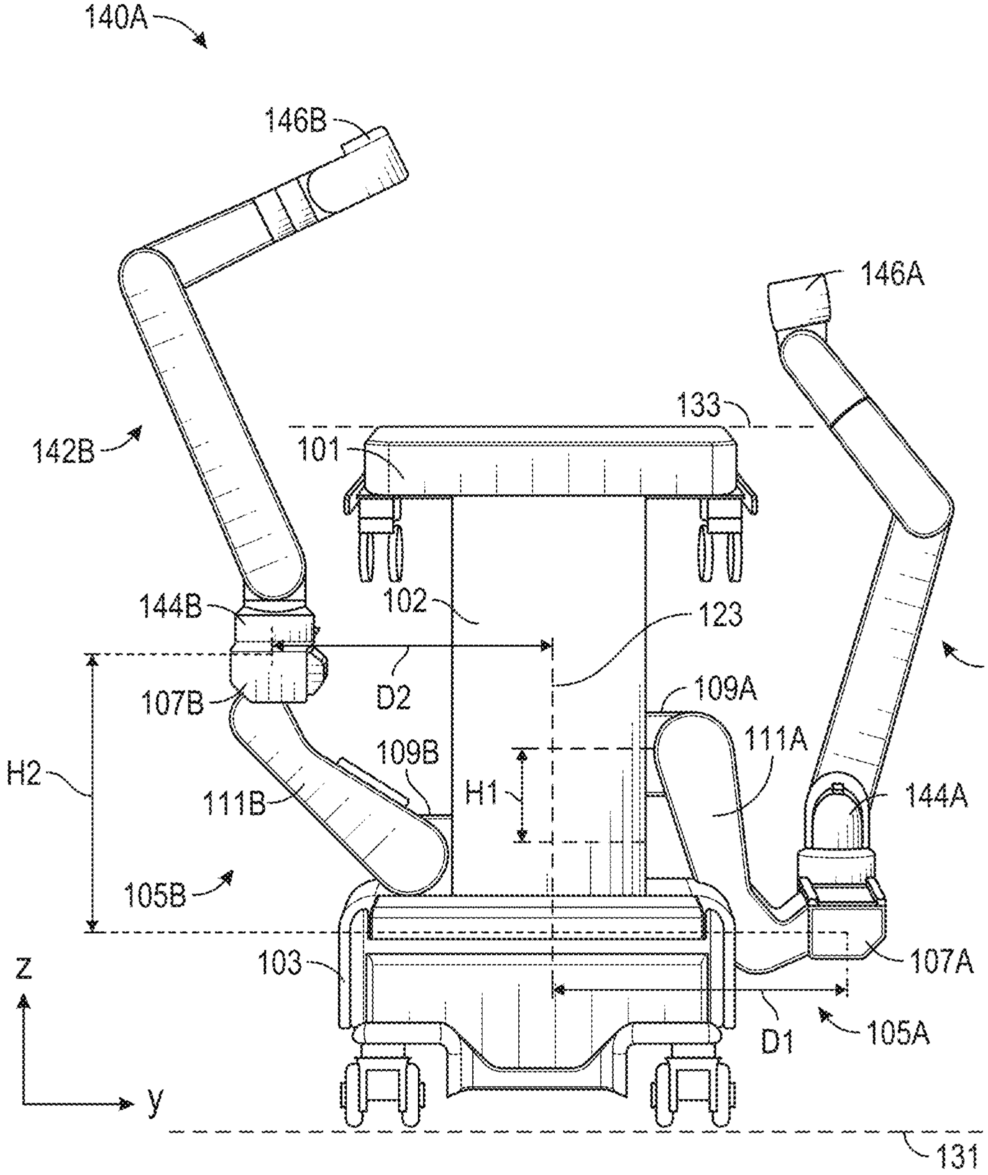
z
127
125
y
103
131
121

FIG. 13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146B
146A
133
142B
101
102
123
144B
D2
107B
109A
111A
142A
109B
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144A
H2
111B
105B
107A
103
D1
105A
z
y
131

FIG. 14

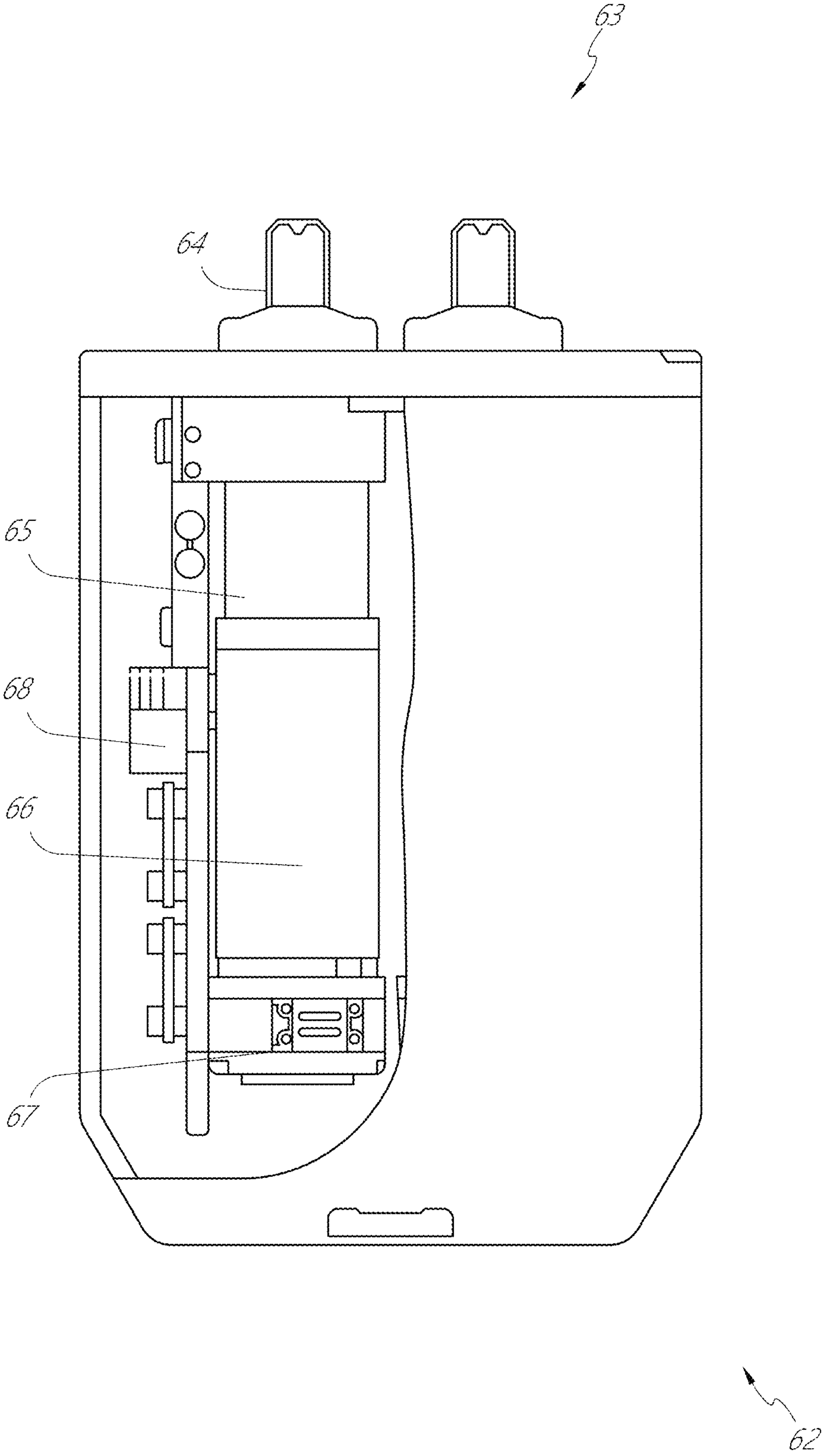

FIG. 15

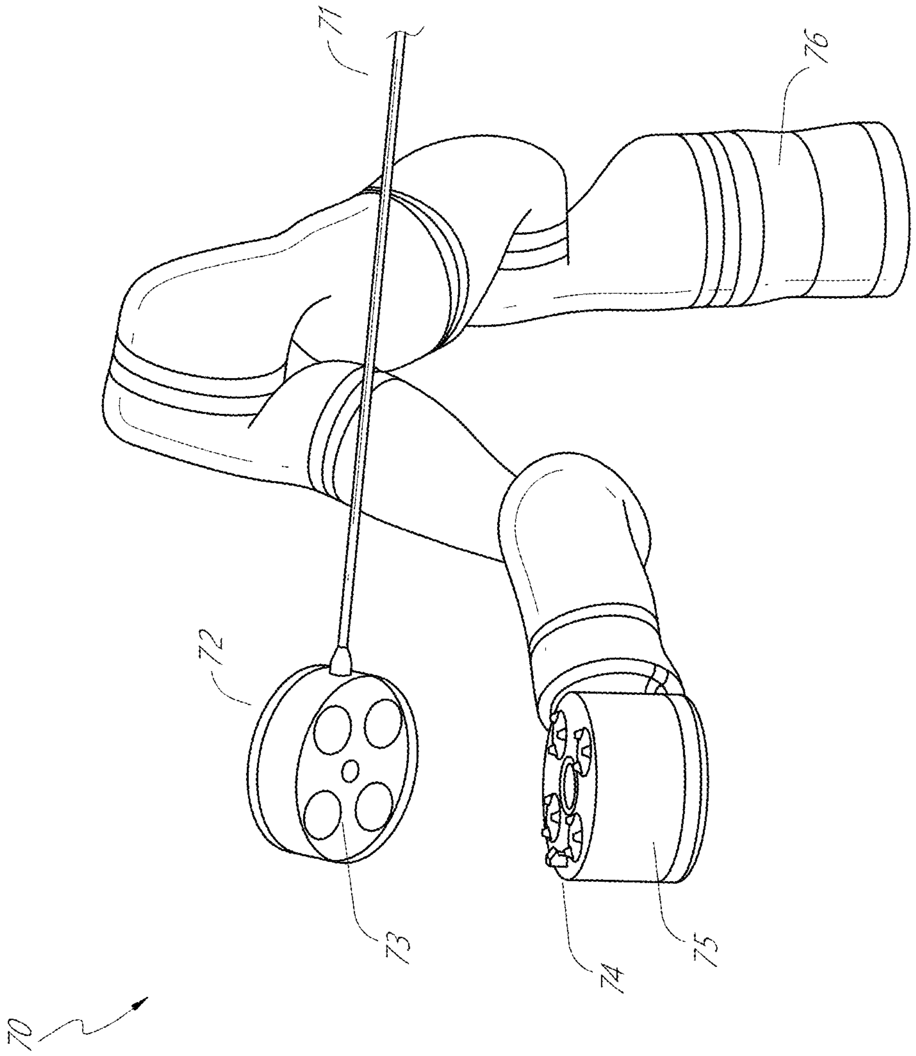

FIG. 16

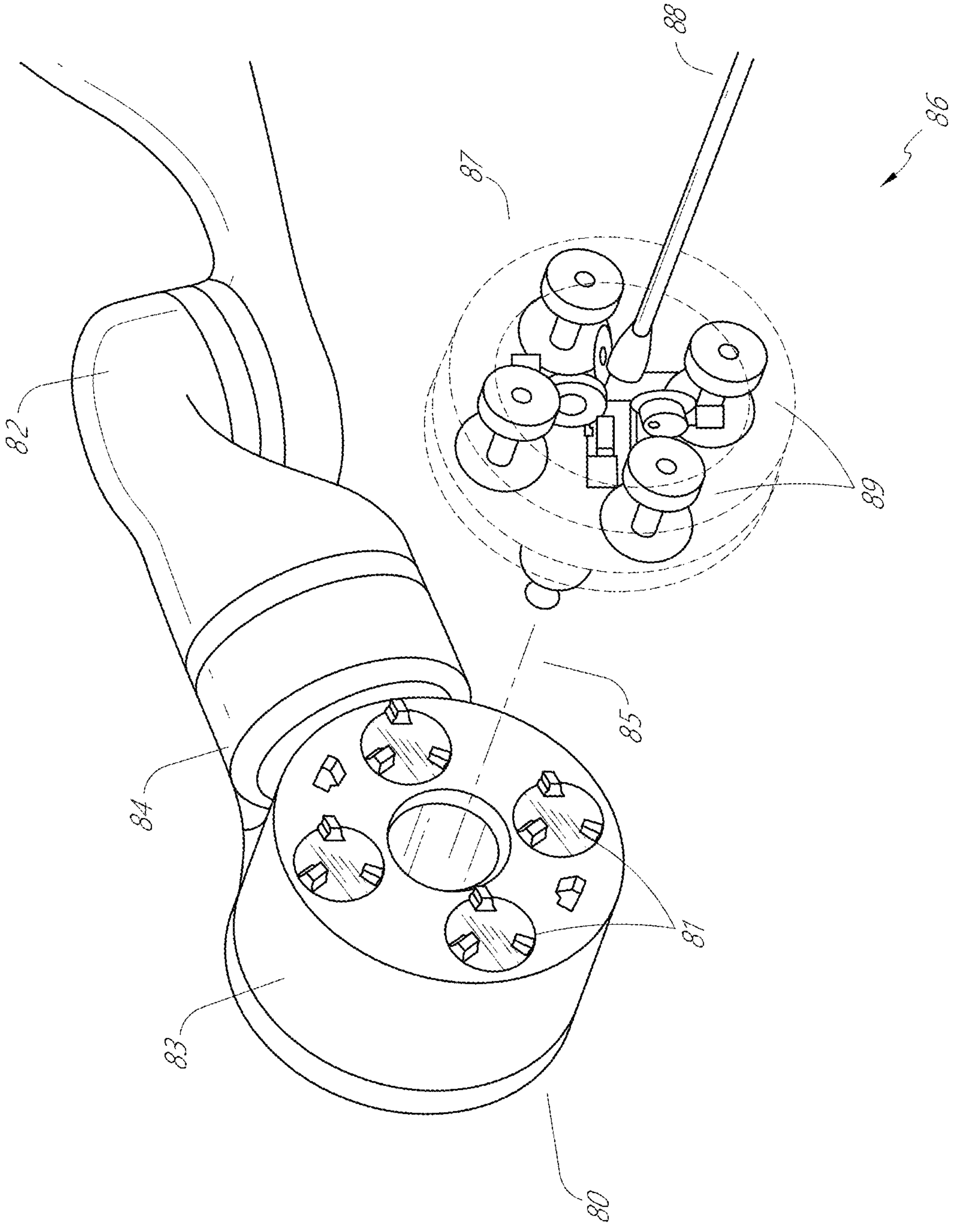

FIG. 17

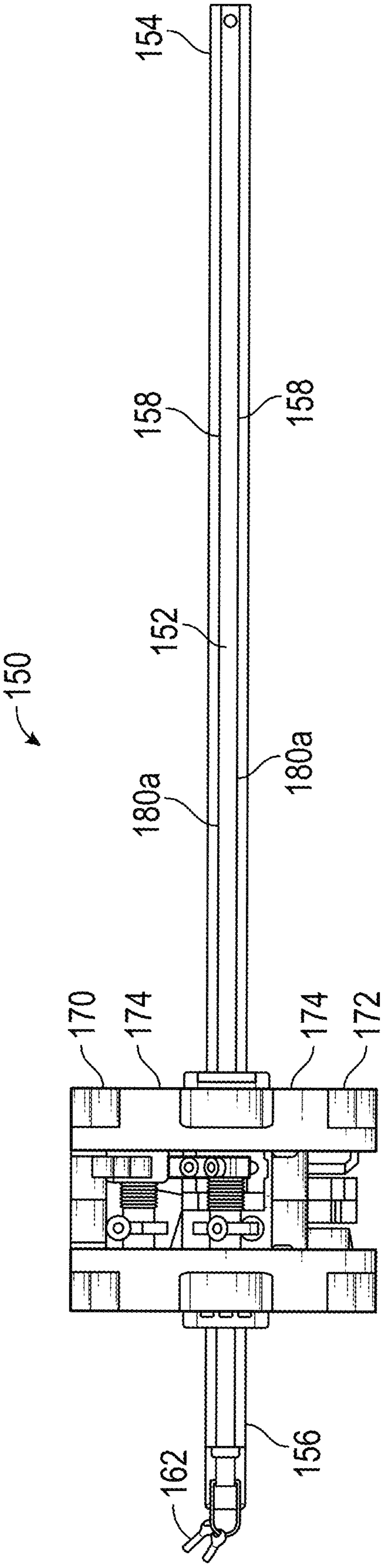

FIG. 18

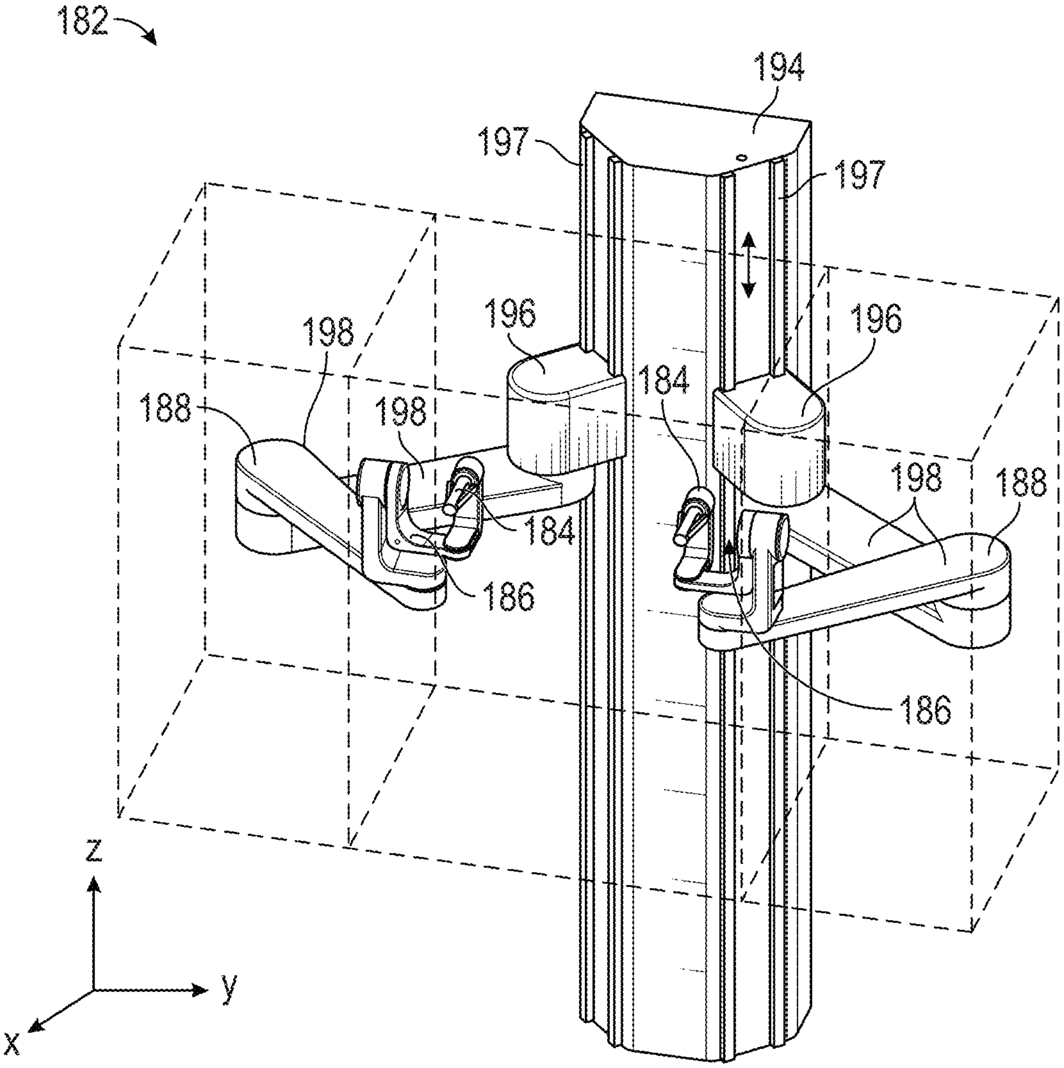

FIG. 19

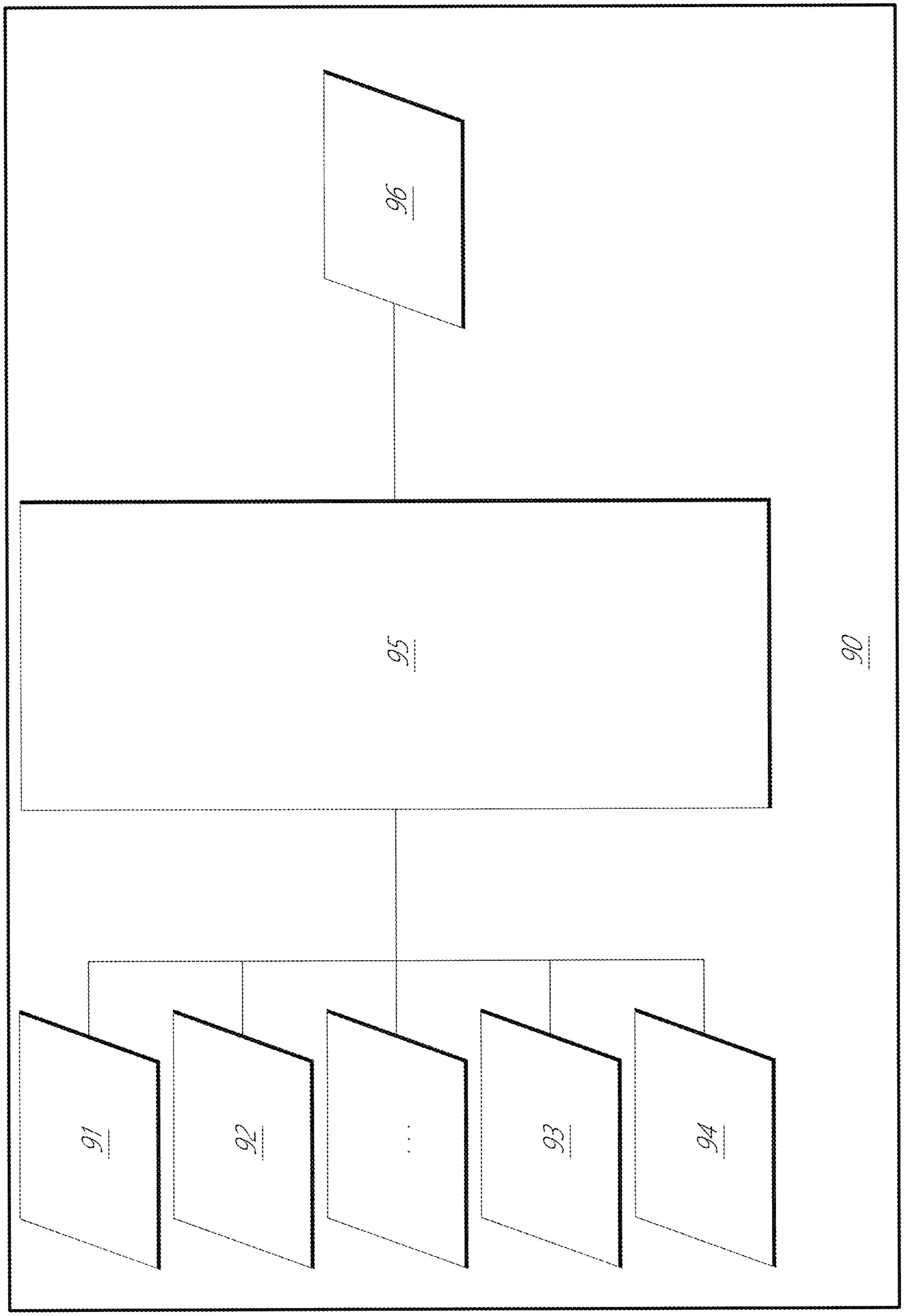

FIG. 20

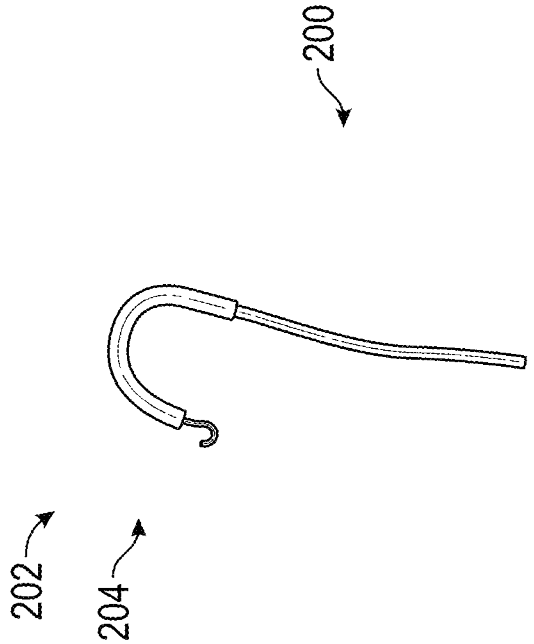

FIG. 21A

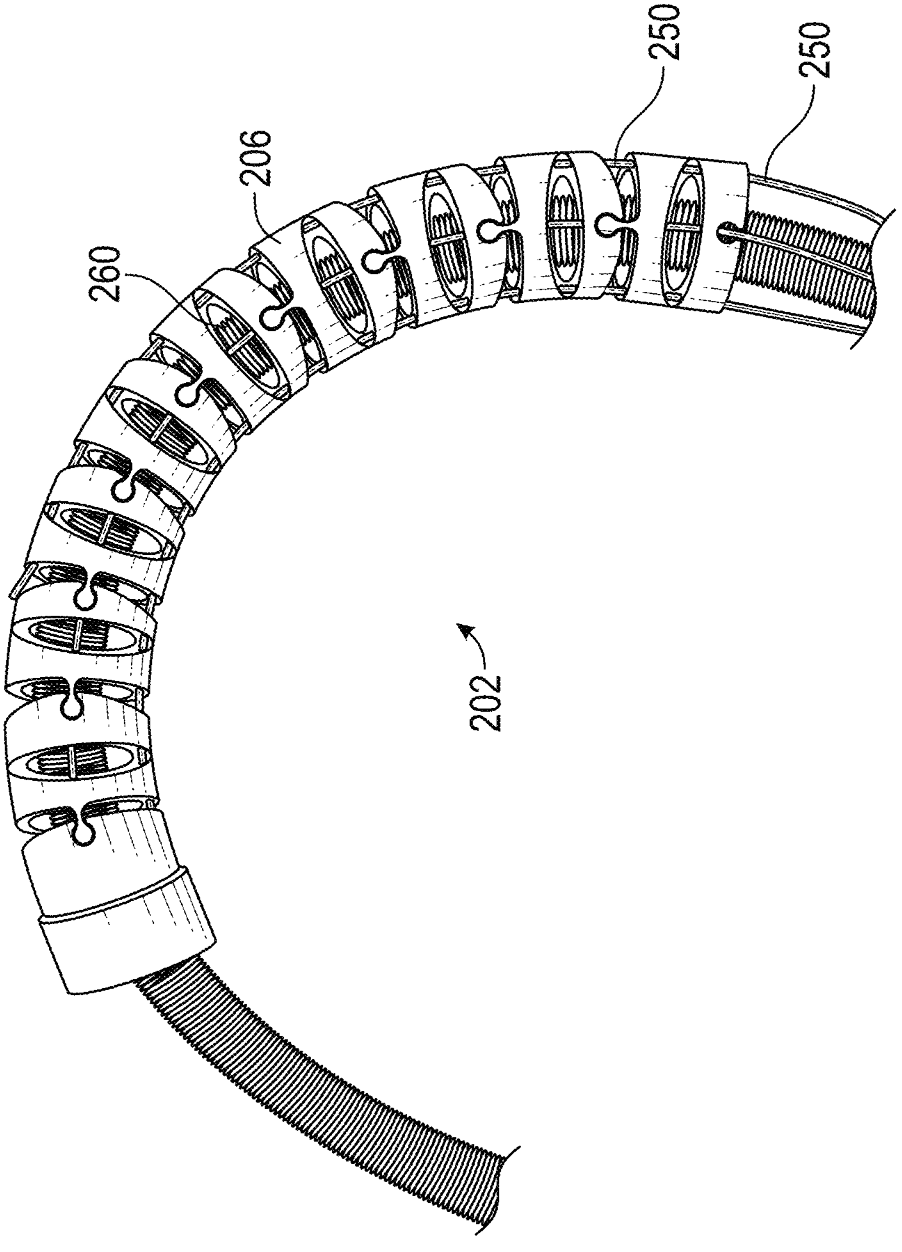

FIG. 21B

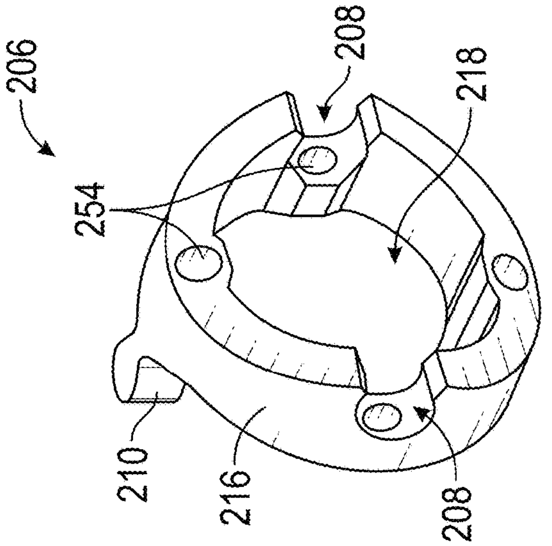

FIG. 22B

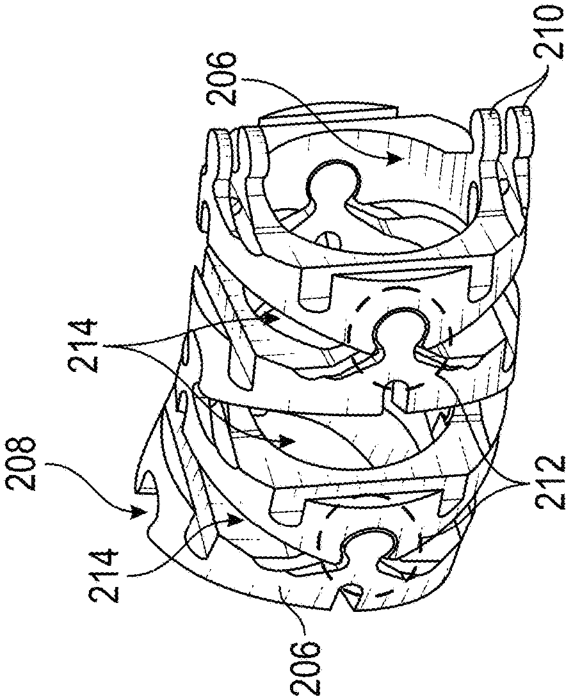

FIG. 22C

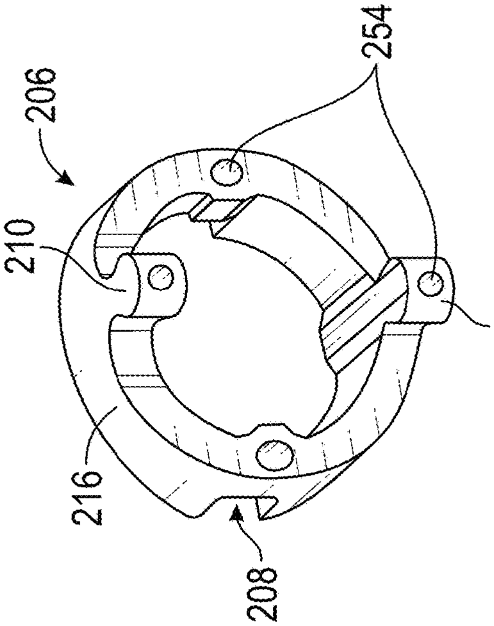

FIG. 22A

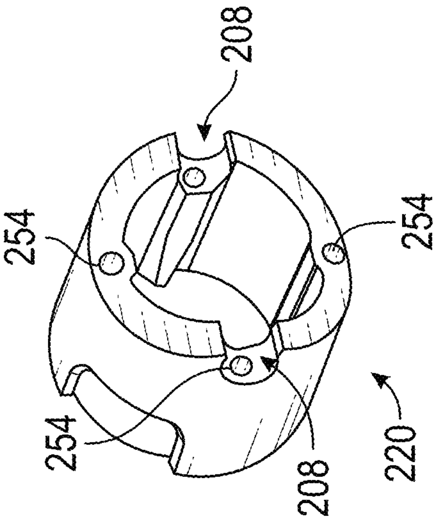

FIG. 23A

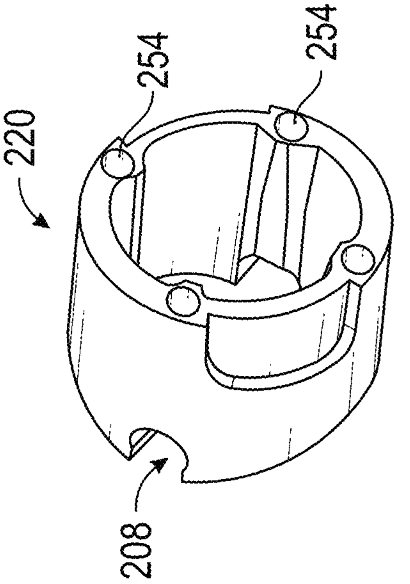

FIG. 23B

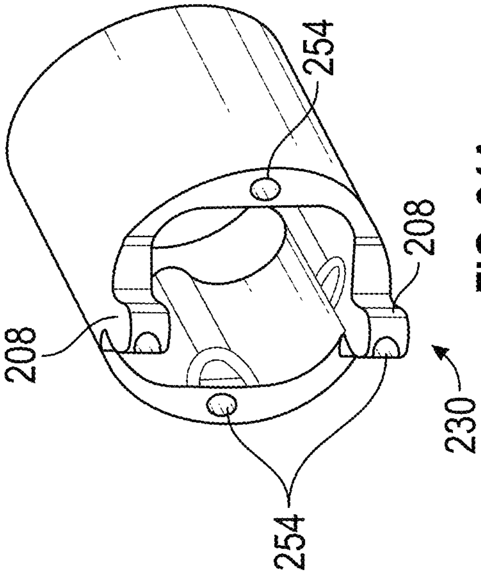

FIG. 24A

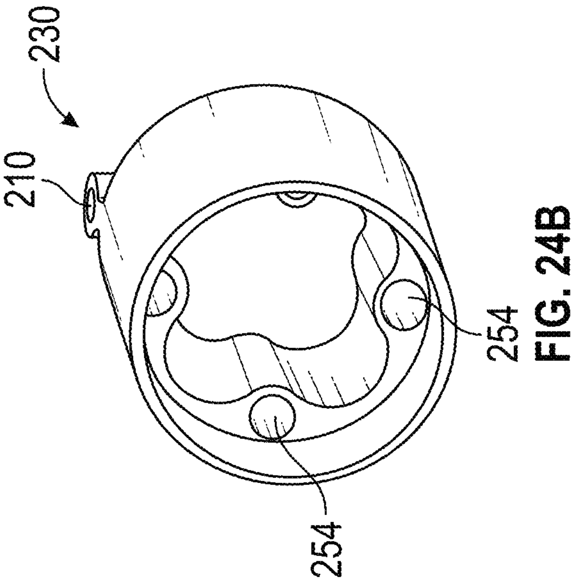

FIG. 24B

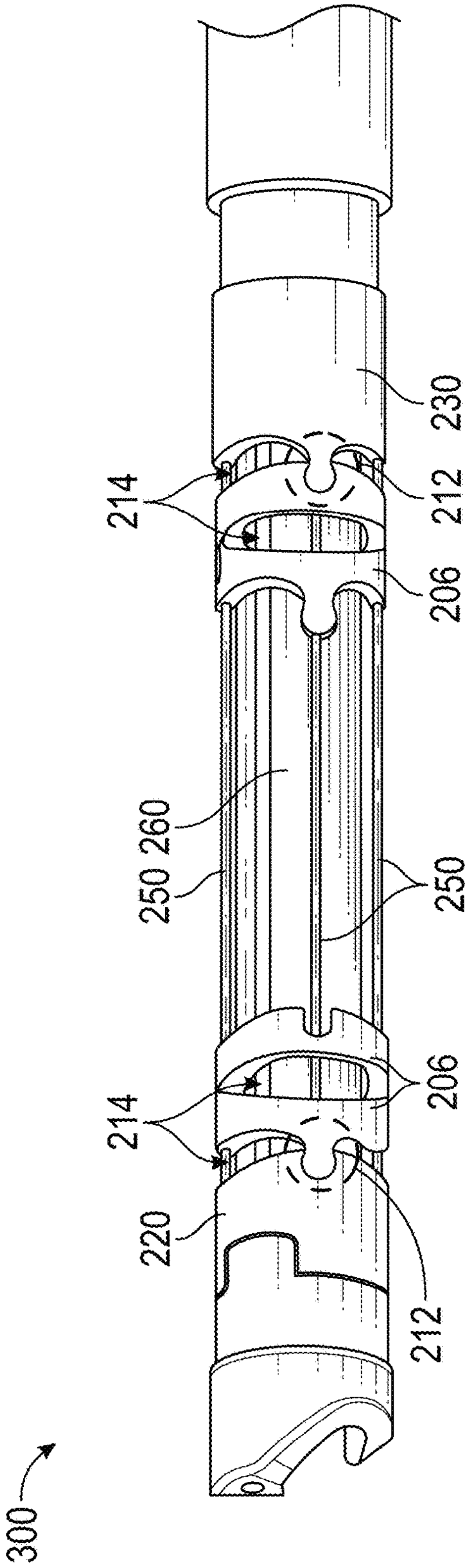

FIG. 25

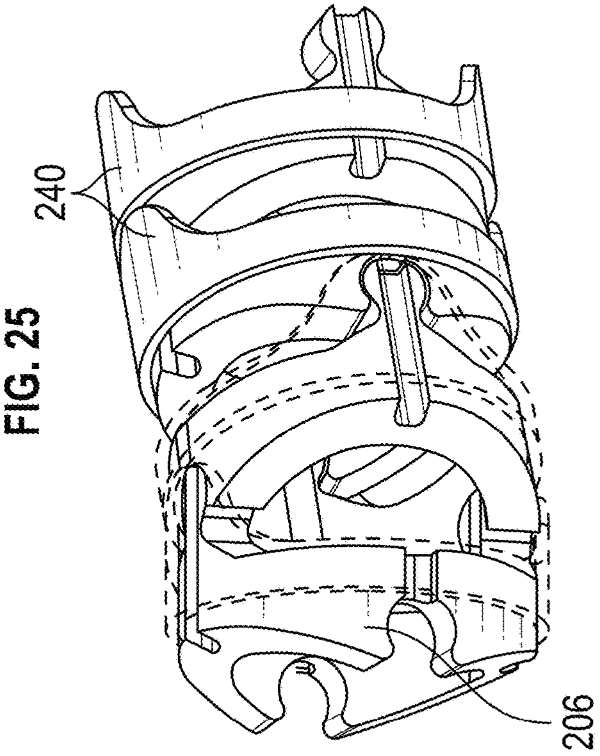

FIG. 26A

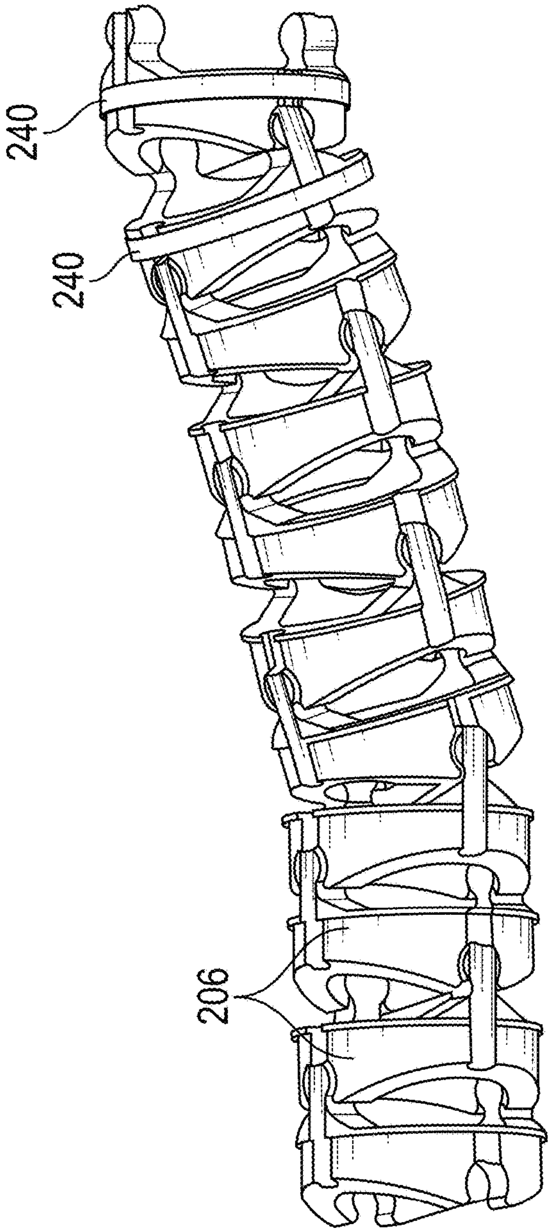

FIG. 26B

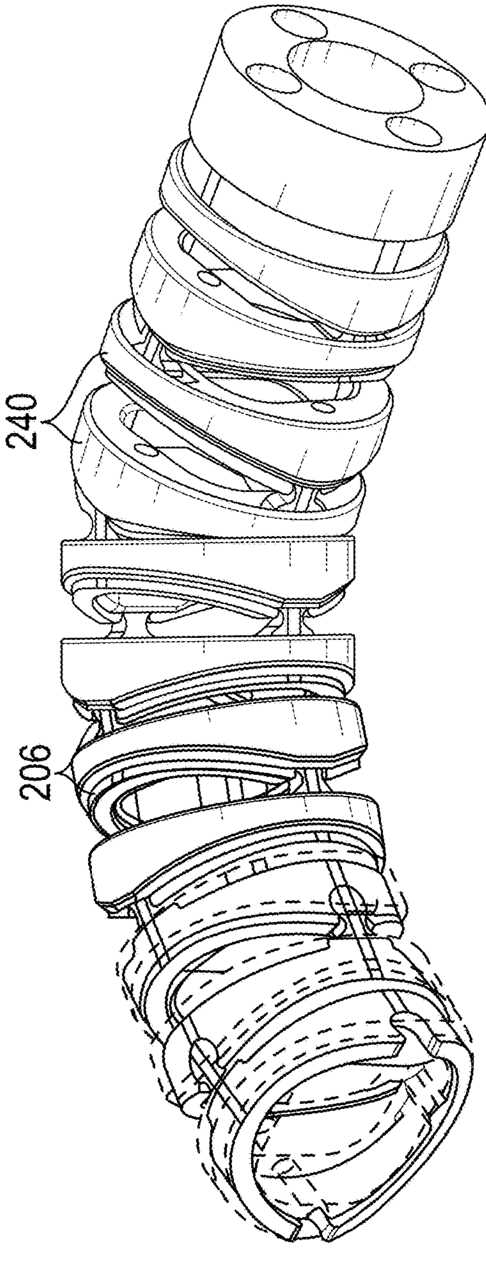

FIG. 26C

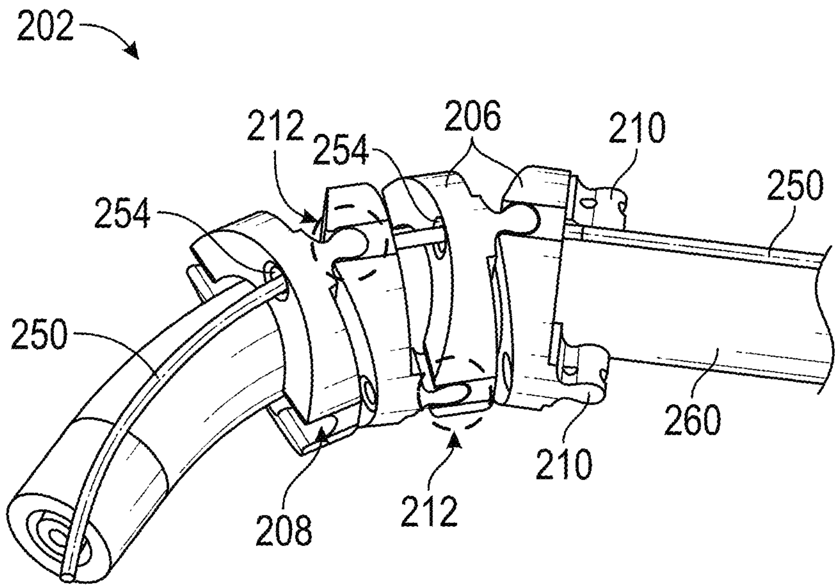

FIG. 27A

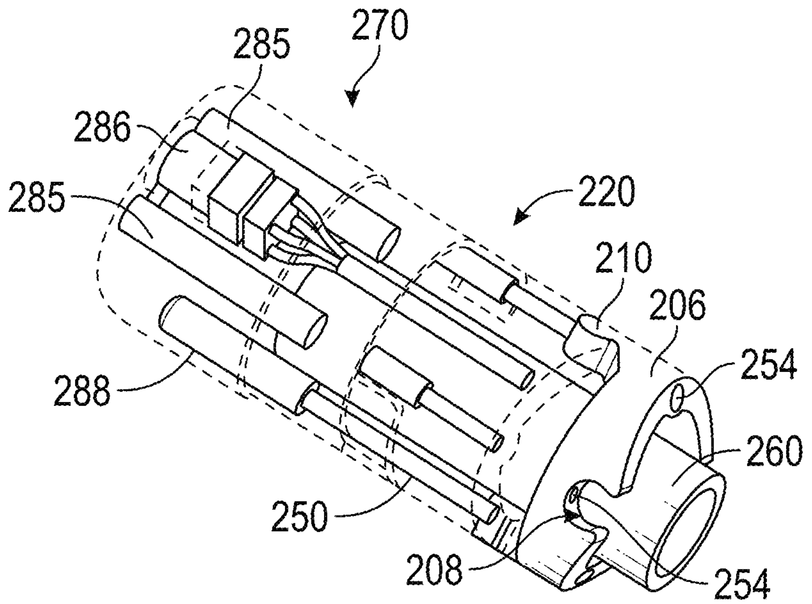

FIG. 27B

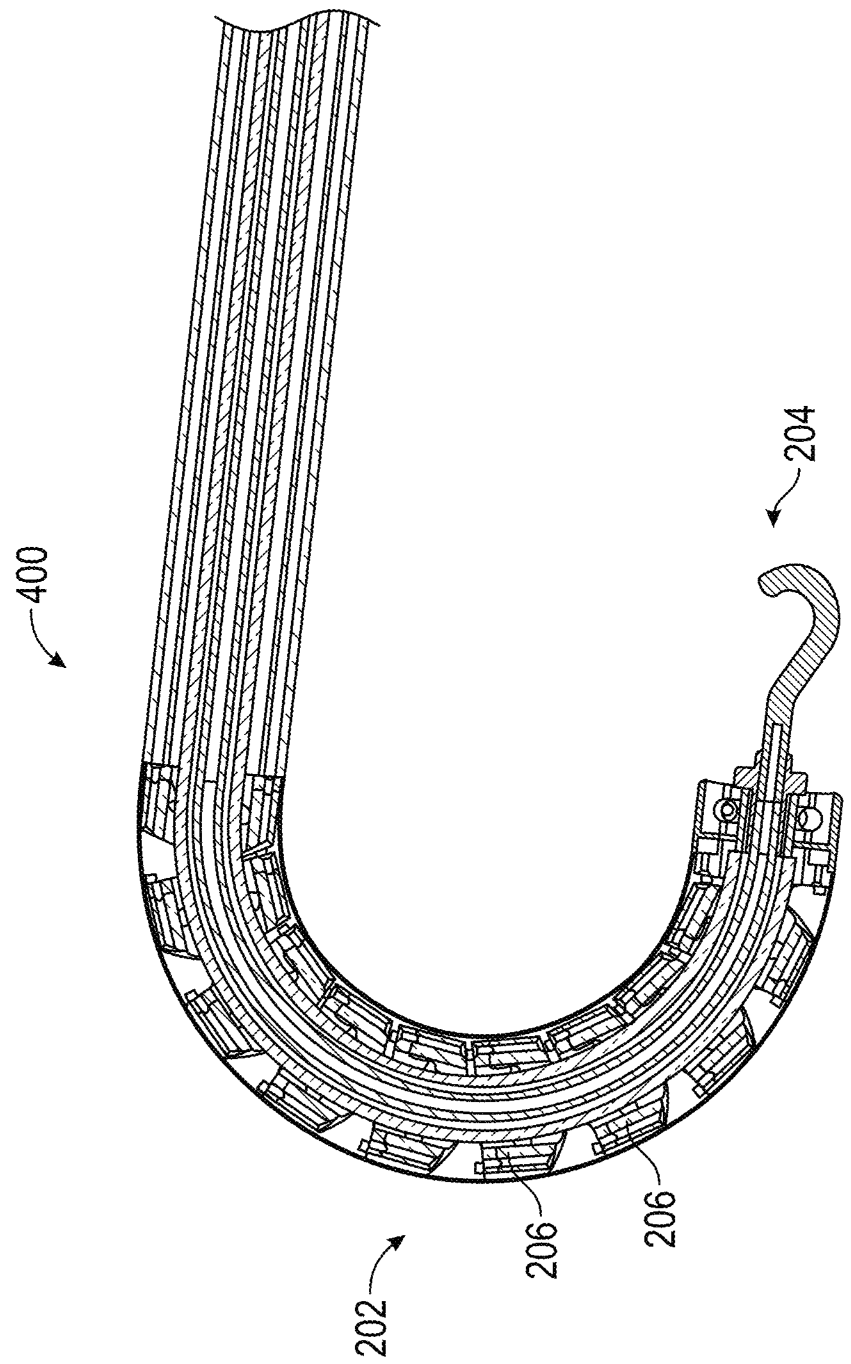

FIG. 28A

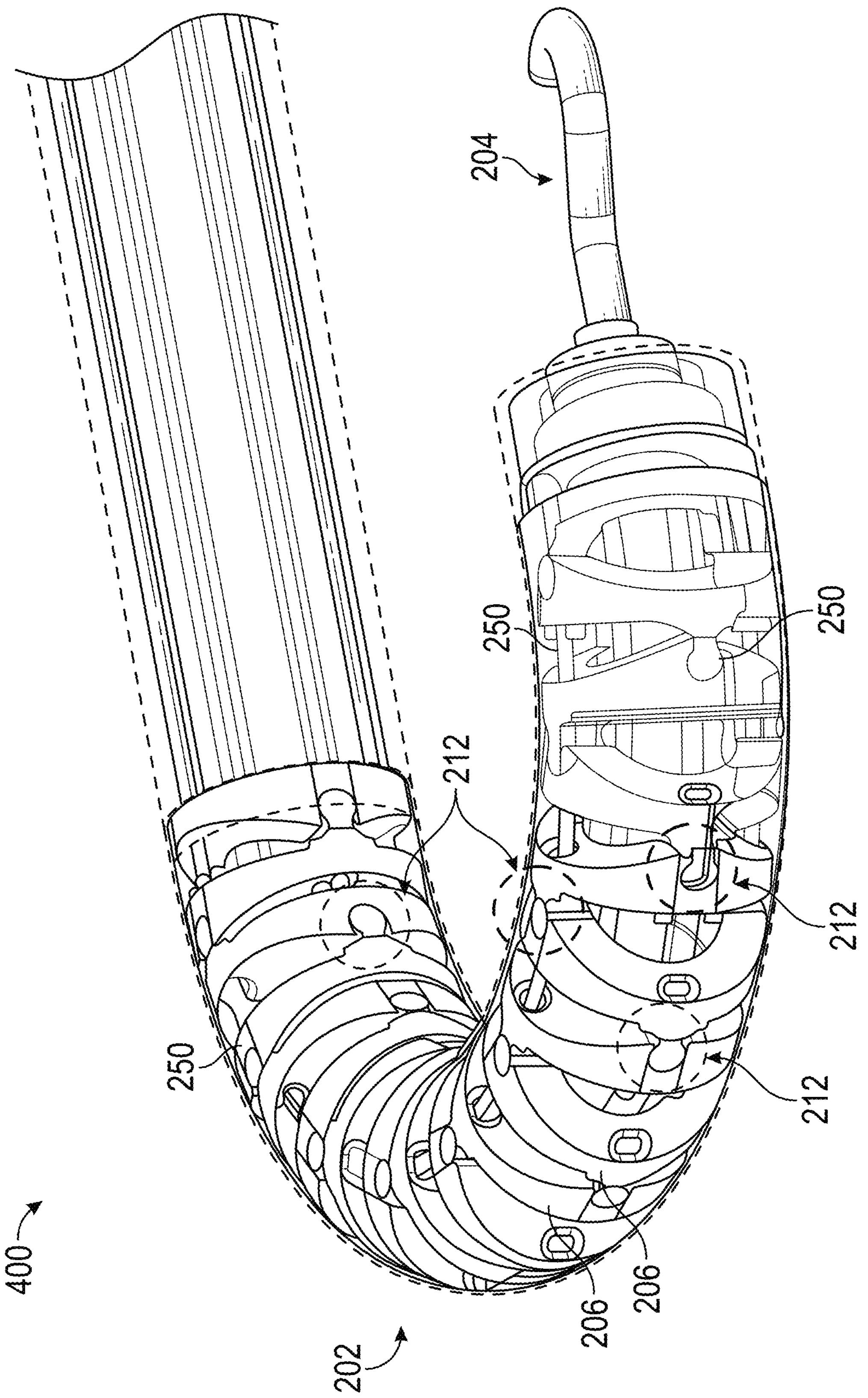

FIG. 28B

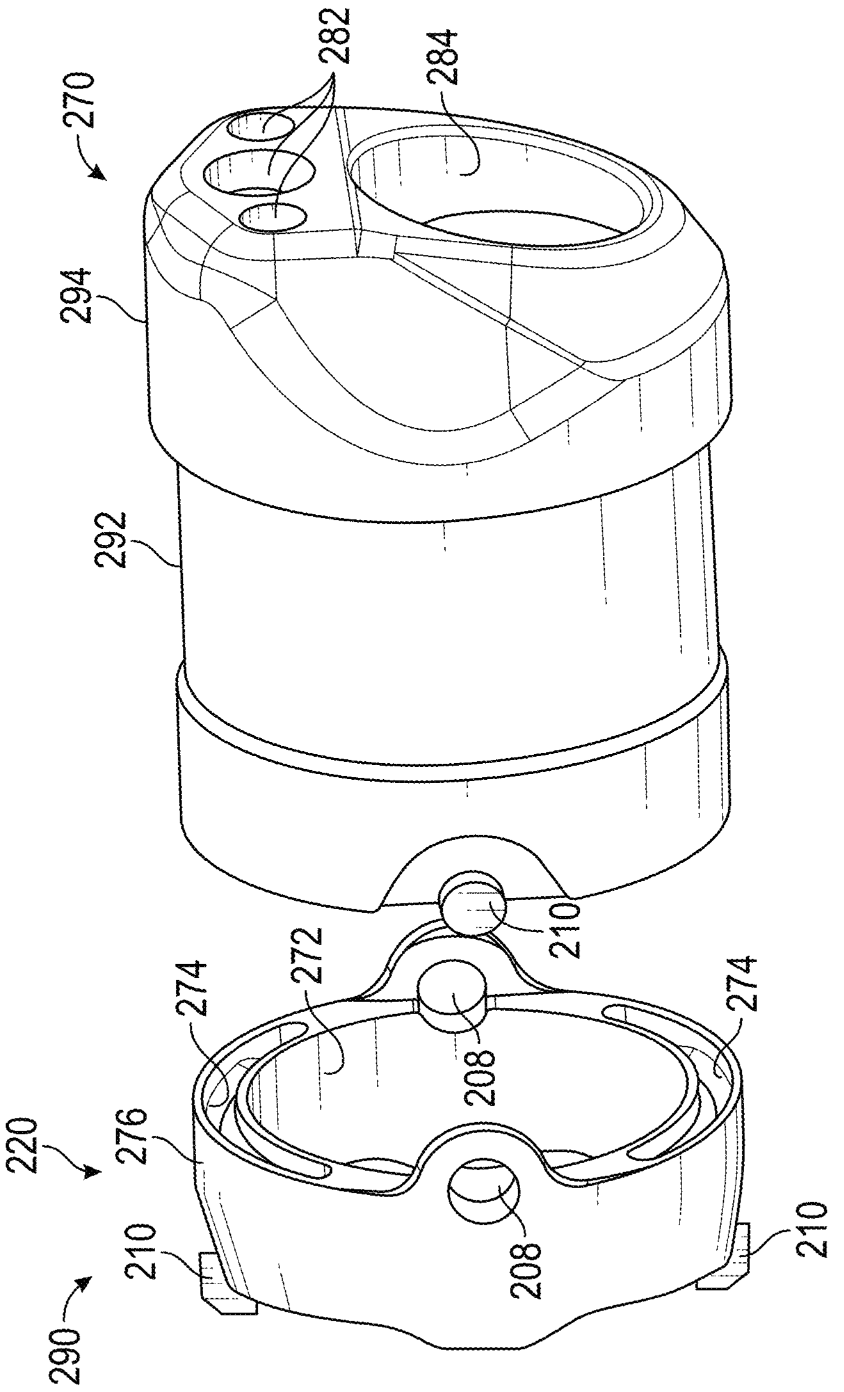

FIG. 29A

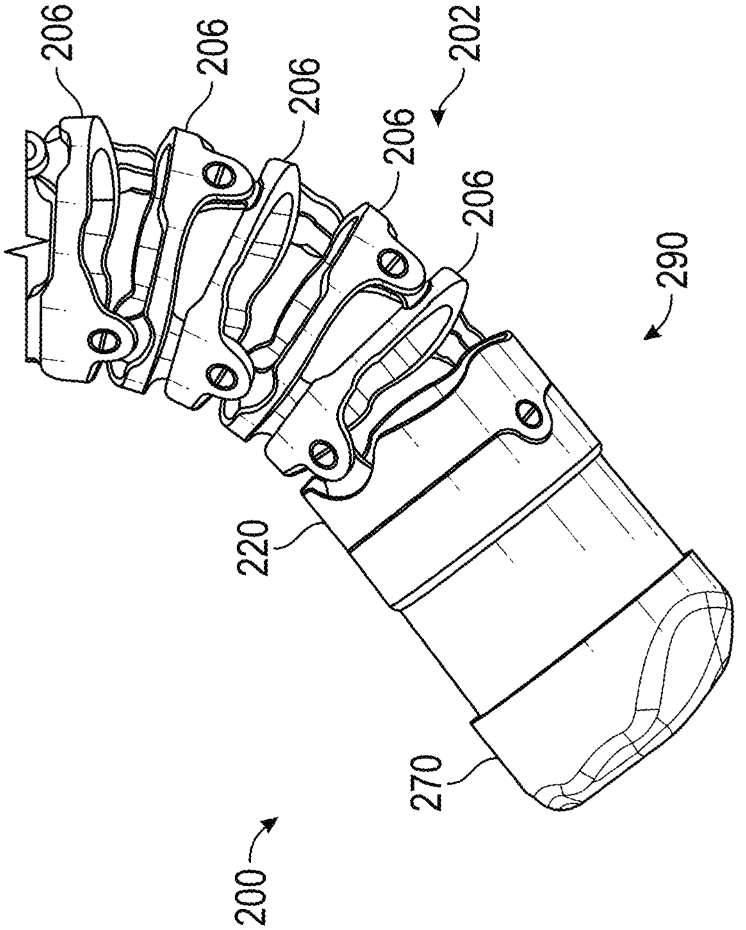

FIG. 29B

MEDICAL INSTRUMENT WITH ARTICULABLE SEGMENT

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 62/786,133, filed Dec. 28, 2018, and U.S. Provisional Application No. 62/868,801, filed Jun. 28, 2019, which are hereby incorporated by reference herein in their entirety.

TECHNICAL FIELD

The systems and methods disclosed herein are directed to medical instruments, and more particularly to medical instruments with bendable sections and tip assemblies.

BACKGROUND

Medical procedures, such as colonoscopy, duodenoscopy, bronchoscopy, ureteroscopy, and the like, may involve using an medical instrument with a bending section to access an internal region of a patient.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosed aspects will hereinafter be described in conjunction with the appended drawings, provided to illustrate and not to limit the disclosed aspects, wherein like designations denote like elements.

FIG. **1** illustrates an embodiment of a cart-based robotic system arranged for diagnostic and/or therapeutic bronchoscopy procedure(s).

FIG. **2** depicts further aspects of the robotic system of FIG. **1**.

FIG. **3** illustrates an embodiment of the robotic system of FIG. **1** arranged for ureteroscopy.

FIG. **4** illustrates an embodiment of the robotic system of FIG. **1** arranged for a vascular procedure.

FIG. **5** illustrates an embodiment of a table-based robotic system arranged for a bronchoscopy procedure.

FIG. **6** provides an alternative view of the robotic system of FIG. **5**.

FIG. **7** illustrates an example system configured to stow robotic arm(s).

FIG. **8** illustrates an embodiment of a table-based robotic system configured for a ureteroscopy procedure.

FIG. **9** illustrates an embodiment of a table-based robotic system configured for a laparoscopic procedure.

FIG. **10** illustrates an embodiment of the table-based robotic system of FIGS. **5-9** with pitch or tilt adjustment.

FIG. **11** provides a detailed illustration of the interface between the table and the column of the table-based robotic system of FIGS. **5-10**.

FIG. **12** illustrates an alternative embodiment of a table-based robotic system.

FIG. **13** illustrates an end view of the table-based robotic system of FIG. **12**.

FIG. **14** illustrates an end view of a table-based robotic system with robotic arms attached thereto.

FIG. **15** illustrates an exemplary instrument driver.

FIG. **16** illustrates an exemplary medical instrument with a paired instrument driver.

FIG. **17** illustrates an alternative design for an instrument driver and instrument where the axes of the drive units are parallel to the axis of the elongated shaft of the instrument.

FIG. **18** illustrates an instrument having an instrument-based insertion architecture.

FIG. **19** illustrates an exemplary controller.

FIG. **20** depicts a block diagram illustrating a localization system that estimates a location of one or more elements of the robotic systems of FIGS. **1-10**, such as the location of the instrument of FIGS. **16-18**, in accordance to an example embodiment.

FIG. **21**A illustrates an embodiment of a medical instrument with a series of articulable segments in a bent configuration.

FIG. **21**B illustrates an embodiment of a series of articulable segments.

FIGS. **22**A and **22**B illustrate various views of an articulable segment of the series of articulable segments of FIG. **21**B.

FIG. **22**C illustrates a series of the articulable segments of FIGS. **22**A and **22**B.

FIGS. **23**A and **23**B illustrate various views of an embodiment of a distal end segment.

FIGS. **24**A and **24**B illustrate various views of an embodiment of a proximal end segment.

FIG. **25** illustrates an example embodiment of a medical instrument with a distal end segment, a proximal end segment, and articulable segments.

FIG. **26**A illustrates an embodiment of a support member for an articulable segment.

FIG. **26**B illustrates another embodiment of a support member for an articulable segment.

FIG. **26**C illustrates another embodiment of a support member for an articulable segment.

FIG. **27**A illustrates a portion of a medical instrument with articulable segments and cables.

FIG. **27**B illustrates an end portion of an medical instrument.

FIGS. **28**A and **28**B illustrate various views of an medical instrument in an articulated configuration.

FIGS. **29**A and **29**B illustrate various views of a tip assembly for a medical instrument.

DETAILED DESCRIPTION

1. Overview.

Aspects of the present disclosure may be integrated into a robotically-enabled medical system capable of performing a variety of medical procedures, including both minimally invasive, such as laparoscopy, and non-invasive, such as endoscopy, procedures. Among endoscopy procedures, the system may be capable of performing bronchoscopy, ureteroscopy, gastroscopy, etc.

In addition to performing the breadth of procedures, the system may provide additional benefits, such as enhanced imaging and guidance to assist the physician. Additionally, the system may provide the physician with the ability to perform the procedure from an ergonomic position without the need for awkward arm motions and positions. Still further, the system may provide the physician with the ability to perform the procedure with improved ease of use such that one or more of the instruments of the system can be controlled by a single user.

Various embodiments will be described below in conjunction with the drawings for purposes of illustration. It should be appreciated that many other implementations of the disclosed concepts are possible, and various advantages can be achieved with the disclosed implementations. Headings are included herein for reference and to aid in locating various sections. These headings are not intended to limit the scope of the concepts described with respect thereto. Such concepts may have applicability throughout the entire specification.

A. Robotic System—Cart.

The robotically-enabled medical system may be configured in a variety of ways depending on the particular procedure. FIG. **1** illustrates an embodiment of a cart-based robotically-enabled system **10** arranged for a diagnostic and/or therapeutic bronchoscopy procedure. During a bronchoscopy, the system **10** may comprise a cart **11** having one or more robotic arms **12** to deliver a medical instrument, such as a steerable endoscope **13**, which may be a procedure-specific bronchoscope for bronchoscopy, to a natural orifice access point (i.e., the mouth of the patient positioned on a table in the present example) to deliver diagnostic and/or therapeutic tools. As shown, the cart **11** may be positioned proximate to the patient's upper torso in order to provide access to the access point. Similarly, the robotic arms **12** may be actuated to position the bronchoscope relative to the access point. The arrangement in FIG. **1** may also be utilized when performing a gastro-intestinal (GI) procedure with a gastroscope, a specialized endoscope for GI procedures. FIG. **2** depicts an example embodiment of the cart in greater detail.

With continued reference to FIG. **1**, once the cart **11** is properly positioned, the robotic arms **12** may insert the steerable endoscope **13** into the patient robotically, manually, or a combination thereof. As shown, the steerable endoscope **13** may comprise at least two telescoping parts, such as an inner leader portion and an outer sheath portion, each portion coupled to a separate instrument driver from the set of instrument drivers **28**, each instrument driver coupled to the distal end of an individual robotic arm. This linear arrangement of the instrument drivers **28**, which facilitates coaxially aligning the leader portion with the sheath portion, creates a "virtual rail" **29** that may be repositioned in space by manipulating the one or more robotic arms **12** into different angles and/or positions. The virtual rails described herein are depicted in the Figures using dashed lines, and accordingly the dashed lines do not depict any physical structure of the system. Translation of the instrument drivers **28** along the virtual rail **29** telescopes the inner leader portion relative to the outer sheath portion or advances or retracts the endoscope **13** from the patient. The angle of the virtual rail **29** may be adjusted, translated, and pivoted based on clinical application or physician preference. For example, in bronchoscopy, the angle and position of the virtual rail **29** as shown represents a compromise between providing physician access to the endoscope **13** while minimizing friction that results from bending the endoscope **13** into the patient's mouth.

The endoscope **13** may be directed down the patient's trachea and lungs after insertion using precise commands from the robotic system until reaching the target destination or operative site. In order to enhance navigation through the patient's lung network and/or reach the desired target, the endoscope **13** may be manipulated to telescopically extend the inner leader portion from the outer sheath portion to obtain enhanced articulation and greater bend radius. The use of separate instrument drivers **28** also allows the leader portion and sheath portion to be driven independent of each other.

For example, the endoscope **13** may be directed to deliver a biopsy needle to a target, such as, for example, a lesion or nodule within the lungs of a patient. The needle may be deployed down a working channel that runs the length of the endoscope to obtain a tissue sample to be analyzed by a pathologist. Depending on the pathology results, additional tools may be deployed down the working channel of the endoscope for additional biopsies. After identifying a nodule to be malignant, the endoscope **13** may endoscopically deliver tools to resect the potentially cancerous tissue. In some instances, diagnostic and therapeutic treatments can be delivered in separate procedures. In those circumstances, the endoscope **13** may also be used to deliver a fiducial to "mark" the location of the target nodule as well. In other instances, diagnostic and therapeutic treatments may be delivered during the same procedure.

The system **10** may also include a movable tower **30**, which may be connected via support cables to the cart **11** to provide support for controls, electronics, fluidics, optics, sensors, and/or power to the cart **11**. Placing such functionality in the tower **30** allows for a smaller form factor cart **11** that may be more easily adjusted and/or re-positioned by an operating physician and his/her staff. Additionally, the division of functionality between the cart/table and the support tower **30** reduces operating room clutter and facilitates improving clinical workflow. While the cart **11** may be positioned close to the patient, the tower **30** may be stowed in a remote location to stay out of the way during a procedure.

In support of the robotic systems described above, the tower **30** may include component(s) of a computer-based control system that stores computer program instructions, for example, within a non-transitory computer-readable storage medium such as a persistent magnetic storage drive, solid state drive, etc. The execution of those instructions, whether the execution occurs in the tower **30** or the cart **11**, may control the entire system or sub-system(s) thereof. For example, when executed by a processor of the computer system, the instructions may cause the components of the robotics system to actuate the relevant carriages and arm mounts, actuate the robotics arms, and control the medical instruments. For example, in response to receiving the control signal, the motors in the joints of the robotics arms may position the arms into a certain posture.

The tower **30** may also include a pump, flow meter, valve control, and/or fluid access in order to provide controlled irrigation and aspiration capabilities to the system that may be deployed through the endoscope **13**. These components may also be controlled using the computer system of tower **30**. In some embodiments, irrigation and aspiration capabilities may be delivered directly to the endoscope **13** through separate cable(s).

The tower **30** may include a voltage and surge protector designed to provide filtered and protected electrical power to the cart **11**, thereby avoiding placement of a power transformer and other auxiliary power components in the cart **11**, resulting in a smaller, more moveable cart **11**.

The tower **30** may also include support equipment for the sensors deployed throughout the robotic system **10**. For example, the tower **30** may include opto-electronics equipment for detecting, receiving, and processing data received from the optical sensors or cameras throughout the robotic system **10**. In combination with the control system, such opto-electronics equipment may be used to generate real-time images for display in any number of consoles deployed throughout the system, including in the tower **30**. Similarly, the tower **30** may also include an electronic subsystem for receiving and processing signals received from deployed electromagnetic (EM) sensors. The tower **30** may also be used to house and position an EM field generator for detection by EM sensors in or on the medical instrument.

The tower **30** may also include a console **31** in addition to other consoles available in the rest of the system, e.g., console mounted on top of the cart. The console **31** may include a user interface and a display screen, such as a touchscreen, for the physician operator. Consoles in system **10** are generally designed to provide both robotic controls as well as pre-operative and real-time information of the procedure, such as navigational and localization information of the endoscope **13**. When the console **31** is not the only console available to the physician, it may be used by a second operator, such as a nurse, to monitor the health or vitals of the patient and the operation of system, as well as provide procedure-specific data, such as navigational and localization information. In other embodiments, the console **30** is housed in a body that is separate from the tower **30**.

The tower **30** may be coupled to the cart **11** and endoscope **13** through one or more cables or connections (not shown). In some embodiments, the support functionality from the tower **30** may be provided through a single cable to the cart **11**, simplifying and de-cluttering the operating room. In other embodiments, specific functionality may be coupled in separate cabling and connections. For example, while power may be provided through a single power cable to the cart, the support for controls, optics, fluidics, and/or navigation may be provided through a separate cable.

FIG. **2** provides a detailed illustration of an embodiment of the cart from the cart-based robotically-enabled system shown in FIG. **1**. The cart **11** generally includes an elongated support structure **14** (often referred to as a "column"), a cart base **15**, and a console **16** at the top of the column **14**. The column **14** may include one or more carriages, such as a carriage **17** (alternatively "arm support") for supporting the deployment of one or more robotic arms **12** (three shown in FIG. **2**). The carriage **17** may include individually configurable arm mounts that rotate along a perpendicular axis to adjust the base of the robotic arms **12** for better positioning relative to the patient. The carriage **17** also includes a carriage interface **19** that allows the carriage **17** to vertically translate along the column **14**.

The carriage interface **19** is connected to the column **14** through slots, such as slot **20**, that are positioned on opposite sides of the column **14** to guide the vertical translation of the carriage **17**. The slot **20** contains a vertical translation interface to position and hold the carriage at various vertical heights relative to the cart base **15**. Vertical translation of the carriage **17** allows the cart **11** to adjust the reach of the robotic arms **12** to meet a variety of table heights, patient sizes, and physician preferences. Similarly, the individually configurable arm mounts on the carriage **17** allow the robotic arm base **21** of robotic arms **12** to be angled in a variety of configurations.

In some embodiments, the slot **20** may be supplemented with slot covers that are flush and parallel to the slot surface to prevent dirt and fluid ingress into the internal chambers of the column **14** and the vertical translation interface as the carriage **17** vertically translates. The slot covers may be deployed through pairs of spring spools positioned near the vertical top and bottom of the slot **20**. The covers are coiled within the spools until deployed to extend and retract from their coiled state as the carriage **17** vertically translates up and down. The spring-loading of the spools provides force to retract the cover into a spool when carriage **17** translates towards the spool, while also maintaining a tight seal when the carriage **17** translates away from the spool. The covers may be connected to the carriage **17** using, for example, brackets in the carriage interface **19** to ensure proper extension and retraction of the cover as the carriage **17** translates.

The column **14** may internally comprise mechanisms, such as gears and motors, that are designed to use a vertically aligned lead screw to translate the carriage **17** in a mechanized fashion in response to control signals generated in response to user inputs, e.g., inputs from the console **16**.

The robotic arms **12** may generally comprise robotic arm bases **21** and end effectors **22**, separated by a series of linkages **23** that are connected by a series of joints **24**, each joint comprising an independent actuator, each actuator comprising an independently controllable motor. Each independently controllable joint represents an independent degree of freedom available to the robotic arm. Each of the arms **12** have seven joints, and thus provide seven degrees of freedom. A multitude of joints result in a multitude of degrees of freedom, allowing for "redundant" degrees of freedom. Redundant degrees of freedom allow the robotic arms **12** to position their respective end effectors **22** at a specific position, orientation, and trajectory in space using different linkage positions and joint angles. This allows for the system to position and direct a medical instrument from a desired point in space while allowing the physician to move the arm joints into a clinically advantageous position away from the patient to create greater access, while avoiding arm collisions.

The cart base **15** balances the weight of the column **14**, carriage **17**, and arms **12** over the floor. Accordingly, the cart base **15** houses heavier components, such as electronics, motors, power supply, as well as components that either enable movement and/or immobilize the cart. For example, the cart base **15** includes rollable wheel-shaped casters **25** that allow for the cart to easily move around the room prior to a procedure. After reaching the appropriate position, the casters **25** may be immobilized using wheel locks to hold the cart **11** in place during the procedure.

Positioned at the vertical end of column **14**, the console **16** allows for both a user interface for receiving user input and a display screen (or a dual-purpose device such as, for example, a touchscreen **26**) to provide the physician user with both pre-operative and intra-operative data. Potential pre-operative data on the touchscreen **26** may include pre-operative plans, navigation and mapping data derived from pre-operative computerized tomography (CT) scans, and/or notes from pre-operative patient interviews. Intra-operative data on display may include optical information provided from the tool, sensor and coordinate information from sensors, as well as vital patient statistics, such as respiration, heart rate, and/or pulse. The console **16** may be positioned and tilted to allow a physician to access the console from the side of the column **14** opposite carriage **17**. From this position, the physician may view the console **16**, robotic arms **12**, and patient while operating the console **16** from behind the cart **11**. As shown, the console **16** also includes a handle **27** to assist with maneuvering and stabilizing cart **11**.

FIG. **3** illustrates an embodiment of a robotically-enabled system **10** arranged for ureteroscopy. In a ureteroscopic procedure, the cart **11** may be positioned to deliver a ureteroscope **32**, a procedure-specific endoscope designed to traverse a patient's urethra and ureter, to the lower abdominal area of the patient. In a ureteroscopy, it may be desirable for the ureteroscope **32** to be directly aligned with the patient's urethra to reduce friction and forces on the sensitive anatomy in the area. As shown, the cart **11** may be aligned at the foot of the table to allow the robotic arms **12** to position the ureteroscope **32** for direct linear access to the patient's urethra. From the foot of the table, the robotic arms

12 may insert the ureteroscope **32** along the virtual rail **33** directly into the patient's lower abdomen through the urethra.

After insertion into the urethra, using similar control techniques as in bronchoscopy, the ureteroscope **32** may be navigated into the bladder, ureters, and/or kidneys for diagnostic and/or therapeutic applications. For example, the ureteroscope **32** may be directed into the ureter and kidneys to break up kidney stone build up using a laser or ultrasonic lithotripsy device deployed down the working channel of the ureteroscope **32**. After lithotripsy is complete, the resulting stone fragments may be removed using baskets deployed down the ureteroscope **32**.

FIG. **4** illustrates an embodiment of a robotically-enabled system similarly arranged for a vascular procedure. In a vascular procedure, the system **10** may be configured such that the cart **11** may deliver a medical instrument **34**, such as a steerable catheter, to an access point in the femoral artery in the patient's leg. The femoral artery presents both a larger diameter for navigation as well as a relatively less circuitous and tortuous path to the patient's heart, which simplifies navigation. As in a ureteroscopic procedure, the cart **11** may be positioned towards the patient's legs and lower abdomen to allow the robotic arms **12** to provide a virtual rail **35** with direct linear access to the femoral artery access point in the patient's thigh/hip region. After insertion into the artery, the medical instrument **34** may be directed and inserted by translating the instrument drivers **28**. Alternatively, the cart may be positioned around the patient's upper abdomen in order to reach alternative vascular access points, such as, for example, the carotid and brachial arteries near the shoulder and wrist.

B. Robotic System—Table.

Embodiments of the robotically-enabled medical system may also incorporate the patient's table. Incorporation of the table reduces the amount of capital equipment within the operating room by removing the cart, which allows greater access to the patient. FIG. **5** illustrates an embodiment of such a robotically-enabled system arranged for a bronchoscopy procedure. System **36** includes a support structure or column **37** for supporting platform **38** (shown as a "table" or "bed") over the floor. Much like in the cart-based systems, the end effectors of the robotic arms **39** of the system **36** comprise instrument drivers **42** that are designed to manipulate an elongated medical instrument, such as a bronchoscope **40** in FIG. **5**, through or along a virtual rail **41** formed from the linear alignment of the instrument drivers **42**. In practice, a C-arm for providing fluoroscopic imaging may be positioned over the patient's upper abdominal area by placing the emitter and detector around table **38**.

FIG. **6** provides an alternative view of the system **36** without the patient and medical instrument for discussion purposes. As shown, the column **37** may include one or more carriages **43** shown as ring-shaped in the system **36**, from which the one or more robotic arms **39** may be based. The carriages **43** may translate along a vertical column interface **44** that runs the length of the column **37** to provide different vantage points from which the robotic arms **39** may be positioned to reach the patient. The carriage(s) **43** may rotate around the column **37** using a mechanical motor positioned within the column **37** to allow the robotic arms **39** to have access to multiples sides of the table **38**, such as, for example, both sides of the patient. In embodiments with multiple carriages, the carriages may be individually positioned on the column and may translate and/or rotate independent of the other carriages. While carriages **43** need not surround the column **37** or even be circular, the ring-shape as shown facilitates rotation of the carriages **43** around the column **37** while maintaining structural balance. Rotation and translation of the carriages **43** allows the system to align the medical instruments, such as endoscopes and laparoscopes, into different access points on the patient. In other embodiments (not shown), the system **36** can include a patient table or bed with adjustable arm supports in the form of bars or rails extending alongside it. One or more robotic arms **39** (e.g., via a shoulder with an elbow joint) can be attached to the adjustable arm supports, which can be vertically adjusted. By providing vertical adjustment, the robotic arms **39** are advantageously capable of being stowed compactly beneath the patient table or bed, and subsequently raised during a procedure.

The arms **39** may be mounted on the carriages through a set of arm mounts **45** comprising a series of joints that may individually rotate and/or telescopically extend to provide additional configurability to the robotic arms **39**. Additionally, the arm mounts **45** may be positioned on the carriages **43** such that, when the carriages **43** are appropriately rotated, the arm mounts **45** may be positioned on either the same side of table **38** (as shown in FIG. **6**), on opposite sides of table **38** (as shown in FIG. **9**), or on adjacent sides of the table **38** (not shown).

The column **37** structurally provides support for the table **38**, and a path for vertical translation of the carriages. Internally, the column **37** may be equipped with lead screws for guiding vertical translation of the carriages, and motors to mechanize the translation of said carriages based the lead screws. The column **37** may also convey power and control signals to the carriage **43** and robotic arms **39** mounted thereon.

The table base **46** serves a similar function as the cart base **15** in cart **11** shown in FIG. **2**, housing heavier components to balance the table/bed **38**, the column **37**, the carriages **43**, and the robotic arms **39**. The table base **46** may also incorporate rigid casters to provide stability during procedures. Deployed from the bottom of the table base **46**, the casters may extend in opposite directions on both sides of the base **46** and retract when the system **36** needs to be moved.

Continuing with FIG. **6**, the system **36** may also include a tower (not shown) that divides the functionality of system **36** between table and tower to reduce the form factor and bulk of the table. As in earlier disclosed embodiments, the tower may provide a variety of support functionalities to table, such as processing, computing, and control capabilities, power, fluidics, and/or optical and sensor processing. The tower may also be movable to be positioned away from the patient to improve physician access and de-clutter the operating room. Additionally, placing components in the tower allows for more storage space in the table base for potential stowage of the robotic arms. The tower may also include a master controller or console that provides both a user interface for user input, such as keyboard and/or pendant, as well as a display screen (or touchscreen) for pre-operative and intra-operative information, such as real-time imaging, navigation, and tracking information. In some embodiments, the tower may also contain holders for gas tanks to be used for insufflation.

In some embodiments, a table base may stow and store the robotic arms when not in use. FIG. **7** illustrates a system **47** that stows robotic arms in an embodiment of the table-based system. In system **47**, carriages **48** may be vertically translated into base **49** to stow robotic arms **50**, arm mounts **51**, and the carriages **48** within the base **49**. Base covers **52** may be translated and retracted open to deploy the carriages **48**, arm mounts **51**, and arms **50** around column **53**, and closed to stow to protect them when not in use. The base covers **52** may be sealed with a membrane **54** along the edges of its opening to prevent dirt and fluid ingress when closed.

FIG. **8** illustrates an embodiment of a robotically-enabled table-based system configured for a ureteroscopy procedure. In a ureteroscopy, the table **38** may include a swivel portion **55** for positioning a patient off-angle from the column **37** and table base **46**. The swivel portion **55** may rotate or pivot around a pivot point (e.g., located below the patient's head) in order to position the bottom portion of the swivel portion **55** away from the column **37**. For example, the pivoting of the swivel portion **55** allows a C-arm (not shown) to be positioned over the patient's lower abdomen without competing for space with the column (not shown) below table **38**. By rotating the carriage **35** (not shown) around the column **37**, the robotic arms **39** may directly insert a ureteroscope **56** along a virtual rail **57** into the patient's groin area to reach the urethra. In a ureteroscopy, stirrups **58** may also be fixed to the swivel portion **55** of the table **38** to support the position of the patient's legs during the procedure and allow clear access to the patient's groin area.

In a laparoscopic procedure, through small incision(s) in the patient's abdominal wall, minimally invasive instruments may be inserted into the patient's anatomy. In some embodiments, the minimally invasive instruments comprise an elongated rigid member, such as a shaft, which is used to access anatomy within the patient. After inflation of the patient's abdominal cavity, the instruments may be directed to perform surgical or medical tasks, such as grasping, cutting, ablating, suturing, etc. In some embodiments, the instruments can comprise a scope, such as a laparoscope. FIG. **9** illustrates an embodiment of a robotically-enabled table-based system configured for a laparoscopic procedure. As shown in FIG. **9**, the carriages **43** of the system **36** may be rotated and vertically adjusted to position pairs of the robotic arms **39** on opposite sides of the table **38**, such that instrument **59** may be positioned using the arm mounts **45** to be passed through minimal incisions on both sides of the patient to reach his/her abdominal cavity.

To accommodate laparoscopic procedures, the robotically-enabled table system may also tilt the platform to a desired angle. FIG. **10** illustrates an embodiment of the robotically-enabled medical system with pitch or tilt adjustment. As shown in FIG. **10**, the system **36** may accommodate tilt of the table **38** to position one portion of the table at a greater distance from the floor than the other. Additionally, the arm mounts **45** may rotate to match the tilt such that the arms **39** maintain the same planar relationship with table **38**. To accommodate steeper angles, the column **37** may also include telescoping portions **60** that allow vertical extension of column **37** to keep the table **38** from touching the floor or colliding with base **46**.

FIG. **11** provides a detailed illustration of the interface between the table **38** and the column **37**. Pitch rotation mechanism **61** may be configured to alter the pitch angle of the table **38** relative to the column **37** in multiple degrees of freedom. The pitch rotation mechanism **61** may be enabled by the positioning of orthogonal axes **1**, **2** at the column-table interface, each axis actuated by a separate motor **3**, **4** responsive to an electrical pitch angle command. Rotation along one screw **5** would enable tilt adjustments in one axis **1**, while rotation along the other screw **6** would enable tilt adjustments along the other axis **2**. In some embodiments, a ball joint can be used to alter the pitch angle of the table **38** relative to the column **37** in multiple degrees of freedom.

For example, pitch adjustments are particularly useful when trying to position the table in a Trendelenburg position, i.e., position the patient's lower abdomen at a higher position from the floor than the patient's lower abdomen, for lower abdominal surgery. The Trendelenburg position causes the patient's internal organs to slide towards his/her upper abdomen through the force of gravity, clearing out the abdominal cavity for minimally invasive tools to enter and perform lower abdominal surgical or medical procedures, such as laparoscopic prostatectomy.

FIGS. **12** and **13** illustrate isometric and end views of an alternative embodiment of a table-based surgical robotics system **100**. The surgical robotics system **100** includes one or more adjustable arm supports **105** that can be configured to support one or more robotic arms (see, for example, FIG. **14**) relative to a table **101**. In the illustrated embodiment, a single adjustable arm support **105** is shown, though an additional arm support can be provided on an opposite side of the table **101**. The adjustable arm support **105** can be configured so that it can move relative to the table **101** to adjust and/or vary the position of the adjustable arm support **105** and/or any robotic arms mounted thereto relative to the table **101**. For example, the adjustable arm support **105** may be adjusted one or more degrees of freedom relative to the table **101**. The adjustable arm support **105** provides high versatility to the system **100**, including the ability to easily stow the one or more adjustable arm supports **105** and any robotics arms attached thereto beneath the table **101**. The adjustable arm support **105** can be elevated from the stowed position to a position below an upper surface of the table **101**. In other embodiments, the adjustable arm support **105** can be elevated from the stowed position to a position above an upper surface of the table **101**.

The adjustable arm support **105** can provide several degrees of freedom, including lift, lateral translation, tilt, etc. In the illustrated embodiment of FIGS. **12** and **13**, the arm support **105** is configured with four degrees of freedom, which are illustrated with arrows in FIG. **12**. A first degree of freedom allows for adjustment of the adjustable arm support **105** in the z-direction ("Z-lift"). For example, the adjustable arm support **105** can include a carriage **109** configured to move up or down along or relative to a column **102** supporting the table **101**. A second degree of freedom can allow the adjustable arm support **105** to tilt. For example, the adjustable arm support **105** can include a rotary joint, which can allow the adjustable arm support **105** to be aligned with the bed in a Trendelenburg position. A third degree of freedom can allow the adjustable arm support **105** to "pivot up," which can be used to adjust a distance between a side of the table **101** and the adjustable arm support **105**. A fourth degree of freedom can permit translation of the adjustable arm support **105** along a longitudinal length of the table.

The surgical robotics system **100** in FIGS. **12** and **13** can comprise a table supported by a column **102** that is mounted to a base **103**. The base **103** and the column **102** support the table **101** relative to a support surface. A floor axis **131** and a support axis **133** are shown in FIG. **13**.

The adjustable arm support **105** can be mounted to the column **102**. In other embodiments, the arm support **105** can be mounted to the table **101** or base **103**. The adjustable arm support **105** can include a carriage **109**, a bar or rail connector **111** and a bar or rail **107**. In some embodiments, one or more robotic arms mounted to the rail **107** can translate and move relative to one another.

The carriage **109** can be attached to the column **102** by a first joint **113**, which allows the carriage **109** to move relative to the column **102** (e.g., such as up and down a first or vertical axis **123**). The first joint **113** can provide the first degree of freedom ("Z-lift") to the adjustable arm support **105**. The adjustable arm support **105** can include a second joint **115**, which provides the second degree of freedom (tilt) for the adjustable arm support **105**. The adjustable arm support **105** can include a third joint **117**, which can provide the third degree of freedom ("pivot up") for the adjustable arm support **105**. An additional joint **119** (shown in FIG. **13**) can be provided that mechanically constrains the third joint **117** to maintain an orientation of the rail **107** as the rail connector **111** is rotated about a third axis **127**. The adjustable arm support **105** can include a fourth joint **121**, which can provide a fourth degree of freedom (translation) for the adjustable arm support **105** along a fourth axis **129**.

FIG. **14** illustrates an end view of the surgical robotics system **140**A with two adjustable arm supports **105**A, **105**B mounted on opposite sides of a table **101**. A first robotic arm **142**A is attached to the bar or rail **107**A of the first adjustable arm support **105**B. The first robotic arm **142**A includes a base **144**A attached to the rail **107**A. The distal end of the first robotic arm **142**A includes an instrument drive mechanism **146**A that can attach to one or more robotic medical instruments or tools. Similarly, the second robotic arm **142**B includes a base **144**B attached to the rail **107**B. The distal end of the second robotic arm **142**B includes an instrument drive mechanism **146**B. The instrument drive mechanism **146**B can be configured to attach to one or more robotic medical instruments or tools.

In some embodiments, one or more of the robotic arms **142**A, **142**B comprises an arm with seven or more degrees of freedom. In some embodiments, one or more of the robotic arms **142**A, **142**B can include eight degrees of freedom, including an insertion axis (1-degree of freedom including insertion), a wrist (3-degrees of freedom including wrist pitch, yaw and roll), an elbow (1-degree of freedom including elbow pitch), a shoulder (2-degrees of freedom including shoulder pitch and yaw), and base **144**A, **144**B (1-degree of freedom including translation). In some embodiments, the insertion degree of freedom can be provided by the robotic arm **142**A, **142**B, while in other embodiments, the instrument itself provides insertion via an instrument-based insertion architecture.

C. Instrument Driver & Interface.

The end effectors of the system's robotic arms comprise (i) an instrument driver (alternatively referred to as "instrument drive mechanism" or "instrument device manipulator") that incorporate electro-mechanical means for actuating the medical instrument and (ii) a removable or detachable medical instrument, which may be devoid of any electro-mechanical components, such as motors. This dichotomy may be driven by the need to sterilize medical instruments used in medical procedures, and the inability to adequately sterilize expensive capital equipment due to their intricate mechanical assemblies and sensitive electronics. Accordingly, the medical instruments may be designed to be detached, removed, and interchanged from the instrument driver (and thus the system) for individual sterilization or disposal by the physician or the physician's staff. In contrast, the instrument drivers need not be changed or sterilized, and may be draped for protection.

FIG. **15** illustrates an example instrument driver. Positioned at the distal end of a robotic arm, instrument driver **62** comprises of one or more drive units **63** arranged with parallel axes to provide controlled torque to a medical instrument via drive shafts **64**. Each drive unit **63** comprises an individual drive shaft **64** for interacting with the instrument, a gear head **65** for converting the motor shaft rotation to a desired torque, a motor **66** for generating the drive torque, an encoder **67** to measure the speed of the motor shaft and provide feedback to the control circuitry, and control circuitry **68** for receiving control signals and actuating the drive unit. Each drive unit **63** being independent controlled and motorized, the instrument driver **62** may provide multiple (e.g., four as shown in FIG. **15**) independent drive outputs to the medical instrument. In operation, the control circuitry **68** would receive a control signal, transmit a motor signal to the motor **66**, compare the resulting motor speed as measured by the encoder **67** with the desired speed, and modulate the motor signal to generate the desired torque.

For procedures that require a sterile environment, the robotic system may incorporate a drive interface, such as a sterile adapter connected to a sterile drape, that sits between the instrument driver and the medical instrument. The chief purpose of the sterile adapter is to transfer angular motion from the drive shafts of the instrument driver to the drive inputs of the instrument while maintaining physical separation, and thus sterility, between the drive shafts and drive inputs. Accordingly, an example sterile adapter may comprise of a series of rotational inputs and outputs intended to be mated with the drive shafts of the instrument driver and drive inputs on the instrument. Connected to the sterile adapter, the sterile drape, comprised of a thin, flexible material such as transparent or translucent plastic, is designed to cover the capital equipment, such as the instrument driver, robotic arm, and cart (in a cart-based system) or table (in a table-based system). Use of the drape would allow the capital equipment to be positioned proximate to the patient while still being located in an area not requiring sterilization (i.e., non-sterile field). On the other side of the sterile drape, the medical instrument may interface with the patient in an area requiring sterilization (i.e., sterile field).

D. Medical Instrument.

FIG. **16** illustrates an example medical instrument with a paired instrument driver. Like other instruments designed for use with a robotic system, medical instrument **70** comprises an elongated shaft **71** (or elongate body) and an instrument base **72**. The instrument base **72**, also referred to as an "instrument handle" due to its intended design for manual interaction by the physician, may generally comprise rotatable drive inputs **73**, e.g., receptacles, pulleys or spools, that are designed to be mated with drive outputs **74** that extend through a drive interface on instrument driver **75** at the distal end of robotic arm **76**. When physically connected, latched, and/or coupled, the mated drive inputs **73** of instrument base **72** may share axes of rotation with the drive outputs **74** in the instrument driver **75** to allow the transfer of torque from drive outputs **74** to drive inputs **73**. In some embodiments, the drive outputs **74** may comprise splines that are designed to mate with receptacles on the drive inputs **73**.

The elongated shaft **71** is designed to be delivered through either an anatomical opening or lumen, e.g., as in endoscopy, or a minimally invasive incision, e.g., as in laparoscopy. The elongated shaft **71** may be either flexible (e.g., having properties similar to an endoscope) or rigid (e.g., having properties similar to a laparoscope) or contain a customized combination of both flexible and rigid portions. When designed for laparoscopy, the distal end of a rigid elongated shaft may be connected to an end effector extending from a jointed wrist formed from a clevis with at least one degree of freedom and a surgical tool or medical instrument, such as, for example, a grasper or scissors, that may be actuated based on force from the tendons as the drive inputs rotate in response to torque received from the drive outputs **74** of the instrument driver **75**. When designed for endoscopy, the distal end of a flexible elongated shaft may include a steerable or controllable bendable section that may be articulated and bent based on torque received from the drive outputs **74** of the instrument driver **75**.

Torque from the instrument driver **75** is transmitted down the elongated shaft **71** using tendons along the shaft **71**. These individual tendons, such as pull wires, may be individually anchored to individual drive inputs **73** within the instrument handle **72**. From the handle **72**, the tendons are directed down one or more pull lumens along the elongated shaft **71** and anchored at the distal portion of the elongated shaft **71**, or in the wrist at the distal portion of the elongated shaft. During a surgical procedure, such as a laparoscopic, endoscopic or hybrid procedure, these tendons may be coupled to a distally mounted end effector, such as a wrist, grasper, or scissor. Under such an arrangement, torque exerted on drive inputs **73** would transfer tension to the tendon, thereby causing the end effector to actuate in some way. In some embodiments, during a surgical procedure, the tendon may cause a joint to rotate about an axis, thereby causing the end effector to move in one direction or another. Alternatively, the tendon may be connected to one or more jaws of a grasper at distal end of the elongated shaft **71**, where tension from the tendon cause the grasper to close.

In endoscopy, the tendons may be coupled to a bending or articulating section positioned along the elongated shaft **71** (e.g., at the distal end) via adhesive, control ring, or other mechanical fixation. When fixedly attached to the distal end of a bendable section, torque exerted on drive inputs **73** would be transmitted down the tendons, causing the softer, bendable section (sometimes referred to as the articulable section or region) to bend or articulate. Along the non-bendable sections, it may be advantageous to spiral or helix the individual pull lumens that direct the individual tendons along (or inside) the walls of the endoscope shaft to balance the radial forces that result from tension in the pull wires. The angle of the spiraling and/or spacing there between may be altered or engineered for specific purposes, wherein tighter spiraling exhibits lesser shaft compression under load forces, while lower amounts of spiraling results in greater shaft compression under load forces, but also exhibits limits bending. On the other end of the spectrum, the pull lumens may be directed parallel to the longitudinal axis of the elongated shaft **71** to allow for controlled articulation in the desired bending or articulable sections.

In endoscopy, the elongated shaft **71** houses a number of components to assist with the robotic procedure. The shaft may comprise of a working channel for deploying surgical tools (or medical instruments), irrigation, and/or aspiration to the operative region at the distal end of the shaft **71**. The shaft **71** may also accommodate wires and/or optical fibers to transfer signals to/from an optical assembly at the distal tip, which may include of an optical camera. The shaft **71** may also accommodate optical fibers to carry light from proximally-located light sources, such as light emitting diodes, to the distal end of the shaft.

At the distal end of the instrument **70**, the distal tip may also comprise the opening of a working channel for delivering tools for diagnostic and/or therapy, irrigation, and aspiration to an operative site. The distal tip may also include a port for a camera, such as a fiberscope or a digital camera, to capture images of an internal anatomical space. Relatedly, the distal tip may also include ports for light sources for illuminating the anatomical space when using the camera.

In the example of FIG. **16**, the drive shaft axes, and thus the drive input axes, are orthogonal to the axis of the elongated shaft. This arrangement, however, complicates roll capabilities for the elongated shaft **71**. Rolling the elongated shaft **71** along its axis while keeping the drive inputs **73** static results in undesirable tangling of the tendons as they extend off the drive inputs **73** and enter pull lumens within the elongated shaft **71**. The resulting entanglement of such tendons may disrupt any control algorithms intended to predict movement of the flexible elongated shaft during an endoscopic procedure.

FIG. **17** illustrates an alternative design for an instrument driver and instrument where the axes of the drive units are parallel to the axis of the elongated shaft of the instrument. As shown, a circular instrument driver **80** comprises four drive units with their drive outputs **81** aligned in parallel at the end of a robotic arm **82**. The drive units, and their respective drive outputs **81**, are housed in a rotational assembly **83** of the instrument driver **80** that is driven by one of the drive units within the assembly **83**. In response to torque provided by the rotational drive unit, the rotational assembly **83** rotates along a circular bearing that connects the rotational assembly **83** to the non-rotational portion **84** of the instrument driver. Power and controls signals may be communicated from the non-rotational portion **84** of the instrument driver **80** to the rotational assembly **83** through electrical contacts may be maintained through rotation by a brushed slip ring connection (not shown). In other embodiments, the rotational assembly **83** may be responsive to a separate drive unit that is integrated into the non-rotatable portion **84**, and thus not in parallel to the other drive units. The rotational mechanism **83** allows the instrument driver **80** to rotate the drive units, and their respective drive outputs **81**, as a single unit around an instrument driver axis **85**.

Like earlier disclosed embodiments, an instrument **86** may comprise an elongated shaft portion **88** and an instrument base **87** (shown with a transparent external skin for discussion purposes) comprising a plurality of drive inputs **89** (such as receptacles, pulleys, and spools) that are configured to receive the drive outputs **81** in the instrument driver **80**. Unlike prior disclosed embodiments, instrument shaft **88** extends from the center of instrument base **87** with an axis substantially parallel to the axes of the drive inputs **89**, rather than orthogonal as in the design of FIG. **16**.

When coupled to the rotational assembly **83** of the instrument driver **80**, the medical instrument **86**, comprising instrument base **87** and instrument shaft **88**, rotates in combination with the rotational assembly **83** about the instrument driver axis **85**. Since the instrument shaft **88** is positioned at the center of instrument base **87**, the instrument shaft **88** is coaxial with instrument driver axis **85** when attached. Thus, rotation of the rotational assembly **83** causes the instrument shaft **88** to rotate about its own longitudinal axis. Moreover, as the instrument base **87** rotates with the instrument shaft **88**, any tendons connected to the drive inputs **89** in the instrument base **87** are not tangled during rotation. Accordingly, the parallelism of the axes of the drive outputs **81**, drive inputs **89**, and instrument shaft **88** allows for the shaft rotation without tangling any control tendons.

FIG. **18** illustrates an instrument having an instrument based insertion architecture in accordance with some embodiments. The instrument **150** can be coupled to any of the instrument drivers discussed above. The instrument **150** comprises an elongated shaft **152**, an end effector **162** connected to the shaft **152**, and a handle **170** coupled to the shaft **152**. The elongated shaft **152** comprises a tubular member having a proximal portion **154** and a distal portion **156**. The elongated shaft **152** comprises one or more channels or grooves **158** along its outer surface. The grooves **158** are configured to receive one or more wires or cables **180** therethrough. One or more cables **180** thus run along an outer surface of the elongated shaft **152**. In other embodiments, cables **180** can also run through the elongated shaft **152**. Manipulation of the one or more cables **180** (e.g., via an instrument driver) results in actuation of the end effector **162**.

The instrument handle **170**, which may also be referred to as an instrument base, may generally comprise an attachment interface **172** having one or more mechanical inputs **174**, e.g., receptacles, pulleys or spools, that are designed to be reciprocally mated with one or more torque couplers on an attachment surface of an instrument driver.

In some embodiments, the instrument **150** comprises a series of pulleys or cables that enable the elongated shaft **152** to translate relative to the handle **170**. In other words, the instrument **150** itself comprises an instrument-based insertion architecture that accommodates insertion of the instrument, thereby minimizing the reliance on a robot arm to provide insertion of the instrument **150**. In other embodiments, a robotic arm can be largely responsible for instrument insertion.

E. Controller.

Any of the robotic systems described herein can include an input device or controller for manipulating an instrument attached to a robotic arm. In some embodiments, the controller can be coupled (e.g., communicatively, electronically, electrically, wirelessly and/or mechanically) with an instrument such that manipulation of the controller causes a corresponding manipulation of the instrument e.g., via master slave control.

FIG. **19** is a perspective view of an embodiment of a controller **182**. In the present embodiment, the controller **182** comprises a hybrid controller that can have both impedance and admittance control. In other embodiments, the controller **182** can utilize just impedance or passive control. In other embodiments, the controller **182** can utilize just admittance control. By being a hybrid controller, the controller **182** advantageously can have a lower perceived inertia while in use.

In the illustrated embodiment, the controller **182** is configured to allow manipulation of two medical instruments, and includes two handles **184**. Each of the handles **184** is connected to a gimbal **186**. Each gimbal **186** is connected to a positioning platform **188**.

As shown in FIG. **19**, each positioning platform **188** includes a SCARA arm (selective compliance assembly robot arm) **198** coupled to a column **194** by a prismatic joint **196**. The prismatic joints **196** are configured to translate along the column **194** (e.g., along rails **197**) to allow each of the handles **184** to be translated in the z-direction, providing a first degree of freedom. The SCARA arm **198** is configured to allow motion of the handle **184** in an x-y plane, providing two additional degrees of freedom.

In some embodiments, one or more load cells are positioned in the controller. For example, in some embodiments, a load cell (not shown) is positioned in the body of each of the gimbals **186**. By providing a load cell, portions of the controller **182** are capable of operating under admittance control, thereby advantageously reducing the perceived inertia of the controller while in use. In some embodiments, the positioning platform **188** is configured for admittance control, while the gimbal **186** is configured for impedance control. In other embodiments, the gimbal **186** is configured for admittance control, while the positioning platform **188** is configured for impedance control. Accordingly, for some embodiments, the translational or positional degrees of freedom of the positioning platform **188** can rely on admittance control, while the rotational degrees of freedom of the gimbal **186** rely on impedance control.

F. Navigation and Control.

Traditional endoscopy may involve the use of fluoroscopy (e.g., as may be delivered through a C-arm) and other forms of radiation-based imaging modalities to provide endoluminal guidance to an operator physician. In contrast, the robotic systems contemplated by this disclosure can provide for non-radiation-based navigational and localization means to reduce physician exposure to radiation and reduce the amount of equipment within the operating room. As used herein, the term “localization” may refer to determining and/or monitoring the position of objects in a reference coordinate system. Technologies such as pre-operative mapping, computer vision, real-time EM tracking, and robot command data may be used individually or in combination to achieve a radiation-free operating environment. In other cases, where radiation-based imaging modalities are still used, the pre-operative mapping, computer vision, real-time EM tracking, and robot command data may be used individually or in combination to improve upon the information obtained solely through radiation-based imaging modalities.

FIG. **20** is a block diagram illustrating a localization system **90** that estimates a location of one or more elements of the robotic system, such as the location of the instrument, in accordance to an example embodiment. The localization system **90** may be a set of one or more computer devices configured to execute one or more instructions. The computer devices may be embodied by a processor (or processors) and computer-readable memory in one or more components discussed above. By way of example and not limitation, the computer devices may be in the tower **30** shown in FIG. **1**, the cart shown in FIGS. **1-4**, the beds shown in FIGS. **5-14**, etc.

As shown in FIG. **20**, the localization system **90** may include a localization module **95** that processes input data **91-94** to generate location data **96** for the distal tip of a medical instrument. The location data **96** may be data or logic that represents a location and/or orientation of the distal end of the instrument relative to a frame of reference. The frame of reference can be a frame of reference relative to the anatomy of the patient or to a known object, such as an EM field generator (see discussion below for the EM field generator).

The various input data **91-94** are now described in greater detail. Pre-operative mapping may be accomplished through the use of the collection of low dose CT scans. Pre-operative CT scans are reconstructed into three-dimensional images, which are visualized, e.g. as “slices” of a cutaway view of the patient’s internal anatomy. When analyzed in the aggregate, image-based models for anatomical cavities, spaces and structures of the patient’s anatomy, such as a patient lung network, may be generated. Techniques such as center-line geometry may be determined and approximated from the CT images to develop a three-dimensional volume of the patient’s anatomy, referred to as model data **91** (also referred to as “preoperative model data” when generated using only preoperative CT scans). The use of center-line geometry is discussed in U.S. patent application Ser. No. 14/523,760, the contents of which are herein incorporated in its entirety.

Network topological models may also be derived from the CT-images, and are particularly appropriate for bronchoscopy.

In some embodiments, the instrument may be equipped with a camera to provide vision data **92**. The localization module **95** may process the vision data to enable one or more vision-based location tracking. For example, the preoperative model data may be used in conjunction with the vision data **92** to enable computer vision-based tracking of the medical instrument (e.g., an endoscope or an instrument advance through a working channel of the endoscope). For example, using the preoperative model data **91**, the robotic system may generate a library of expected endoscopic images from the model based on the expected path of travel of the endoscope, each image linked to a location within the model. Intra-operatively, this library may be referenced by the robotic system in order to compare real-time images captured at the camera (e.g., a camera at a distal end of the endoscope) to those in the image library to assist localization.

Other computer vision-based tracking techniques use feature tracking to determine motion of the camera, and thus the endoscope. Some features of the localization module **95** may identify circular geometries in the preoperative model data **91** that correspond to anatomical lumens and track the change of those geometries to determine which anatomical lumen was selected, as well as the relative rotational and/or translational motion of the camera. Use of a topological map may further enhance vision-based algorithms or techniques.

Optical flow, another computer vision-based technique, may analyze the displacement and translation of image pixels in a video sequence in the vision data **92** to infer camera movement. Examples of optical flow techniques may include motion detection, object segmentation calculations, luminance, motion compensated encoding, stereo disparity measurement, etc. Through the comparison of multiple frames over multiple iterations, movement and location of the camera (and thus the endoscope) may be determined.

The localization module **95** may use real-time EM tracking to generate a real-time location of the endoscope in a global coordinate system that may be registered to the patient's anatomy, represented by the preoperative model. In EM tracking, an EM sensor (or tracker) comprising of one or more sensor coils embedded in one or more locations and orientations in a medical instrument (e.g., an endoscopic tool) measures the variation in the EM field created by one or more static EM field generators positioned at a known location. The location information detected by the EM sensors is stored as EM data **93**. The EM field generator (or transmitter), may be placed close to the patient to create a low intensity magnetic field that the embedded sensor may detect. The magnetic field induces small currents in the sensor coils of the EM sensor, which may be analyzed to determine the distance and angle between the EM sensor and the EM field generator. These distances and orientations may be intra-operatively "registered" to the patient anatomy (e.g., the preoperative model) in order to determine the geometric transformation that aligns a single location in the coordinate system with a position in the pre-operative model of the patient's anatomy. Once registered, an embedded EM tracker in one or more positions of the medical instrument (e.g., the distal tip of an endoscope) may provide real-time indications of the progression of the medical instrument through the patient's anatomy.

Robotic command and kinematics data **94** may also be used by the localization module **95** to provide localization data **96** for the robotic system. Device pitch and yaw resulting from articulation commands may be determined during pre-operative calibration. Intra-operatively, these calibration measurements may be used in combination with known insertion depth information to estimate the position of the instrument. Alternatively, these calculations may be analyzed in combination with EM, vision, and/or topological modeling to estimate the position of the medical instrument within the network.

As FIG. **20** shows, a number of other input data can be used by the localization module **95**. For example, although not shown in FIG. **20**, an instrument utilizing shape-sensing fiber can provide shape data that the localization module **95** can use to determine the location and shape of the instrument.

The localization module **95** may use the input data **91-94** in combination(s). In some cases, such a combination may use a probabilistic approach where the localization module **95** assigns a confidence weight to the location determined from each of the input data **91-94**. Thus, where the EM data may not be reliable (as may be the case where there is EM interference) the confidence of the location determined by the EM data **93** can be decrease and the localization module **95** may rely more heavily on the vision data **92** and/or the robotic command and kinematics data **94**.

As discussed above, the robotic systems discussed herein may be designed to incorporate a combination of one or more of the technologies above. The robotic system's computer-based control system, based in the tower, bed and/or cart, may store computer program instructions, for example, within a non-transitory computer-readable storage medium such as a persistent magnetic storage drive, solid state drive, or the like, that, upon execution, cause the system to receive and analyze sensor data and user commands, generate control signals throughout the system, and display the navigational and localization data, such as the position of the instrument within the global coordinate system, anatomical map, etc.

2. Introduction to a Medical Instrument with a Bendable section

Embodiments of the disclosure relate to systems and techniques related to a medical instrument that can include a bendable section articulable by cables.

FIG. **21**A illustrates an example embodiment of medical instrument **200** that includes a bendable section **202** and a distal end **204**. The bendable section **202** can couple to the distal end **204** such that bending of the bendable section **202** can articulate the distal end **204** of the medical instrument **200**. The bendable section **202** is illustrated and described herein with respect to the illustrated medical instrument **200** which can be any of a variety of types of instruments including, but not limited to, endoscopes, gastroscopes, bronchoscopes, and/or ureteroscopes. The distal end **204** of the medical instrument **200** can include instruments and effectors such as, but not limited to, one or more forceps, guide wires, cutters, staplers, brushes, scopes, imaging devices, and the like and can include one or more passages for delivering such instruments and/or for delivering and/or removing fluids. While the bendable section **102** is described in the context of certain embodiments of medical instruments or robotic systems, the bendable section **102** can be used with other medical instruments and non-robotic systems.

FIG. **21**B illustrates the bendable section **202** of the medical instrument **200** of FIG. **21**A in additional detail. As shown, the bendable section **202** can be formed from a series of articulable segments **206**. The bendable section **202** can have a length that defines an axis about which the bendable section **202** can bend. The series of articulable segments **206** can be operably coupled together to form the bendable section **202** such that articulation of the articulable segments **206** can cause the bendable section **202** to bend in at least one degree of movement. In some examples, the series of articulable segments **206** can allow the bendable section **202** to have at least two degrees of movement.

In some examples, the bendable section **202** of the medical instrument **200** can include one or more cables **250**. The cables **250** and the articulable segments **206** of the bendable section **202** will be further described in paragraphs below.

Articulable Segments

FIGS. **22**A and **22**B illustrate different views of the articulable segment **206** of FIG. **21**B. The articulable segment **206** can include a body **216**, one or more recesses **208**, one or more protrusions **210**, and one or more pathways **254**. The body **216** can be ring-shaped and can include an opening **218** to allow an inner shaft **260** (e.g., as seen in FIG. **25**) of the medical instrument **200** to extend through. The body **216** of the articulable segment **206** can be substantially circular in shape. In some examples, the opening **218** can be circular. The inner shaft **260** can be a tubular element through which other components can extend there through.

The one or more recesses **208** can be formed and/or coupled to a distal or a proximal side of the articulable segment **206**. The one or more protrusions **210** can be formed and/or coupled to a distal or proximal side of the articulable segment **206**. For example, the one or more recesses **208** can be formed on a distal side of the articulable segment **206** while the one or more protrusions **210** can be formed on a proximal side of the articulable segment **206**. In another example, the one or more recesses **208** and the one or more protrusions **210** can be formed opposite sides of the articulable segment **206**. Alternatively, the one or more recesses **208** and the one or more protrusions **210** can be positioned and/or formed on the same side of the articulable segments **206**.

In some examples, each of the articulable segments **206** can include two recesses **208** and two protrusions **210**, as shown in FIGS. **22**A and **22**B. The two recesses **208** can be formed on a first side of the articulable segment **206** while the two protrusions **210** can be formed on a second side of the articulable segment **206**. The two recesses **208** can be positioned 180 degrees offset from each other. Similarly, the two protrusions **210** can be positioned 180 degrees offset from each other. The recesses **208** and the protrusions **210** can be positioned such that one of the recesses **208** (or one of the protrusions **210**) is 90 degrees offset from the protrusions **210** (or the recesses **208**).

The articulable segments **206** can couple to adjacent articulable segments **206** via their recesses **208** and the protrusions **210**. For example, the recesses **208** of a first articulable segment **206** can couple to the protrusions **210** of a second articulable segment **206**. In some examples, the second articulable segment **206** can be 90 degrees rotationally offset from the first articulable segment **206**. Similarly, the recesses **208** of the second articulable segment **206** can couple to the protrusions **210** of a third articulable segment **206** that is 90 degrees rotationally offset from the second articulable segment **206**.

In some examples, the bendable section **202** can include the series of articulable segments **206** where each subsequent articulable segment **206** can be offset by a predetermined angle from each preceding articulable segment **206**. The predetermined offset angle can be between about 10 degrees and about 90 degrees, between about 20 degrees and about 80 degrees, between about 30 degrees and about 70 degrees, between about 40 degrees and about 60 degrees, or about 10 degrees, 20 degrees, 30 degrees, 40 degrees, 50 degrees, 60 degrees, 70 degrees, 80 degrees, 90 degrees, or ranges between any two of aforementioned values.

The pathways **254**, as shown in FIGS. **22**A and **22**B, can be associated with the recesses **208** and the protrusions **210** of the articulable segment **206**. The pathways **254** can extend through the width of the articulable segment **206**, where the width corresponds to the thickness of the segment **206** in the longitudinal direction. The pathways **254** of the articulable segment **206** can allow the cables **250** (see FIG. **21**B) to extend through the bendable section **202** of the medical instrument **200**. In some examples, the pathways **254** can be enclosed openings as shown in FIGS. **22**A and **22**B. In other examples, the pathways **254** can be partially enclosed to form grooves.

FIG. **22**C illustrates a series of articulable segments **206** which can be configured as described above with reference to FIGS. **22**A and **22**B connected in series. The recesses **208** and the protrusions **210** of the articulable segments **206** can be dimensioned to couple to form hinges **212**. For example, the recesses **208** of a first articulable segment **206** can couple with the corresponding protrusions of a second articulable segment **206** that is immediately adjacent to the first articulable segment **206**. Each pair of adjacent articulable segments **206** can include at least two hinges **212**. As discussed above, the protrusions **210** and the recesses **208** can include the pathways **254** to allow the cable **250** (see FIG. **27**A) to extend through. In this regard, each of the hinges **212** can include the pathway **254** to allow the cable **250** to extend through. In the example shown in FIG. **22**C, the pathways **254** can be formed using a pair of perpendicular cuts or voids at each pathway **254** extending through the body. As seen in FIG. **22**C, a cut on one side of the segment **206** can provide a recess **208** for a hinge, while a perpendicular cut on an opposite side of the segment **206** can extend through the protrusion **210** and intersect with the opposing cut to open up the pathway **254** extending through the hinge.

The recesses **208** and the protrusions **210** can be positioned such that the hinges **212** can be positioned between each of adjacent articulable segments **206**. The hinges **212** can allow the articulable segments **206** to articulate (for example, rotate) about an axis that is transversal to the length of the bendable section **202**. The hinges **212** that couple each pair of adjacent articulable segments **206**, as discussed above, can allow the series of articulable segments to articulate the bendable section **202** to bend and/or articulate in one or more degrees of movement.

In some examples, each pair of adjacent articulable segments **206** can include a gap **214** formed between the articulable segments. The gap **214** can advantageously allow immediately adjacent articulable segments **206** to freely articulate without contacting each other and thereby limiting and/or reducing articulation angle of the bendable section **202**.

Distal and Proximal End Segments

FIGS. **23**A and **23**B illustrate different views of an distal end segment **220** which can form part of or be otherwise coupled to the bendable section **202** described above. The distal end segment **220** can include one or more recesses **208** and/or one or more protrusions **210**. The one or more recesses **208** or one or more protrusions **210** can be formed and/or positioned on a proximal side of the distal end segment **220**. The distal end segment **220** can include one or more pathways **254**. The pathways **254** can be associated with the recesses **208** and/or the protrusions **210**. In some examples, the pathways **254** can be formed within the recesses **208** and/or the protrusions **210** such that the cable **250** can extend through the recesses **208** and/or the protrusions **210**. The distal end segment **220** can include a cavity for the inner shaft **260** of the medical instrument **200**.

FIGS. **24**A and **24**B illustrate different views of an exemplary proximal end segment **230** that can in some embodiments form part of or be otherwise coupled to the bendable segment **202**. The proximal end segment **230** can include one or more recesses **208** and/or one or more protrusions **210**. The one or more recesses **208** or one or more protrusions **210** can be formed and/or positioned on a distal side of the proximal end segment **230**. The one or more recesses **208** and/or one or more protrusions **210** can couple with one or more protrusions and/or one or more recesses of articulable segments **206**. The proximal end segment **230** can include one or more pathways **254**. The pathways **254** can be associated with the recesses **208** and/or the protrusions **210**. In some examples, the pathways **254** can be formed within the recesses **208** and/or the protrusions **210** such that the cable **250** can extend through the recesses **208** and/or the protrusions **210**. The proximal end segment **230** can include a cavity for the inner shaft **260** of the medical instrument **200**.

In some examples, the proximal end segment **230** and the distal end segment **220** can have a cross-sectional area that is about the same as that of the articulable segments **206** of the bendable section **202**. In other examples, the proximal end segment **230** and the distal end segment **220** can have a cross-sectional shape that is about the same or similar to that of the articulable segments **206**. The distal end segment **220** and the proximal end segment **230** can provide ends to the bendable portion **202** and can be connected to other components of the medical device **200**. In certain embodiments, the distal end segment **220** and/or the proximal end segment **230** can be omitted from the bendable portions **202** and/or portions of these segments can be combined with the distal or proximal most articulable segment.

FIG. **25** illustrates a distal portion of an exemplary medical instrument **300** that includes the distal end segment **220**, the proximal end segment **230**, and the articulating segments **206** as described above. In the illustration shown in FIG. **25**, intermediate articulable segments **206** have been shown as being removed to better illustrate the cables **250**.

As shown in FIG. **25**, the one or more recesses **208** and/or one or more protrusions **210** of the distal end segment **220** and the proximal end segment **230** can couple with one or more protrusions and/or one or more recesses of articulable segments **206**. As seen in FIG. **25**, the protrusions and recesses form a series of hinges **212** in the bendable section **202** that connect the proximal end **230** segment, articulating segments **206**, and distal end segment **220**. The proximal end segment **230** and the distal end segment **220** can define a proximal end and a distal end of the bendable section **202**. In some examples, the distal end segment **220** and the proximal end segment **230** can be fixedly attached to the medical instrument **300** such that the bendable section **202** can be fixedly attached to the medical instrument **300**.

Support Sleeve

FIGS. **26**A-**26**C illustrate different exemplary support members **240** for a series of the articulable segments **206**. The support members **240** can wrap at least a portion of the body **216** of the articulable segments **206**. In some examples, the support members **240** can wrap individual articulable segments **206**. The support members **240** and the articulable segments **206** can be made out of the same or different materials. Optionally, the support members **240** can couple to all articulable segments **206** of the medical instrument **200**.

Pull Wire

The medical instrument **200** can also include one or more cables **250**. FIG. **27**A illustrates the medical instrument **200** with a portion of the articulable segments **206** shown to illustrate the cables **250**. The cables **250** can extend through the medical instrument **200** and can be used to articulate the medical instrument **200** in one or more degrees of movement (see FIGS. **28**A and **28**B). The cables **250** can be terminated at the distal end segment **220** as shown in FIG. **27**B. The distal end segment **220** can be attached to a distal tip component **270** at a distal end or distal side of the distal end segment **220**. The distal tip component **270** can provide a housing for holding one or more functional and/or electronic components. For example, one or more cameras **286**, one or more illuminators **285**, and/or one or more EM sensors **288** can be embedded in the distal tip component **270**.

Pulling and/or relaxing a combination of the cables **250** can articulate the articulable segments **206** of the bendable section **202**, causing the bendable section **202** to bend. When the cables **250** are pulled towards a proximal end of the medical instrument **200**, they can engage the hinges **212** and the articulable segments **206** to cause them to actuate (e.g., rotate) about the axes associated with the hinges **212**. In some examples, relaxing the cable **250** can cause the series of articulable segments **206** to articulate and bend the bendable section **202**. In addition, the cables **250** can advantageously stabilize the bendable section **202** of the medical instrument **200**, and provide biasing and predictability for operation of the medical instrument **200**.

In some embodiments, the cables **250** may be under a predetermined tension. In this regard, increasing the amount of tension of one of the cables **250** while relaxing (e.g., reducing tension) an opposing cable **250** can articulate the articulable segments **206** and bend the bendable section **202**.

FIGS. **28**A and **28**B illustrates different views of the medical instrument **400** with the bendable section **202** bent. As discussed above, actuating (e.g., pulling/relaxing) one or more of the cables **250** can cause the bendable section **202** to bend. Actuating different combinations of the cables **250** can result in different orientations of the bendable section **202**.

The cables **250** can be actuated using human interaction or robotic system including an actuator (or a controller). An actuator can be coupled to the cables **250** to pull/relax the cables **250**. In some examples, separate actuators can be coupled to each of the cables **250** of the medical instrument **200**. For example, the medical instrument **200** can include four cables **250** and four actuators coupled to the corresponding cables **250**. In some embodiments, an actuator can be coupled to two or more of the cables and thus be configured to actuate multiple cables **250**.

In some examples, simultaneous motion about two or more degrees of movement of the bendable section **202** can be accomplished by a more complex control scheme for pulling and/or pushing the cables **250**. The control scheme can involve a computer-based control system that stores computer program instructions of a master device configured to interpret the motions of the user into corresponding actions of the medical instrument **200**. The computer program may be configured to measure the electric load required to rotate the actuators (or input controllers) to compute the length and/or movement of the cables **250**. The computer program may be further configured to compensate for changes in cable elasticity, such as if the cables **250** are a polymer, by increasing/decreasing the amount of rotation needed for the actuators (or input controllers) to change the length of the cable **250**. The tension may be adjusted by increasing or decreasing the rotation of all the actuators (or input controllers) in coordination. The tension can be increased by simultaneously increasing rotation, and the tension can be decreased by simultaneously decreasing rotation. The computer program may be further configured to maintain a minimum level of tension in the cables **250**. If the tension in any of the cables **250** is sensed to drop below a lower minimum tension threshold, then the computer program may increase rotation of all actuators (or input controllers) in coordination until the cable tension in all cables **250** is above the lower minimum tension threshold. If the tension in all of the cables **250** is sensed to rise above an upper minimum tension threshold, then the computer program may decrease rotation of all actuators (or input controllers) in coordination until the cable tension in any of the cables **250** is below the upper minimum tension threshold. The computer program may be further configured to recognize the grip strength of the operator based on the load of the motors actuating the actuators (or input controllers) coupled to the cables **250**.

Tip Assembly

The medical instrument **200** can include a tip assembly **290** that facilitates attachment of the one or more cables **250** and/or embedding or housing of one or more functional and/or electronic components in the distal tip of the instrument. FIGS. **29**A-**29**B illustrate examples of a tip assembly **290** that can be used at a distal tip of the medical instrument **200**, for example at the distal end of the elongated shaft **71** (FIG. **16**). FIG. **29**A shows the tip assembly **290** in an unassembled configuration, while FIG. **29**B shows the tip assembly **290** in an assembled configuration in which it is attached at the distal end of the bendable section **202**.

The tip assembly **290** includes distal end segment **220** and a distal tip component **270**. The distal end segment **220** can be configured as a control member to which one or more cables **250** are anchored. Accordingly, the distal end segment **220** can provide a termination and fixation point for cables **250**, which can be configured to bend the bendable section and thereby steer the tip assembly **290** based on forces applied to the cables **250**. The distal tip component **270** provides a housing that serves to hold functional components therein. For example, one or more electronic components, such as one or more cameras, one or more LEDs, one or more optical fibers, and/or one or more EM sensors can be embedded in the distal tip component **270** to provide functionality associated with a scope or other type of medical instrument.

As seen in FIGS. **29**A-**29**B, the distal tip component **270** can be a separate part from the distal end segment **220**. By providing the distal end segment **220** and the distal tip component **270** as a separate parts attached to each other, manufacturing or design constraints can be removed. For example, the cables **250** can be attached and anchored to the distal end segment **220** by soldering the cables thereto, while electronic components can be embedded in the distal tip component in a separate operation. The housing which holds electronic components can thus, for example, be freed of a constraint requiring soldering of the cables **250** thereto, allowing the housing to be made shorter or be more easily machined with complex geometries. Additionally or alternatively, such a construction can allow portions of the bendable section and the distal tip component to have different useful lives and be readily separable for sterilization or re-use of one component or the other. As an example, this may allow the distal tip component **270** to be separated from the bendable section, so that the bendable section may be discarded while distal dip component **270** and functional components therein, such as imaging devices, position sensors, and/or other electronic components, may be re-used for a longer useful life. [0146] The distal end segment **220** can be configured as a control ring or ring-shaped segment having an annular portion **276** and a central opening **272** extending through the annular portion **276**. The distal end segment **220** can include one or more slots **274** formed therein. The slots **274** can be formed in the annular portion **276** and can provide a fixation point for anchoring the cables **250** thereto. For example, the cables **250** can be bonded to the slots **274** by soldering the cables **250** to the annular portion **276** in the slots **274** so as to form a strong and secure attachment that allows the scope to be reused for multiple procedures. Alternatively, or in combination, the cables **250** can be anchored to the distal end segment **220** via adhesive, welding, or any suitable attachment technique.

The distal end segment **220** can include recesses **208** and/or protrusions **210** to facilitate hinged connection and/or snap-fit connection to other segments that are on or otherwise coupled to the elongate shaft **72**. In the example shown, a proximal side of the distal end segment **220** includes protrusions **210** that are configured to connect to an adjacent articulating segment **206** of the bendable section **202**. Accordingly, forces applied to the distal end segment **220**, via the control cables **250**, can transmit to components of the tip assembly **290** that are fixed to the distal end segment **220**, and such forces can bend the bendable section **206** to steer the tip assembly **290** in a desired direction. The slots **274** can be circumferentially and axially aligned with the hinges on a proximal side of the ring, which are joined to a proximal articulating segment, to facilitate routing of the cables **250** through the hinges and to the anchoring point in the slots **274**.

The distal side of the distal end segment **220** is also shown with recesses **208**, which are configured to connect to protrusions **210** on a proximal side of the distal tip component **270**. The protrusion connection to the distal tip component **270** can facilitate manufacturing by, for example, allowing a snap fit to mechanically connect the distal end segment **220** to the distal tip component **270**. It may be desirable to rigidly attach the distal end segment **220** to the distal tip component **270** so that there is no relative motion or rotation therebetween. This can permit the distal end segment **220** to act as a control member that steers the functional components within the distal tip component **270** directly in a precise manner where the motion of the control member substantially matches the motion of the functional components. The hinge coupling can be converted to a rigid connection by, for example, having the distal side of the distal end segment **220** and the proximal side of the distal tip component **270** adjoin substantially flush with each other. The distal side of the distal tip component **270** substantially flush with the proximal side of the distal tip component **270** can restrict relative rotation between the control member and the distal tip component **270** about the hinge coupling. Additionally or alternatively, such a rigid connection can be achieved by inserting a component, such as a potting adhesive, into the space near the interface between the distal end segment **220** and distal tip component **270** to fix such parts together. Additionally or alternatively, such a compound can serve to provide a seal between such parts and/or seal functional components within the distal tip component **270**.

The recesses **208** and protrusions **210** forming the hinge connections can take a variety of shapes, sizes, and/or orientations in various embodiments. In FIGS. **29**A-**29**B, the protrusions **210** are configured as radial protrusions that extend outward in a radial direction. In various embodiments, the protrusions can, for example, extend radially inward, radially outward, longitudinally in a proximal direction, or longitudinally in a distal direction.

The distal tip component **270** can be provided with one or more openings for fitting functional components therein and/or for permitting other instruments to be inserted therethrough. For example, the distal tip component **270** can include one or more ports **282** and an opening of a working channel **284**. The one or more ports **282** can be configured to hold optical devices, such as cameras **286** and/or illuminators **285**, configured to facilitate visualization of an internal anatomy of a patient. It is contemplated that any appropriate number of one or more ports **282** may be used for holding one or more functional components. In the example shown in FIG. **29**A, three ports **282** are shown. The middle of the three ports can hold a camera **286** therein, which can have a field of view extending distally out of the port. Each of the other two ports can hold an illuminator **285** therein, such as an LED or optical fiber, which can provide illumination distally to illuminate at least a portion of the field of view of the camera. The opening of the working channel **284** can allow other instruments, such as biopsy needles, graspers, and/or treatment delivery devices to be inserted therethrough. Such other instruments may be configured to pass through the central opening **272** of the distal end segment **220**, the opening of the working channel **284** in the distal tip component **270**, and out of the distal end of the tip assembly **290** when inserted therethrough. In some embodiments, the distal end segment **220** can enclose a proximal part of one or more of the electronic and/or functional components embedded within the distal tip component **270**. For example, the EM sensor **288** may have a length such that a proximal end of the EM sensor **288** protrudes proximally out of the proximal side of the distal tip component **270** when the distal end segment **220** is manufactured as a separate part. However, the distal end segment **220** can be configured to surround the proximal end of the EM sensor **288** to provide a seal around such component.

The distal tip component **270** can include a proximal section **292** and a distal section **294**. The proximal section **292** can have a reduced outer diameter relative to the distal section **294**, such that the distal section **294** is provided with a flange portion that protrudes radially relative to the outer diameter of proximal section **292**. The distal end segment **220** can also have a reduced outer diameter relative to the distal section **294**, for example, by having an outer diameter that substantially matches the outer diameter of the proximal section **292**. The reduced outer diameter of proximal section **292** can allow for a sleeve (or "jacket") to extend around the outer surface of the proximal section **292** (or otherwise be fitted over the control member), adjoin the distal section **294** (e.g., abut against the proximal side of the flange portion), and form a lap joint with the distal section **294** for secure attachment. Such a sleeve (not visible in FIGS. **29**A-**29**B) can also extend around the distal end segment **220** and articulating segments **206**, to thereby enclose and/or seal components therein.

In the illustrated example, the distal end segment **220** providing the control member and the distal tip component **270** providing the housing are axially arranged, with the housing disposed distal to the control member so as to hold functional components at a leading terminal end of the instrument. Such an arrangement can improve manufacturability or steerability of the instrument. However, it is also contemplated that the control member for anchoring the cables **250** and the housing for holding embedded components can be arranged laterally with respect to each other.

3. Implementing Systems and Terminology.

Implementations disclosed herein provide systems and apparatus for an medical instrument including a bendable section articulable by cables.

It should be noted that the terms "couple," "coupling," "coupled" or other variations of the word couple as used herein may indicate either an indirect connection or a direct connection. For example, if a first component is "coupled" to a second component, the first component may be either indirectly connected to the second component via another component or directly connected to the second component.

The functions of pulling and/or relaxing of the cables described herein may be stored as one or more instructions on a processor-readable or computer-readable medium. The term "computer-readable medium" refers to any available medium that can be accessed by a computer or processor. By way of example, and not limitation, such a medium may comprise random access memory (RAM), read-only memory (ROM), electrically erasable programmable read-only memory (EEPROM), flash memory, compact disc read-only memory (CD-ROM) or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to store desired program code in the form of instructions or data structures and that can be accessed by a computer. It should be noted that a computer-readable medium may be tangible and non-transitory. As used herein, the term "code" may refer to software, instructions, code or data that is/are executable by a computing device or processor.

The methods disclosed herein comprise one or more steps or actions for achieving the described method. The method steps and/or actions may be interchanged with one another without departing from the scope of the claims. In other words, unless a specific order of steps or actions is required for proper operation of the method that is being described, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims.

As used herein, the term "plurality" denotes two or more. For example, a plurality of components indicates two or more components. The term "determining" encompasses a wide variety of actions and, therefore, "determining" can include calculating, computing, processing, deriving, investigating, looking up (e.g., looking up in a table, a database or another data structure), ascertaining and the like. Also, "determining" can include receiving (e.g., receiving information), accessing (e.g., accessing data in a memory) and the like. Also, "determining" can include resolving, selecting, choosing, establishing and the like.

The phrase "based on" does not mean "based only on," unless expressly specified otherwise. In other words, the phrase "based on" describes both "based only on" and "based at least on."

The previous description of the disclosed implementations is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these implementations will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other implementations without departing from the scope of the invention. For example, it will be appreciated that one of ordinary skill in the art will be able to employ a number corresponding alternative and equivalent structural details, such as equivalent ways of fastening, mounting, coupling, or engaging tool components, equivalent mechanisms for producing particular actuation motions, and equivalent mechanisms for delivering electrical energy. Thus, the present invention is not intended to be limited to the implementations shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

What is claimed is:

1. A medical instrument comprising:

an elongate body having a distal end and a proximal end;

a bendable section positioned proximal to the distal end having at least two degrees of movement, the bendable section comprising a series of articulable segments positioned along the bendable section, wherein:

the series of articulable segments includes at least one pair of adjacent articulable segments comprising a first articulable segment and a second articulable segment,

the first and second articulable segments are connected by a first hinge and a second hinge,

the first hinge is formed by a first protrusion of the first articulable segment and a corresponding first recess of the second articulable segment,

the second hinge is formed by a second protrusion of the first articulable segment and a corresponding second recess of the second articulable segment,

the first recess is formed on a first axial side of the second articulable segment, and

a first perpendicular cut is formed on a second axial side of the second articulable segment that extends through a body of the second articulable segment to intersect with the first recess to form a cable pathway through the second articulable segment; and

at least one cable extending through the cable pathway.

2. The medical instrument of claim **1**, wherein a second perpendicular cut is formed through the first protrusion on a side of the first articulable segment that faces the first axial side of the second articulable segment.

3. The medical instrument of claim **1**, further comprising a third articulable segment connected to the second articulable segment, wherein the second and third articulable segments are connected by third and fourth hinges that are positioned 90 degrees offset from the first and second hinges, wherein the third and fourth hinges are each formed by a recess or protrusion of the second articulable segment that engages a corresponding recess or protrusion of the third articulable segment.

4. The medical instrument of claim **1**, wherein the first perpendicular cut is laterally open on first and second ends thereof.

5. The medical instrument of claim **1**, wherein the the second axial side of the second articulable segment comprises third and fourth protrusions that alternate around a circumference of the second articulable segment with the first and second recesses, the first and second recesses being formed on the first axial side of the second articulable segment.

6. The medical instrument of claim **5**, wherein third and fourth recesses are formed on the first side of the second articulable segment opposite the third and fourth protrusions, respectively.

7. The medical instrument of claim **5** further comprising:

a second perpendicular cut formed on the second axial side of the second articulable segment opposite the second recess;

a third perpendicular cut formed on the second axial side of the second articulable segment through the third protrusion; and

a fourth perpendicular cut formed on the second axial side of the second articulable segment through the fourth protrusion;

wherein:

the first and second perpendicular cuts are parallel to one another; and

the third and fourth perpendicular cuts are parallel to one another and perpendicular to the first and second perpendicular cuts.

* * * * *