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(54) SYSTEMS AND METHODS OF COMMUNICATING THERMAL INFORMATION FOR SURGICAL ROBOTIC DEVICES

(71) Applicant: **Auris Health, Inc.**, Redwood City, CA (US)

(72) Inventors: **Marissa Anne Crosetti**, San Francisco, CA (US); **Alexander Tarek Hassan**, San Francisco, CA (US); **Charles J. Scheib**, Loveland, OH (US)

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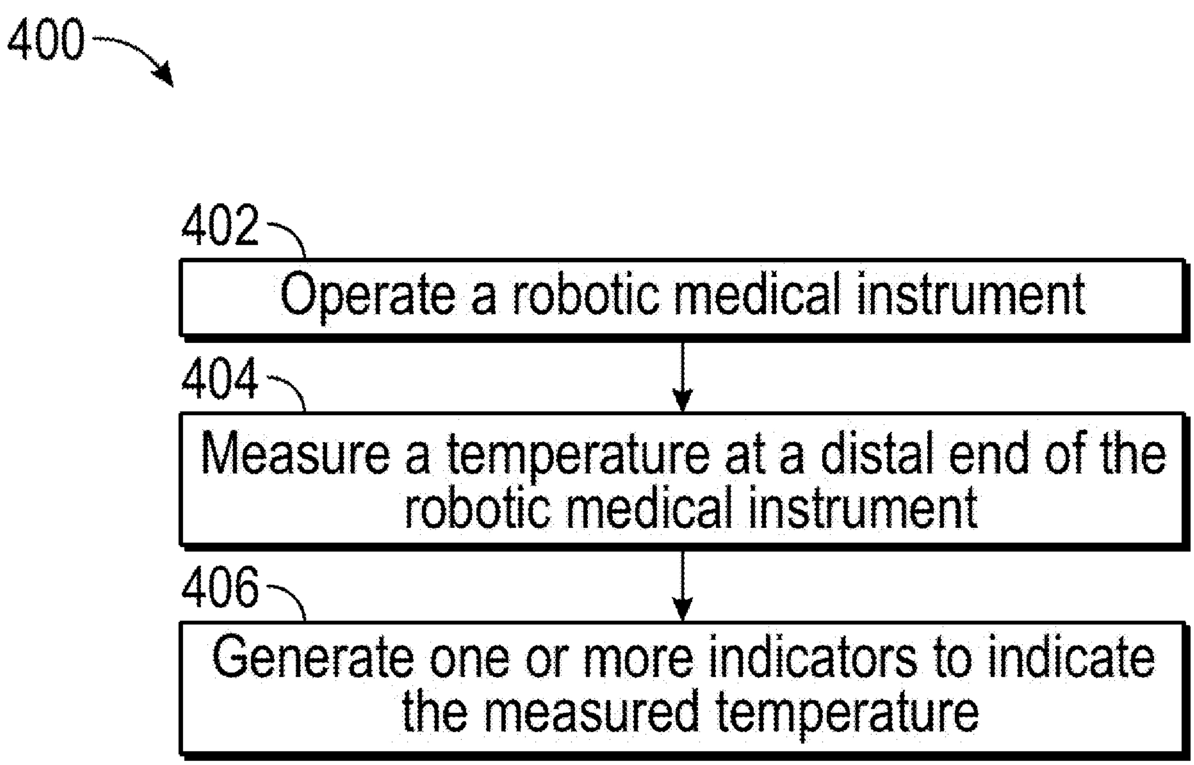
CPC ***A61B 34/37*** (2016.02); *A61B 2018/00714* (2013.01); *A61B 2562/0271* (2013.01); ***A61B 18/085*** (2013.01)

(57) **ABSTRACT**

A robotic medical system can include a medical instrument that can include a distal end configured to be inserted into a patient and apply heat to tissue within the patient. The robotic manipulator can be engaged with the medical instrument and configured to operate the medical instrument. The system can further include a temperature sensor configured to take one or more temperature readings of the medical instrument. The system can also include a viewer configured to display an image of the medical instrument and an image overlay conveying information indicative of a temperature of the medical instrument. The information conveyed by the image overlay can be based on the one or more temperature readings taken by the temperature sensor.



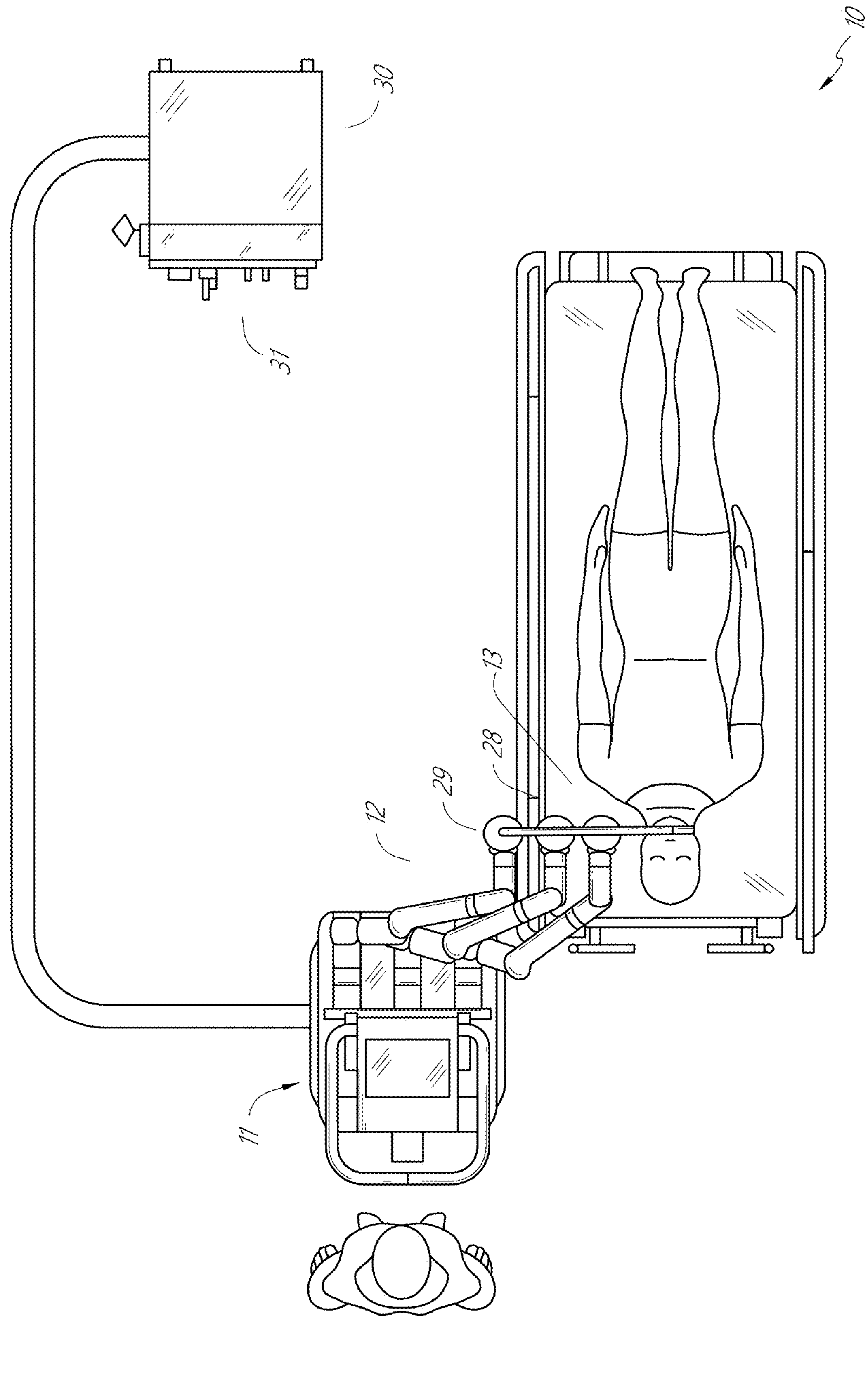


FIG. 1

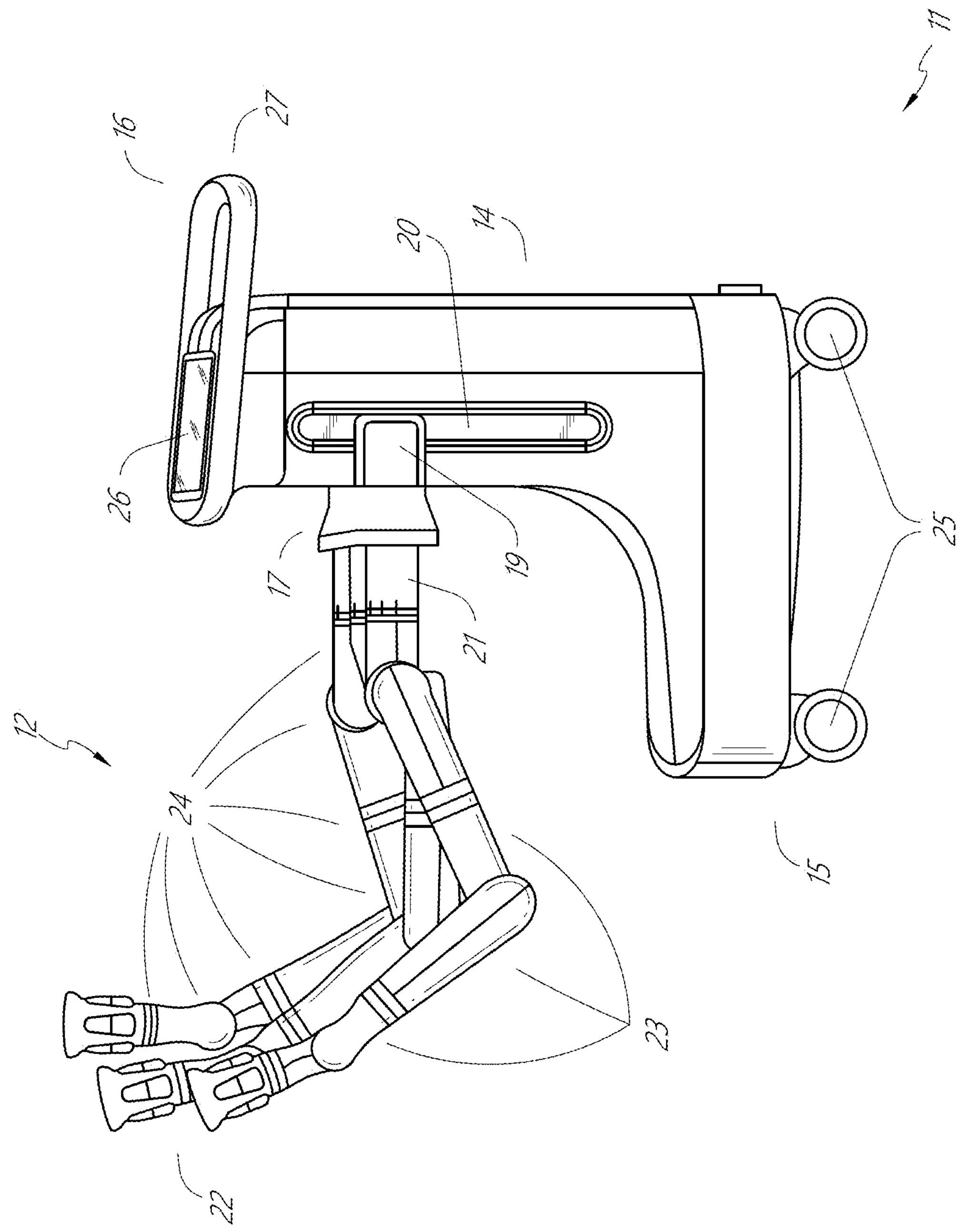


FIG. 2

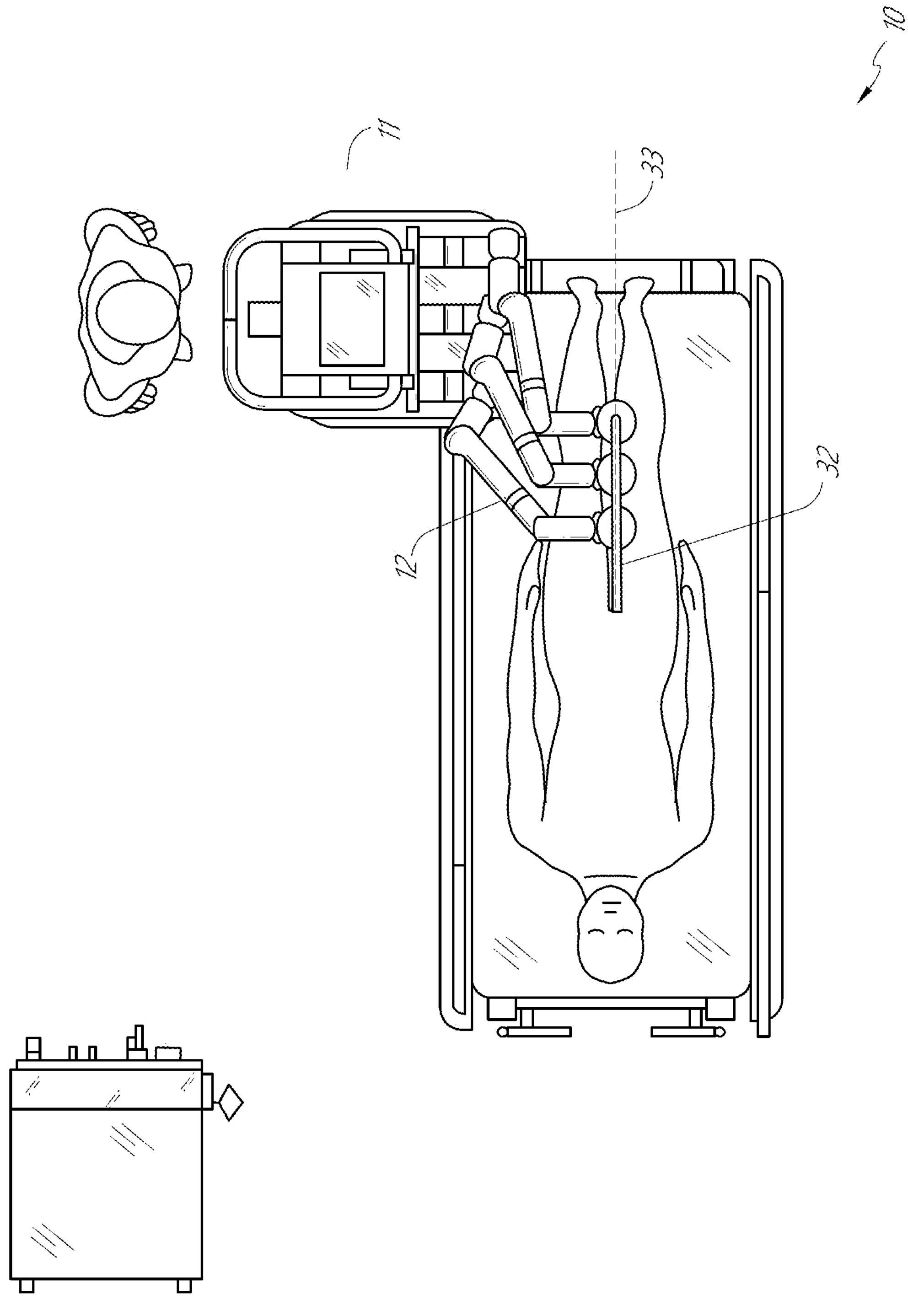


FIG. 3

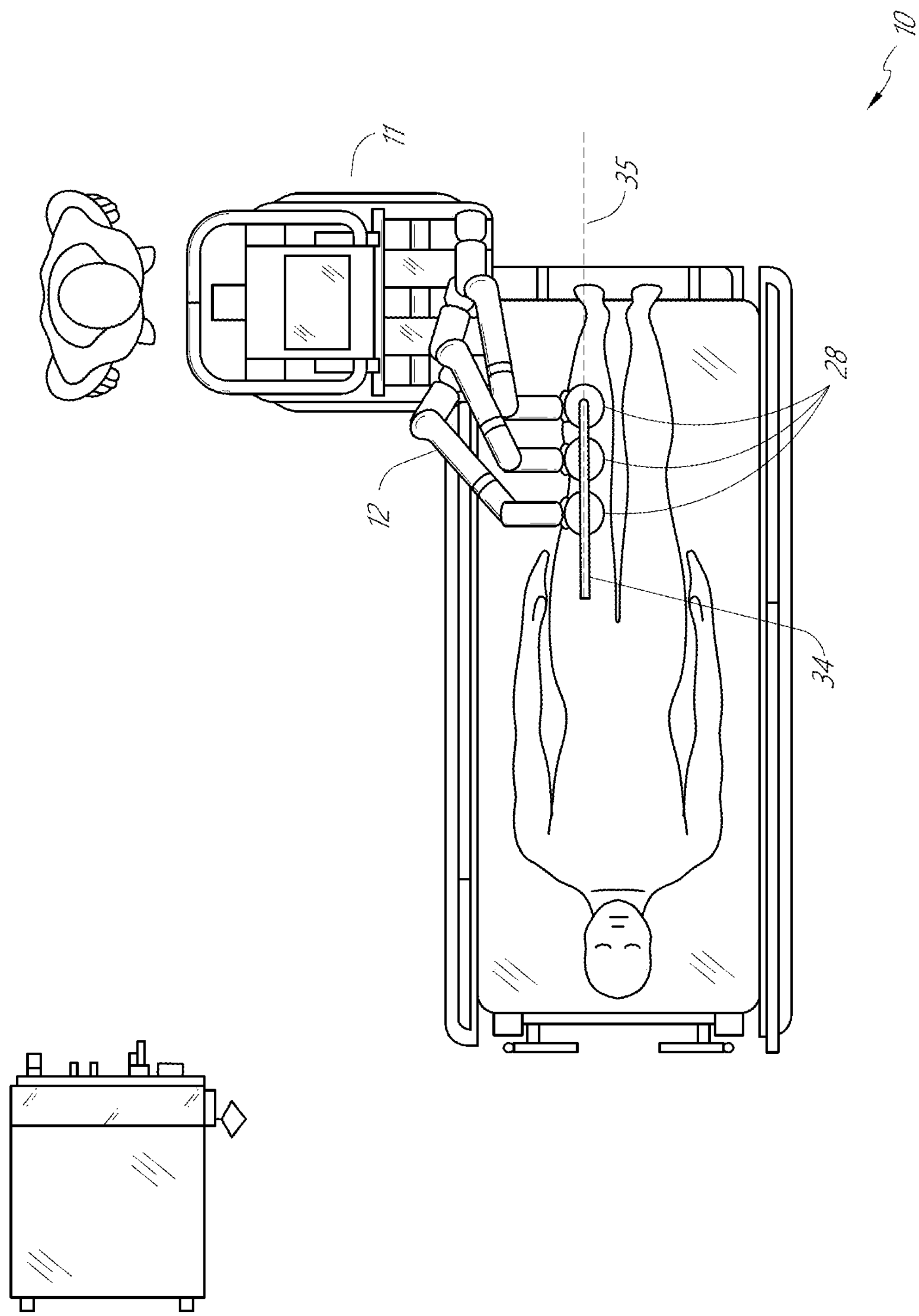


FIG. 4

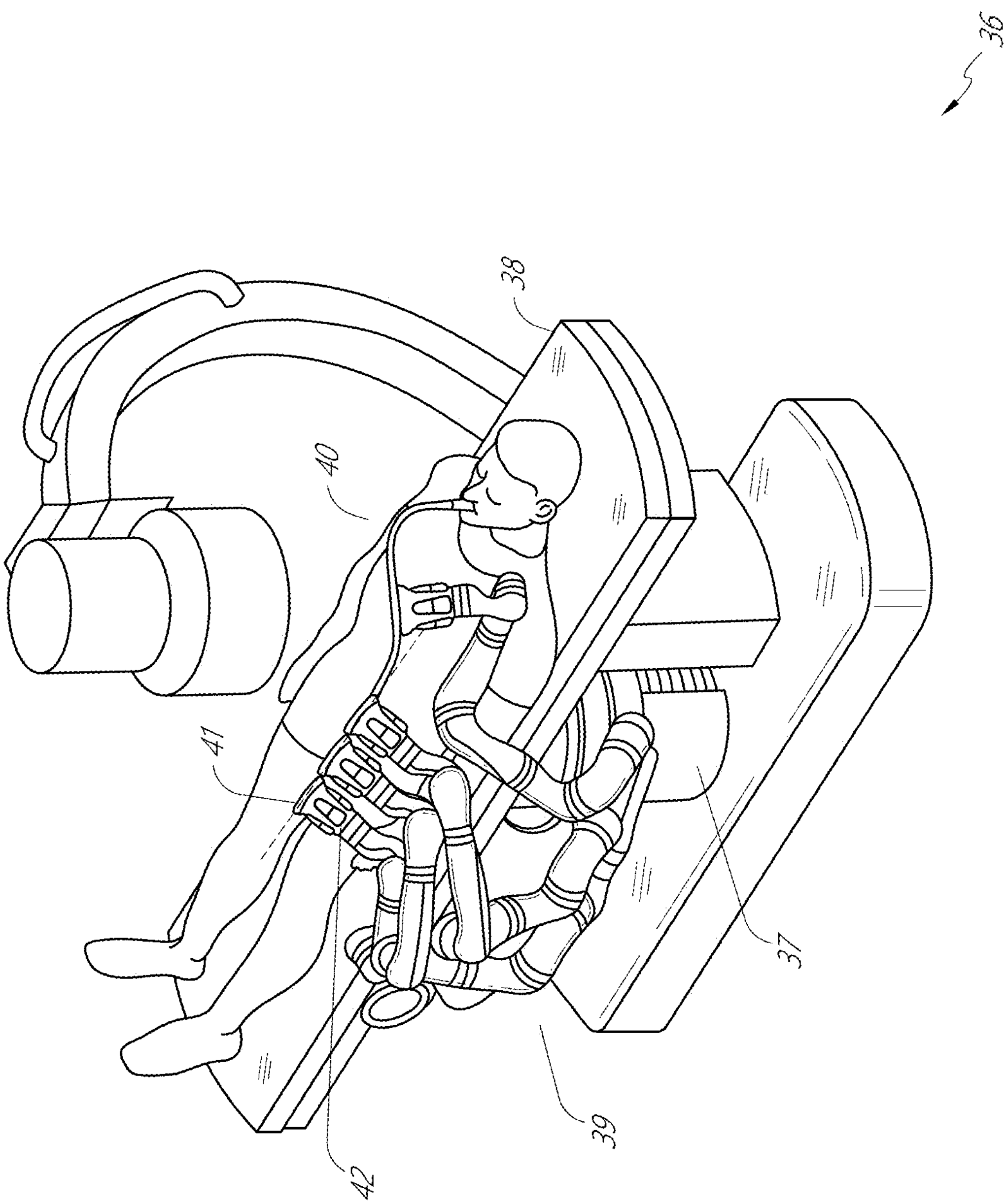


FIG. 5

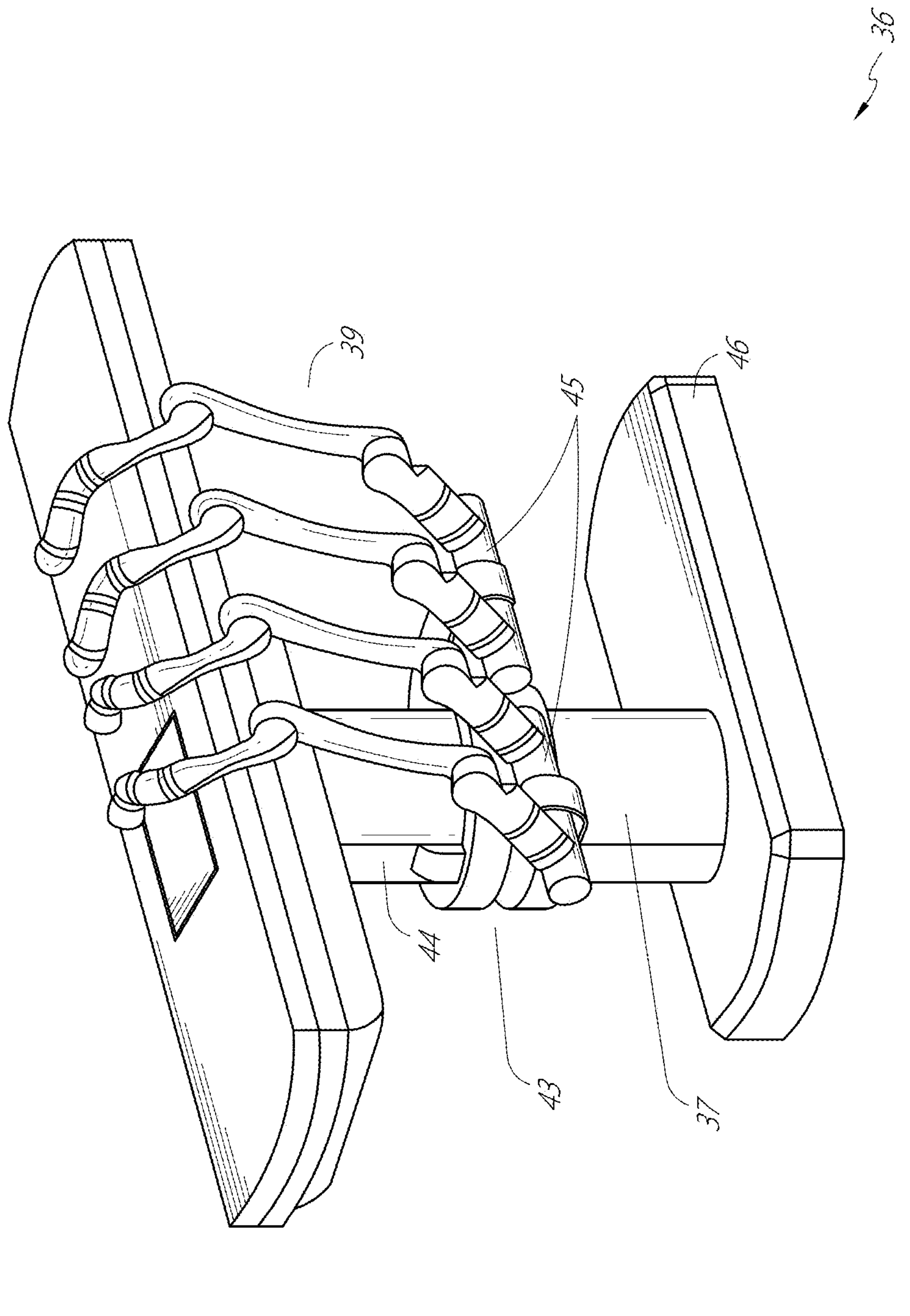


FIG. 6

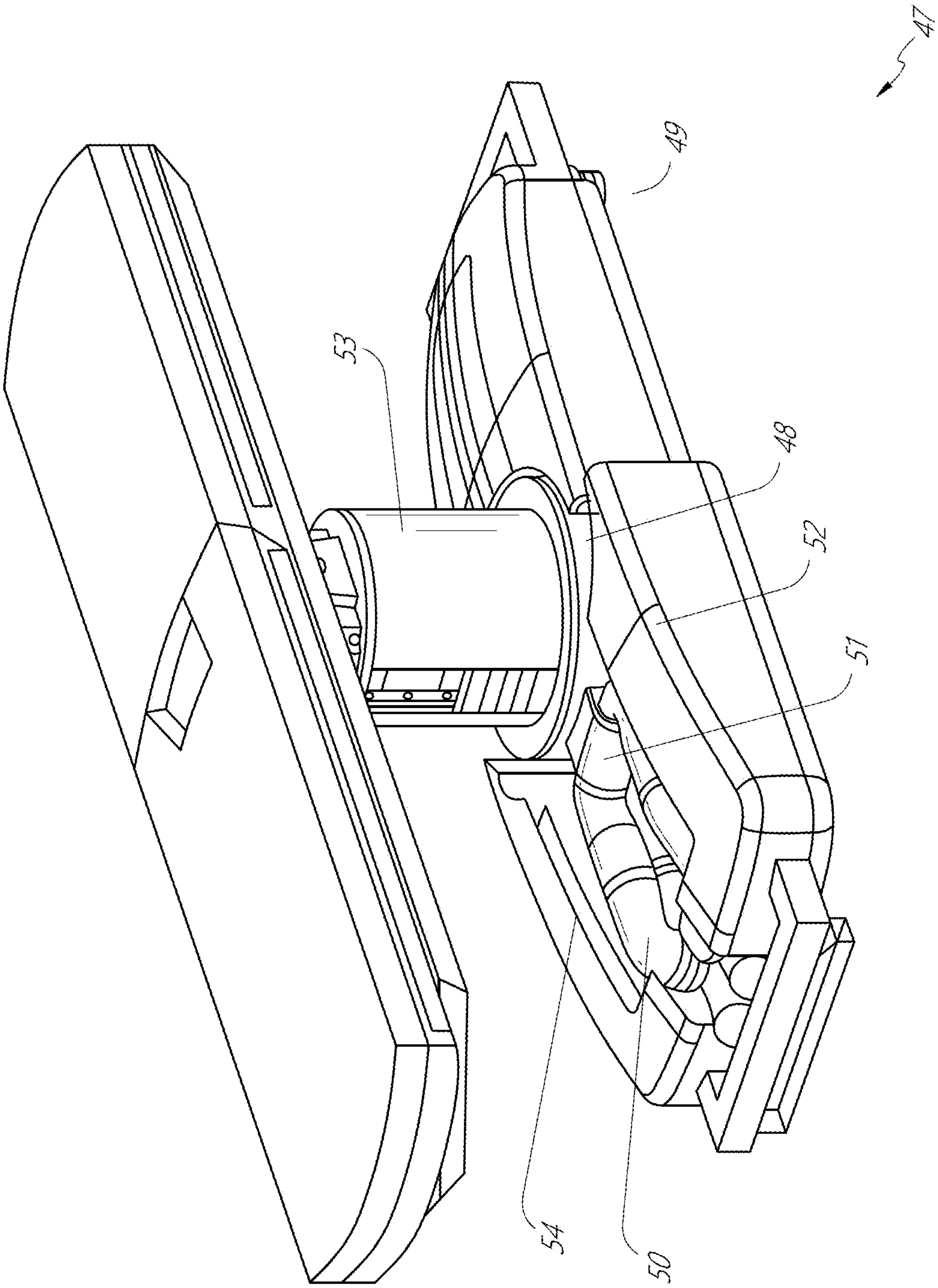


FIG. 7

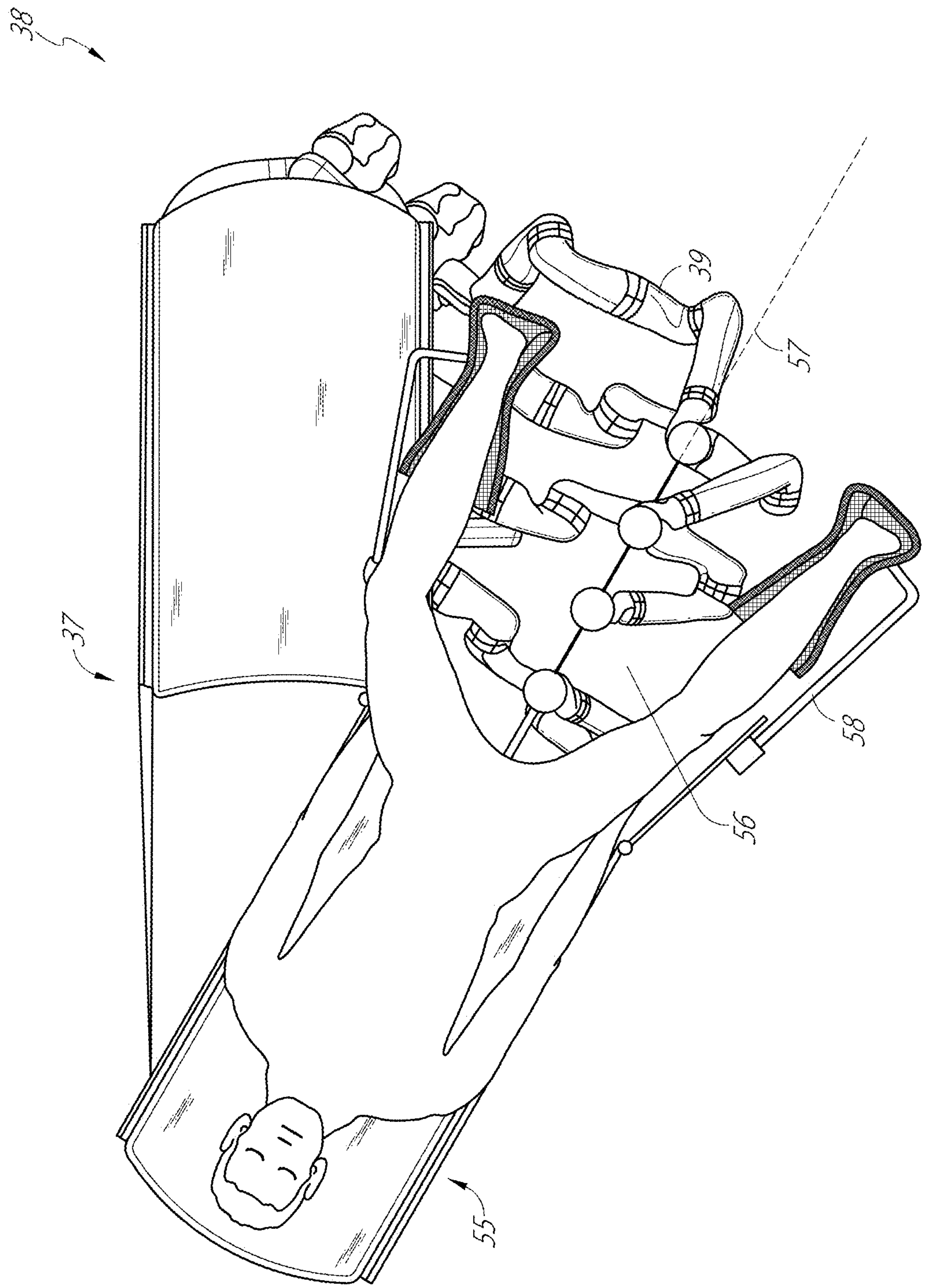


FIG. 8

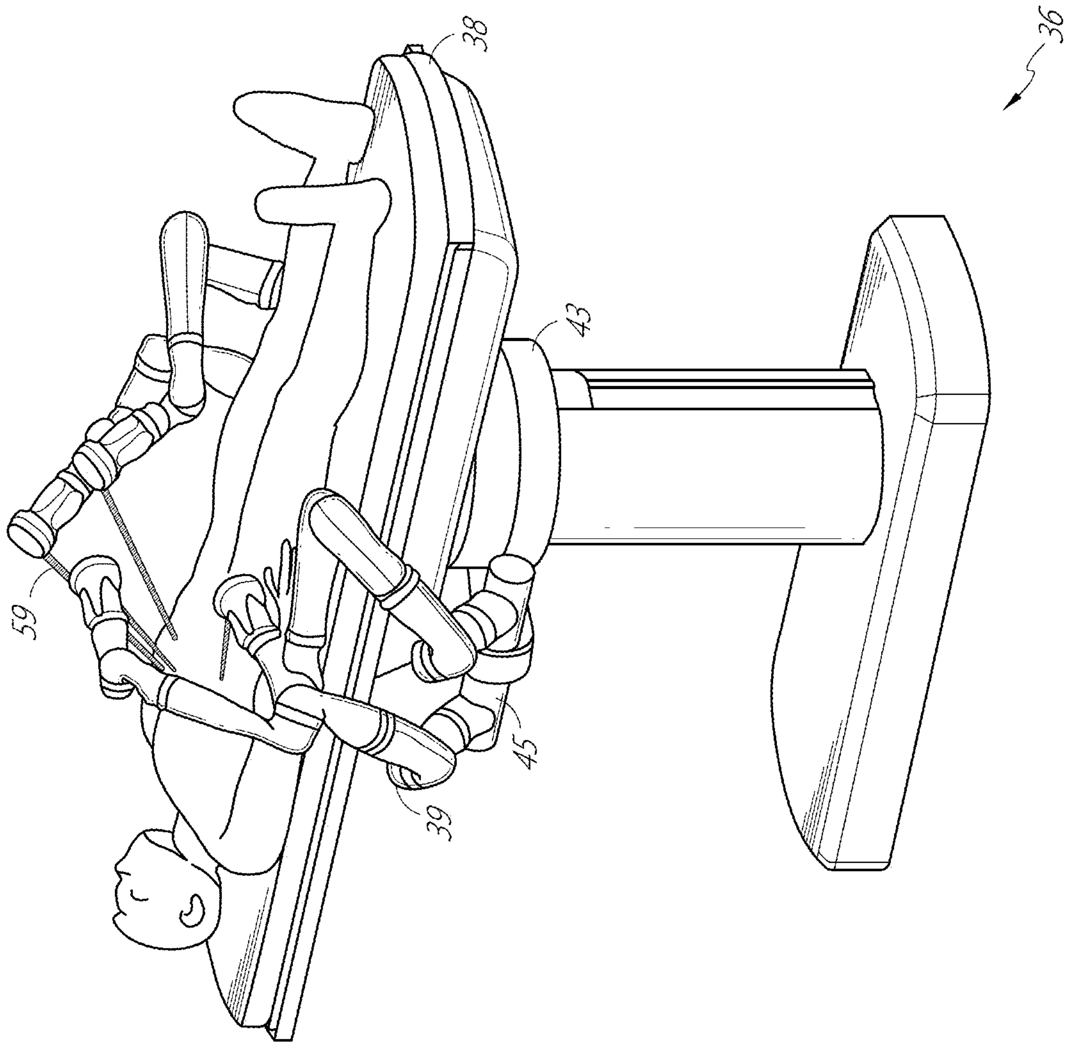


FIG. 9

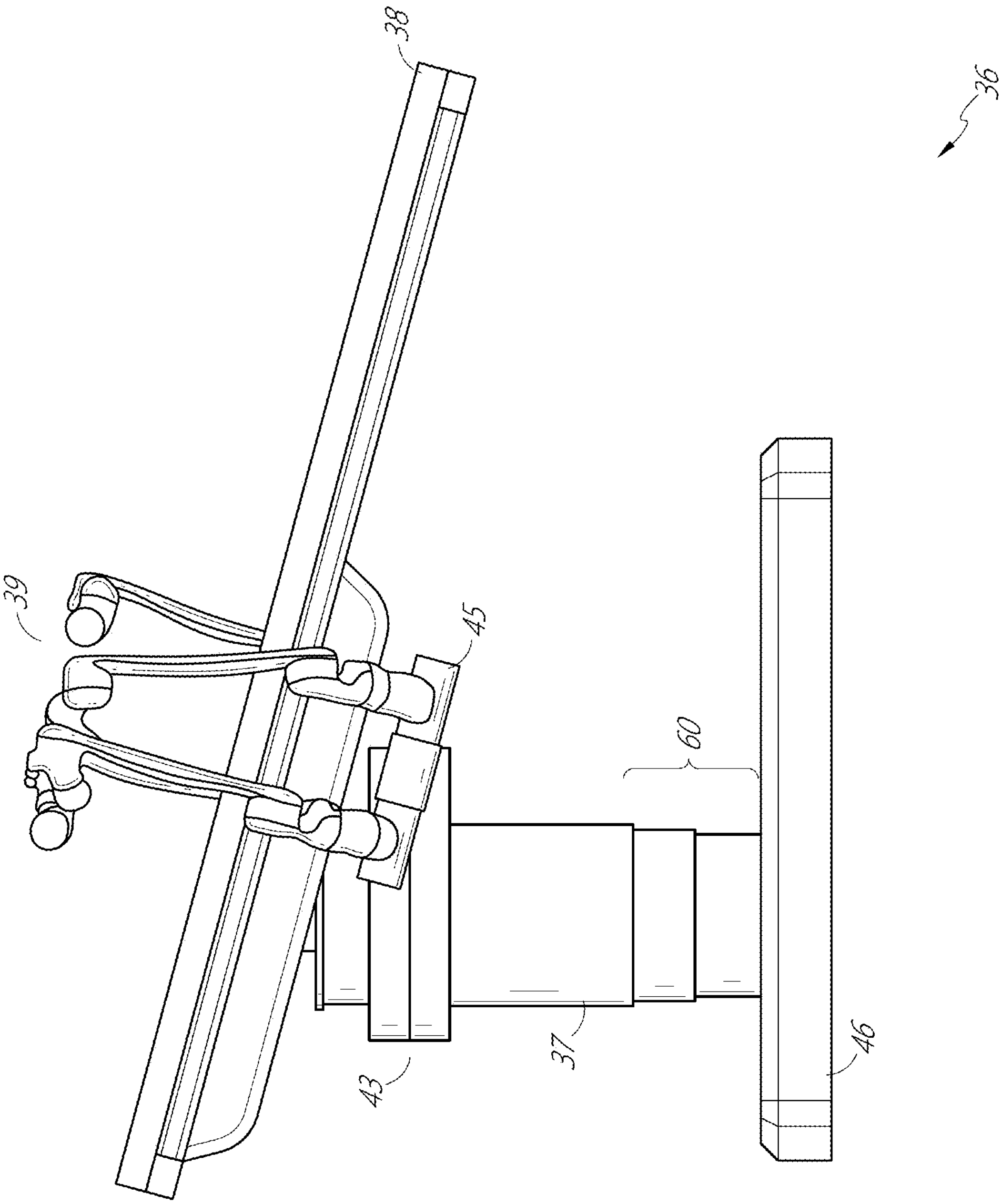


FIG. 10

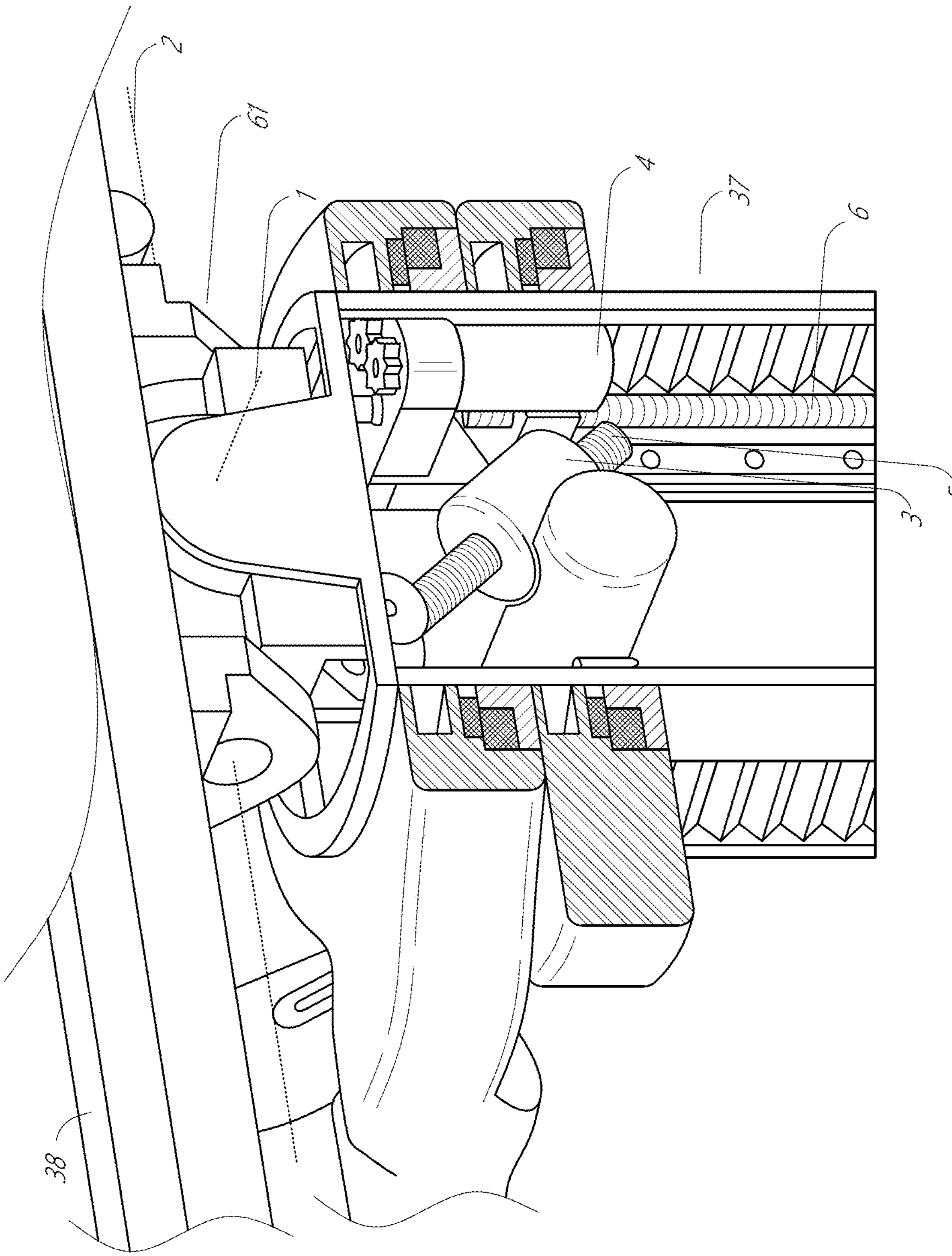


FIG. 11

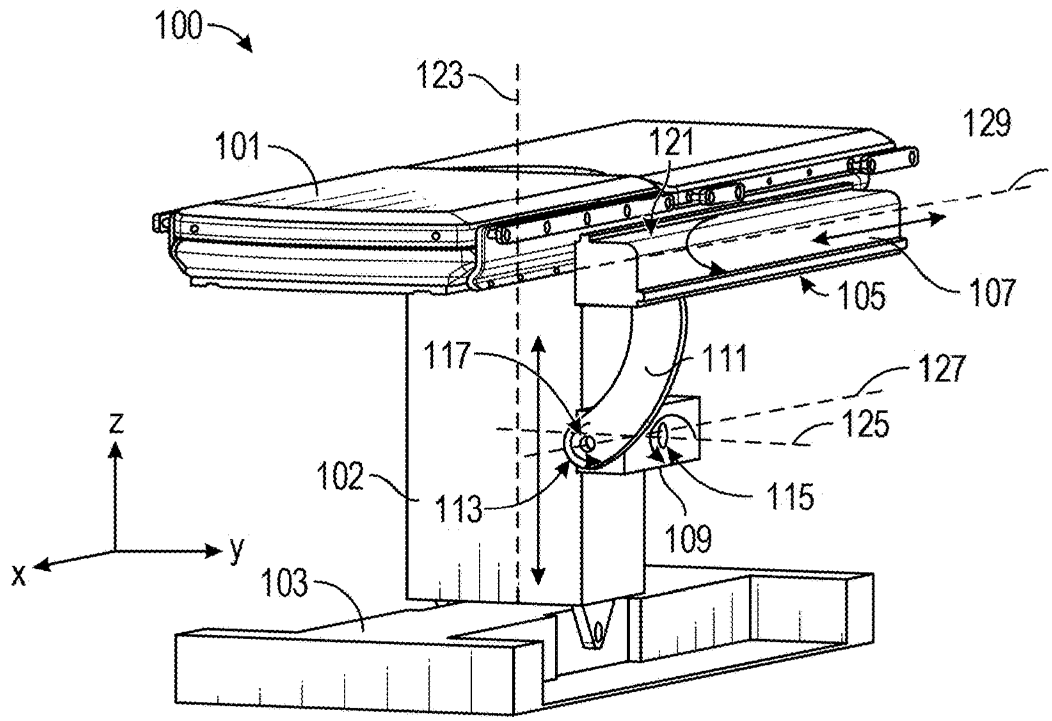

100
123
129
101
121
105
107
117
111
127
125
z
102
113
115
109
x
y
103

FIG. 12

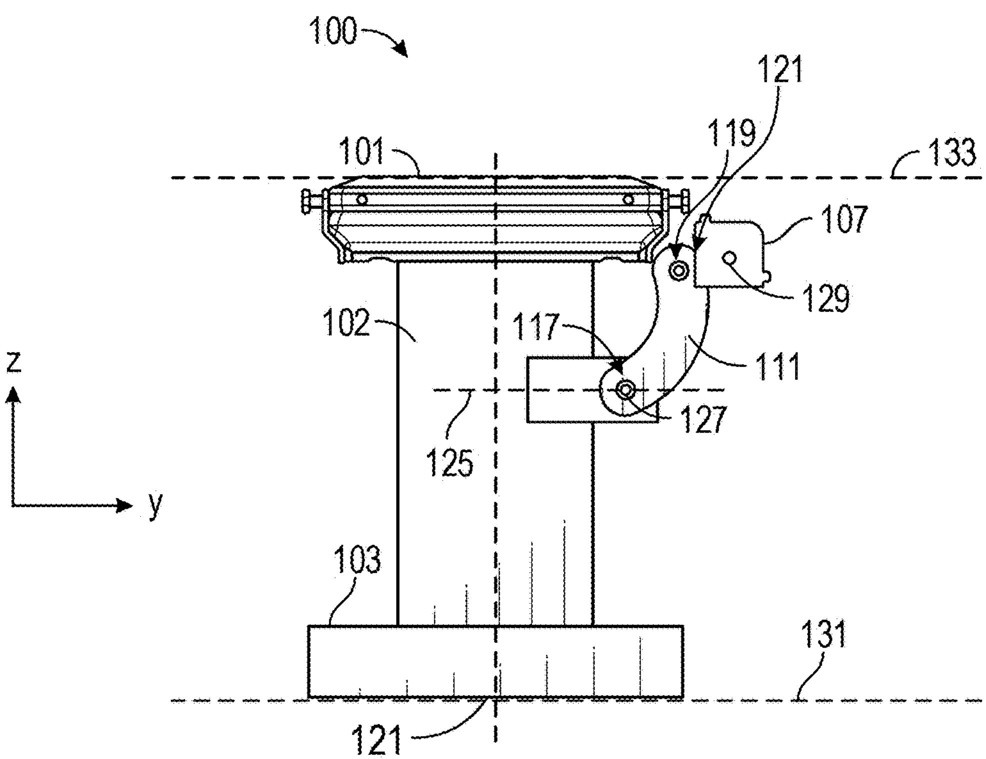

100
121
119
133
101
107
129
102
117
111
z
127
125
y
103
131
121

FIG. 13

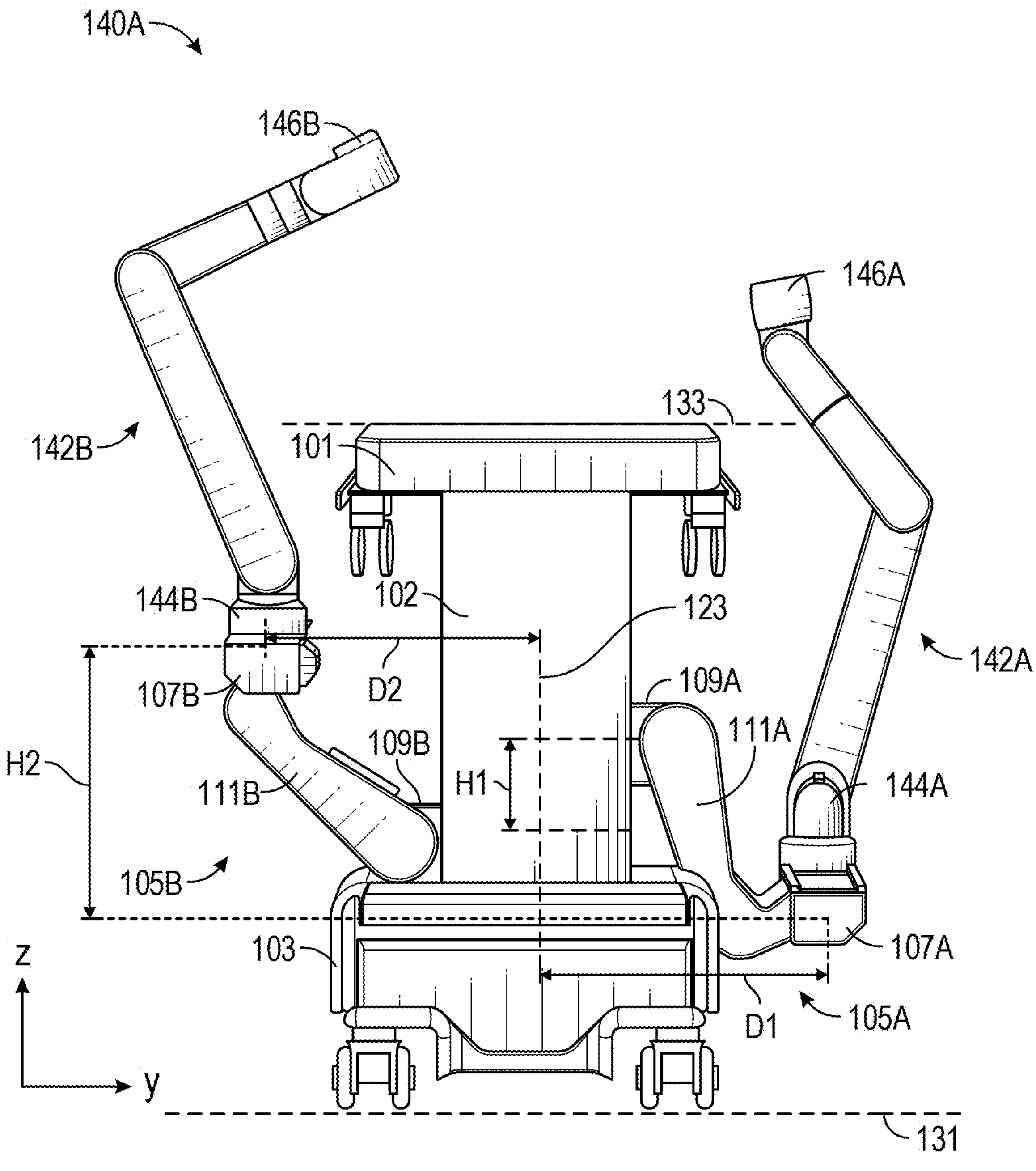

140A
146B
146A
133
101
142B
102
123
144B
142A
D2
109A
107B
111A
109B
H2
H1
144A
111B
105B
107A
z
103
105A
D1
y
131

FIG. 14

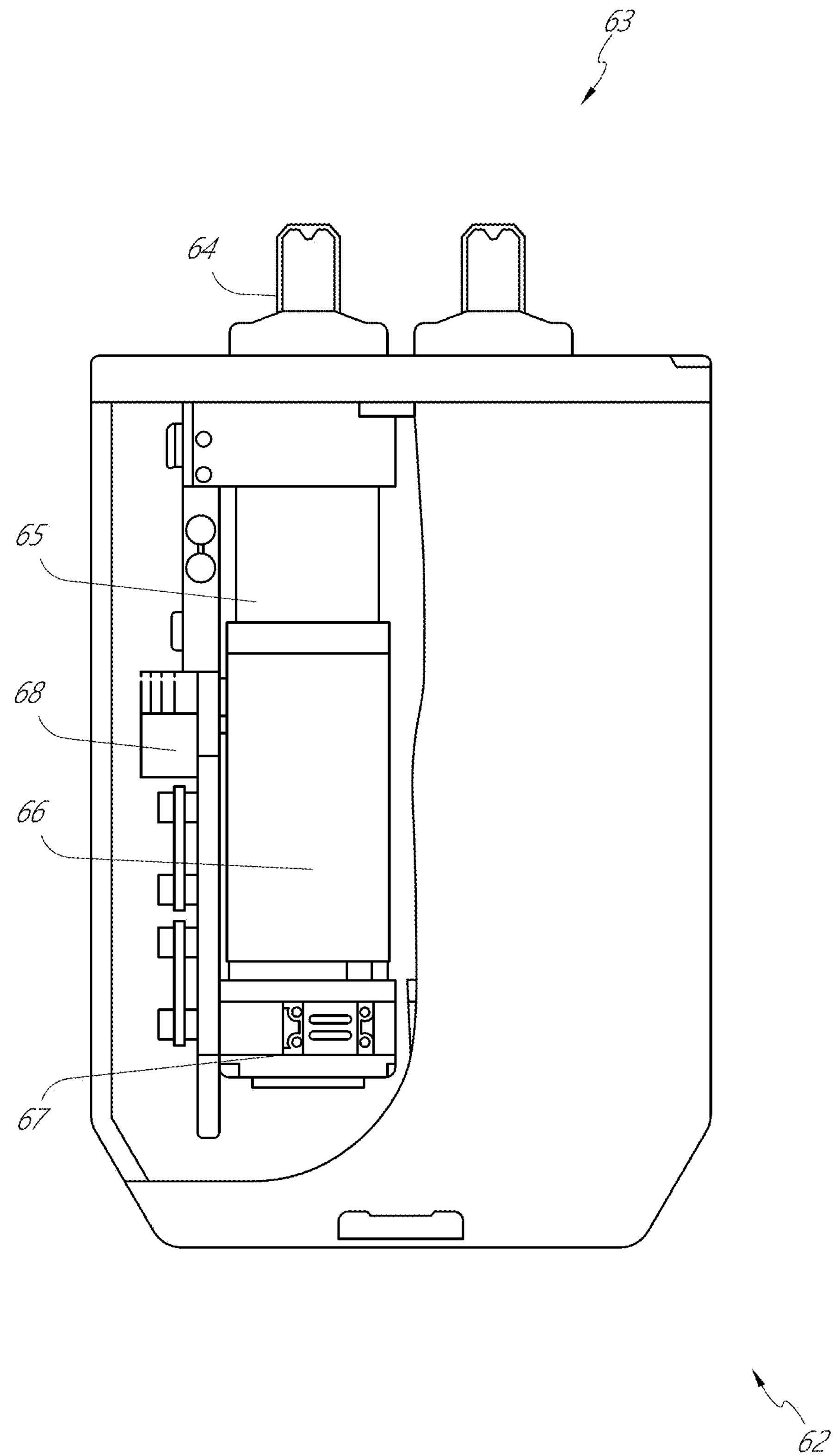


FIG. 15

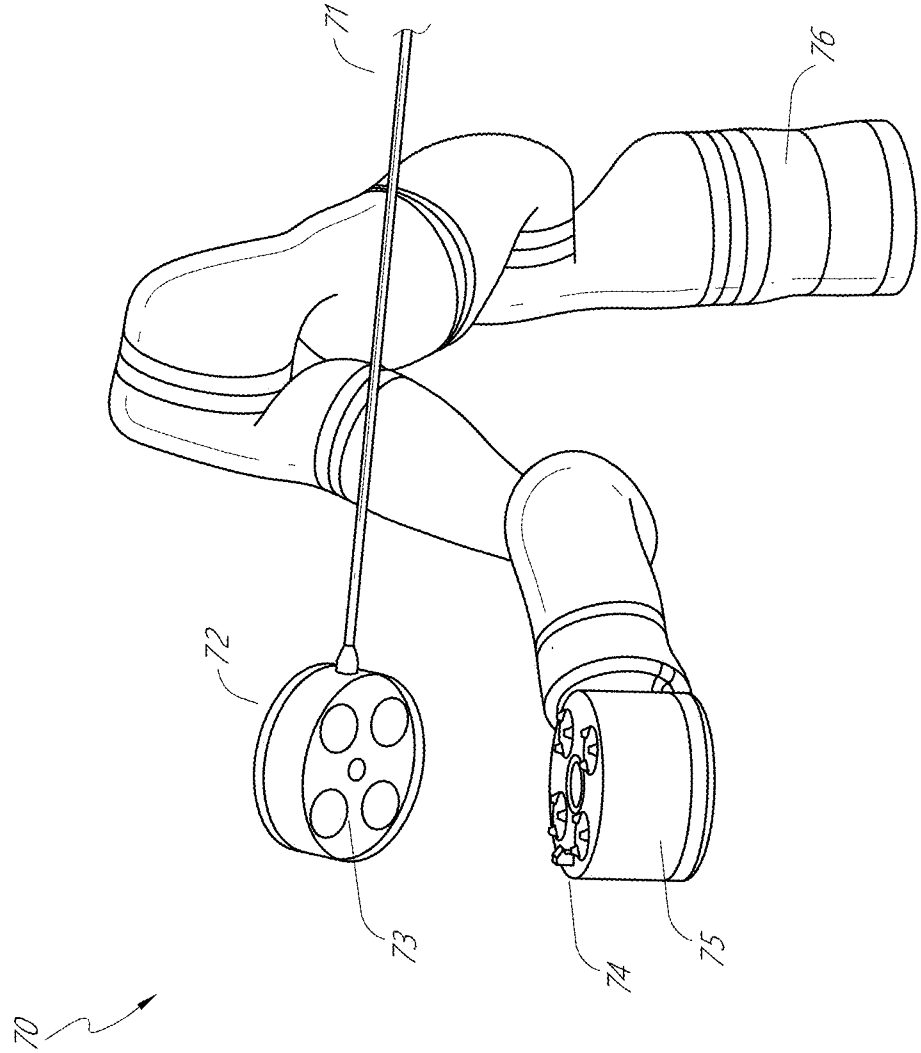


FIG. 16

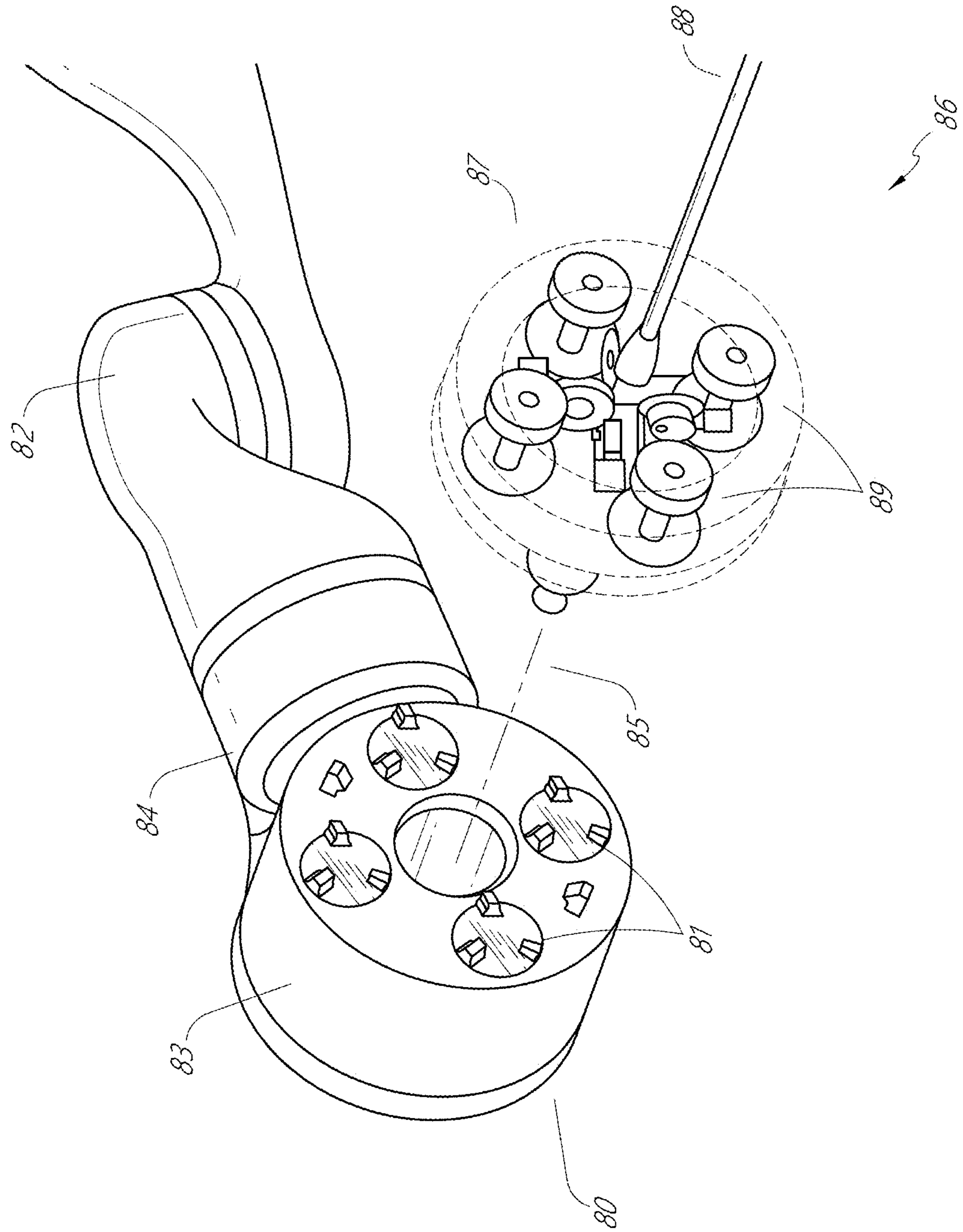


FIG. 17

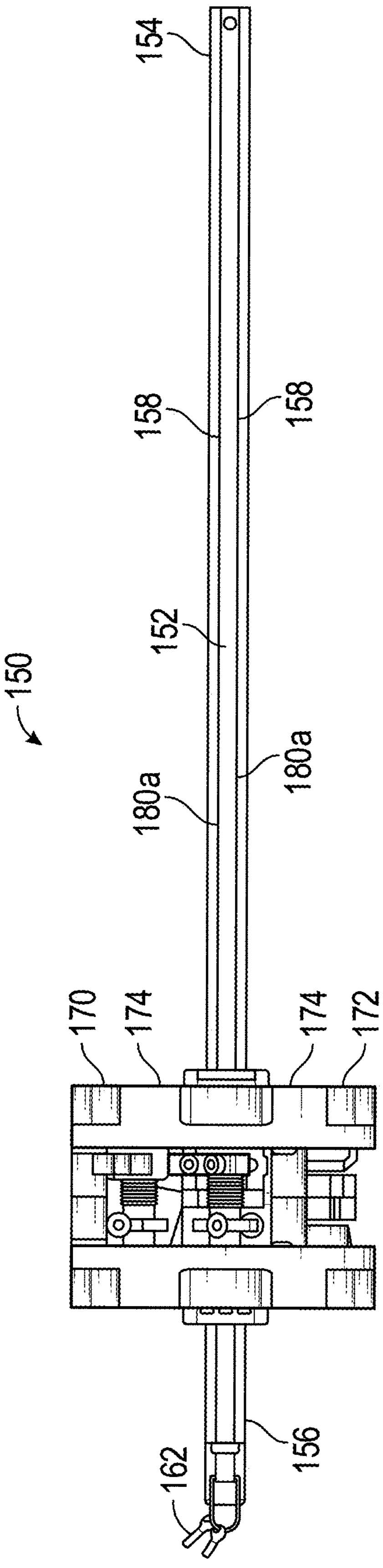


FIG. 18

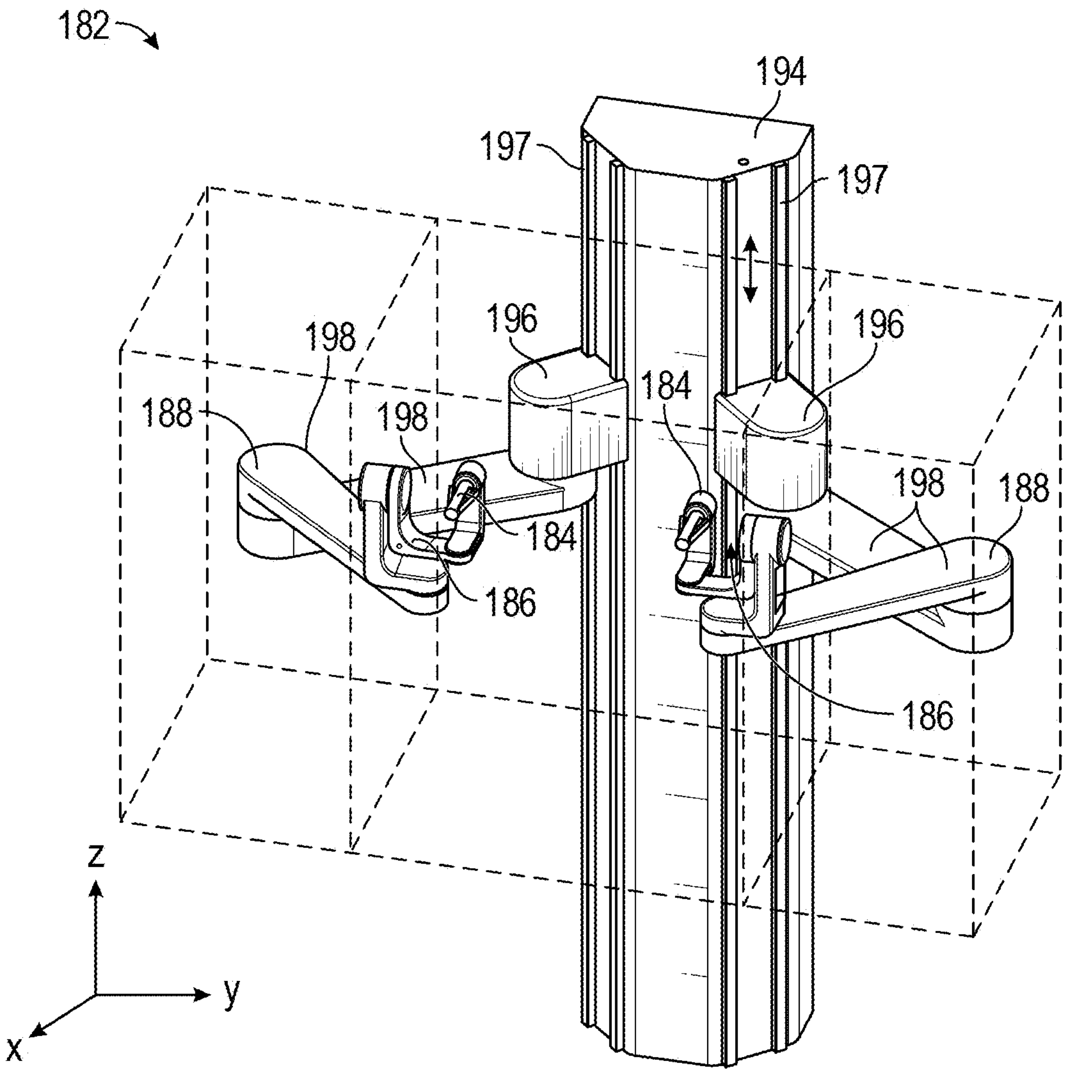


FIG. 19

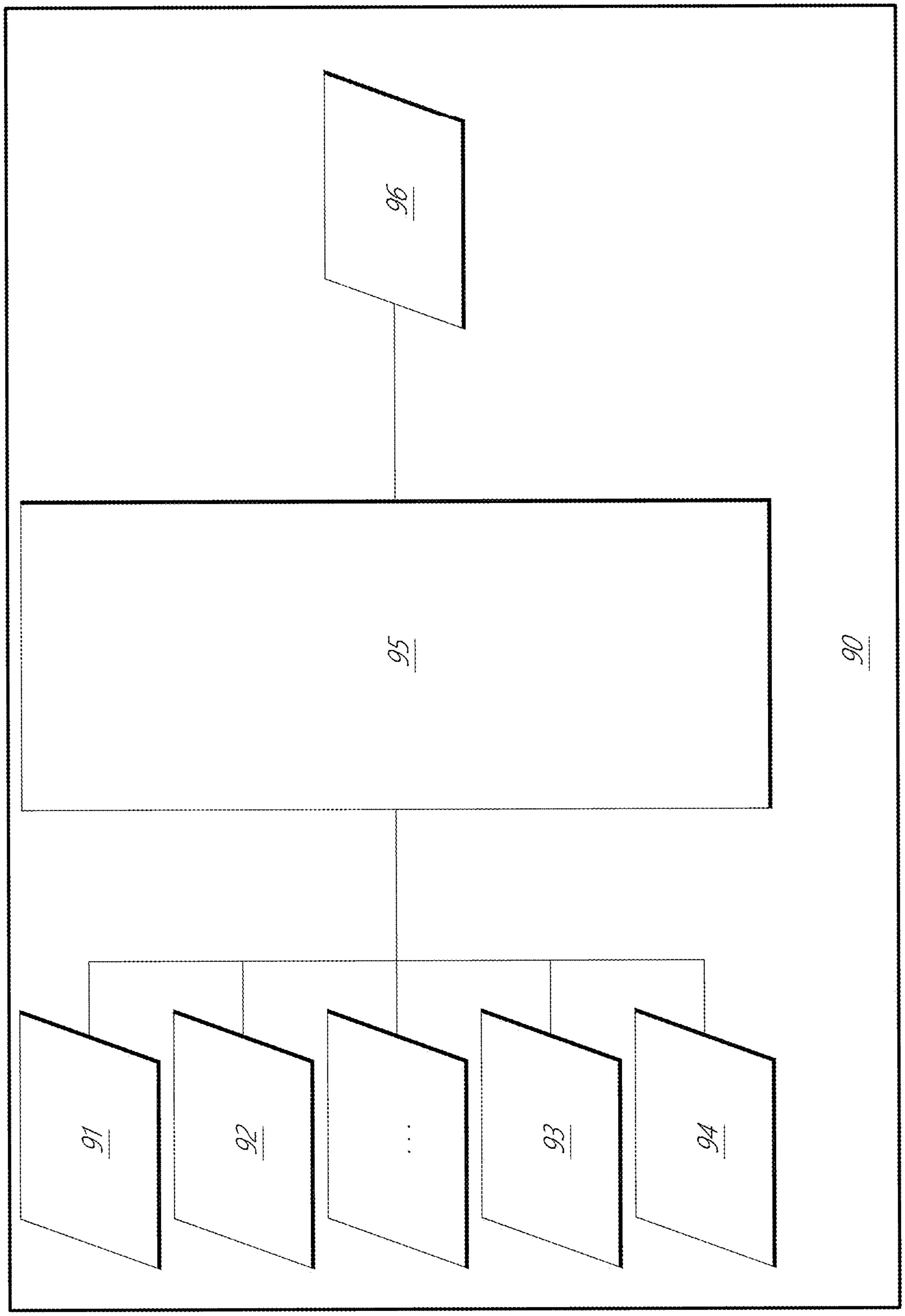


FIG. 20

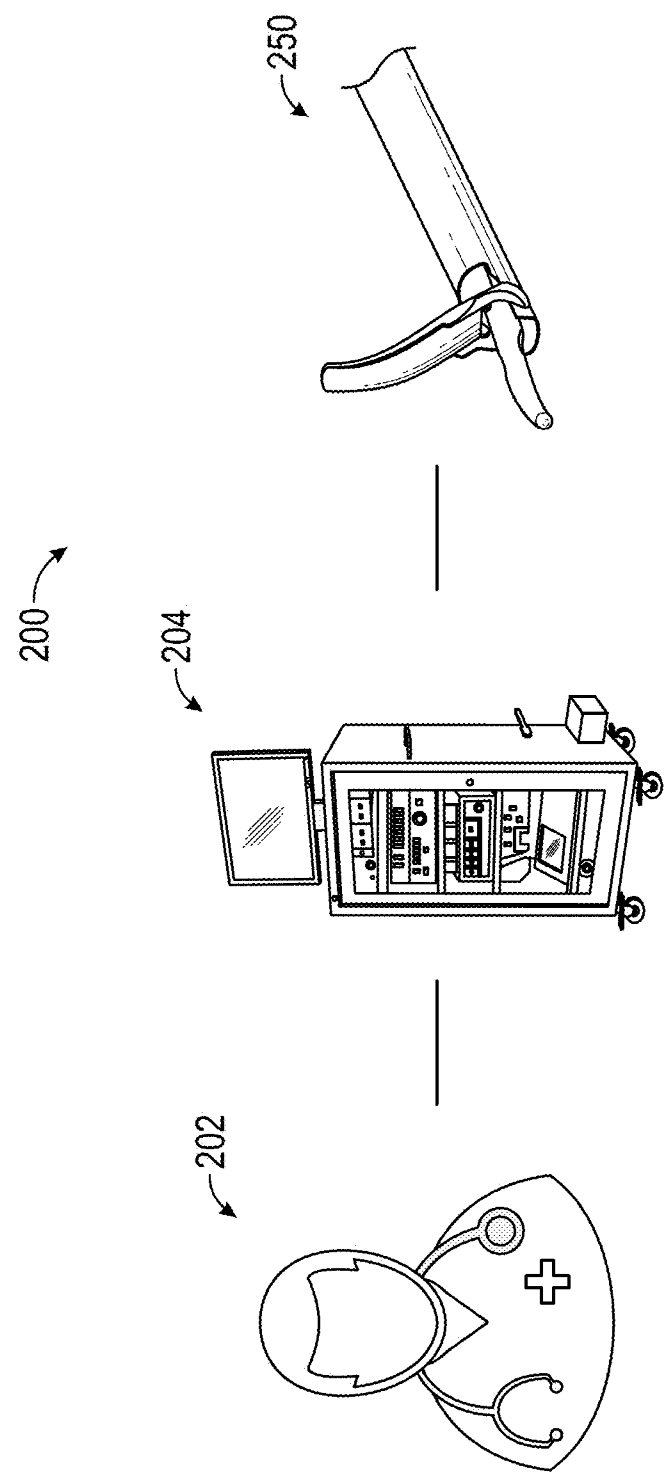


FIG. 21A

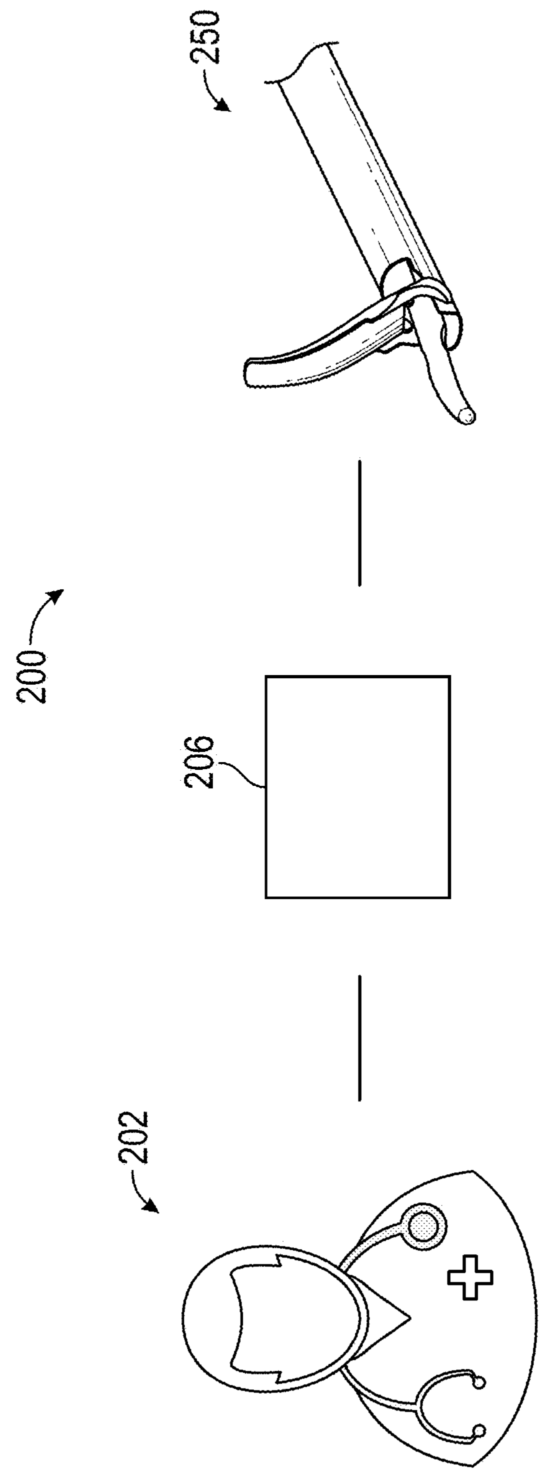


FIG. 21B

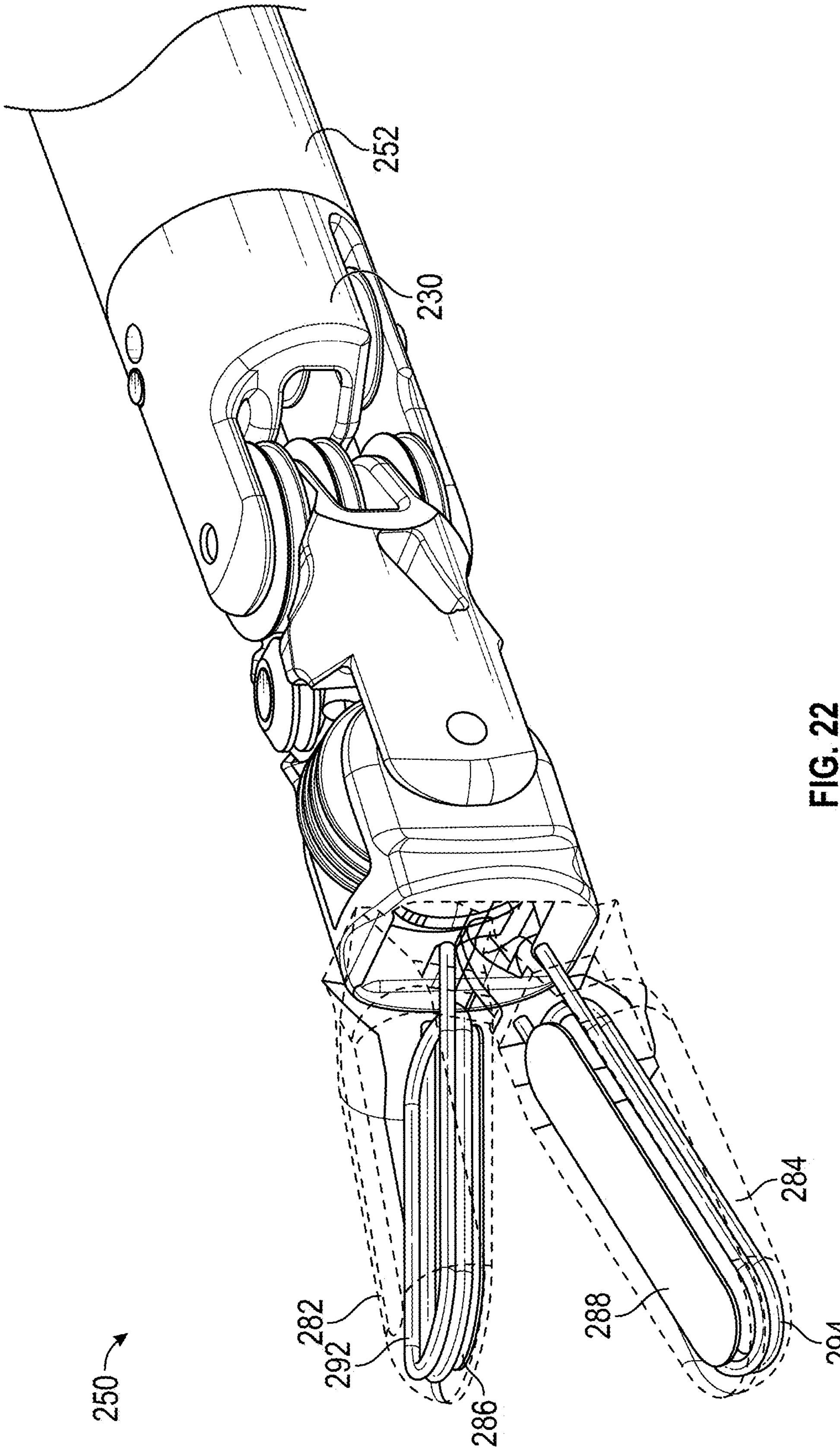


FIG. 22

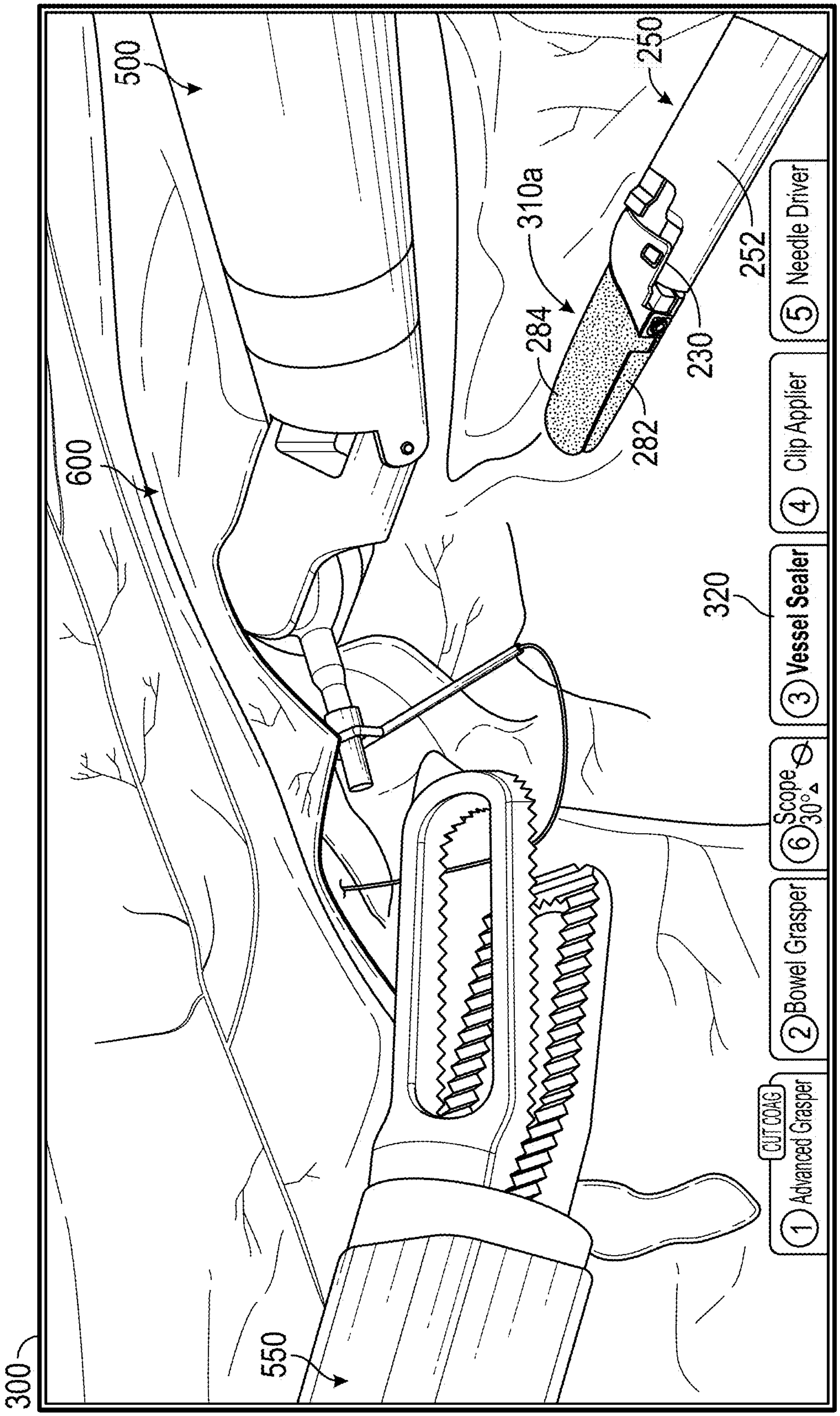

300
500
250
310a
284
230
252
282
600
320
550
CUT COAG
1 Advanced Grasper
2 Bowel Grasper
6 Scope 30°
3 Vessel Sealer
4 Clip Applier
5 Needle Driver

FIG. 23A

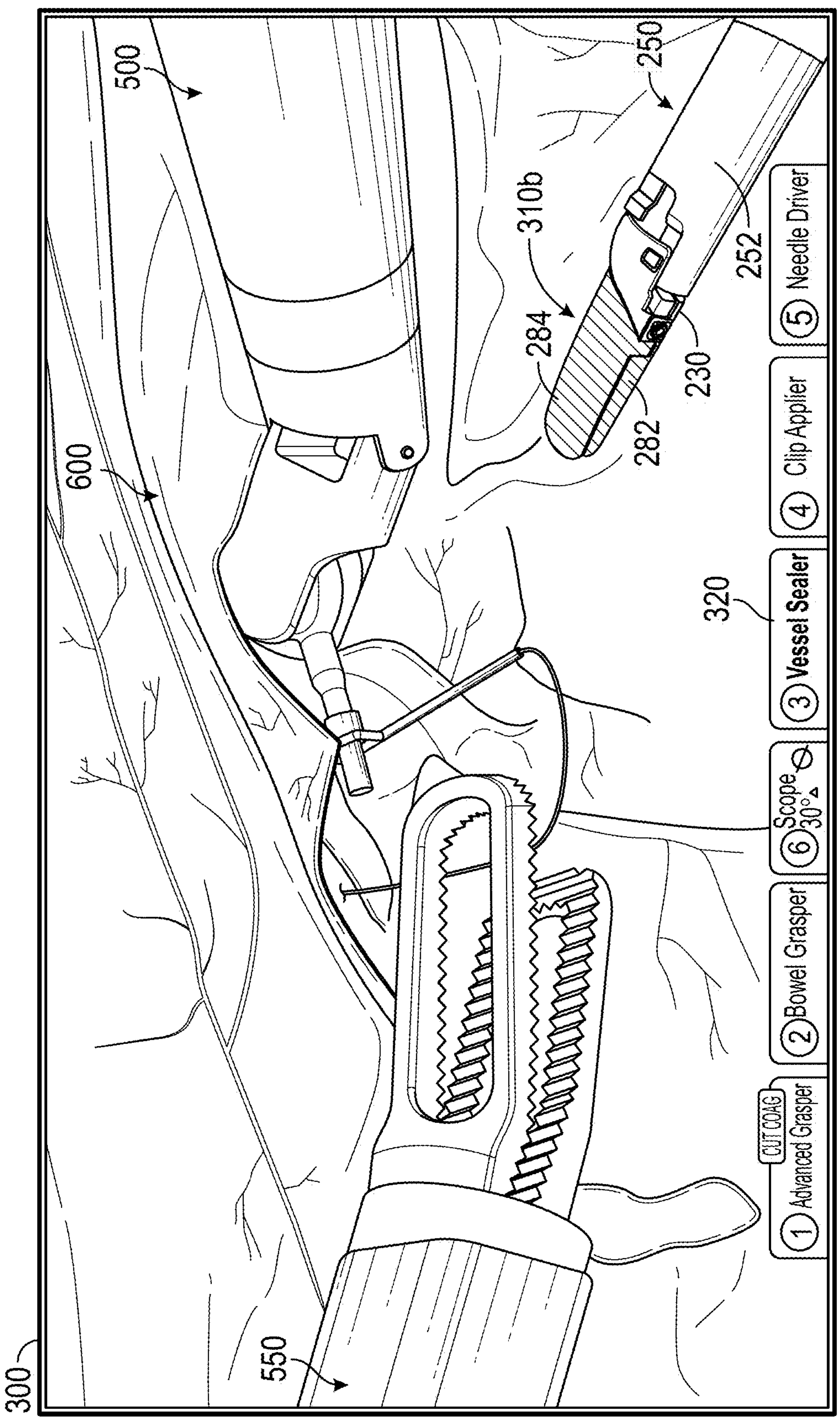

300
500
250
310b
284
252
230
282
600
320
550
CUT COAG
1 Advanced Grasper
2 Bowel Grasper
6 Scope 30°
3 Vessel Sealer
4 Clip Applier
5 Needle Driver

FIG. 23B

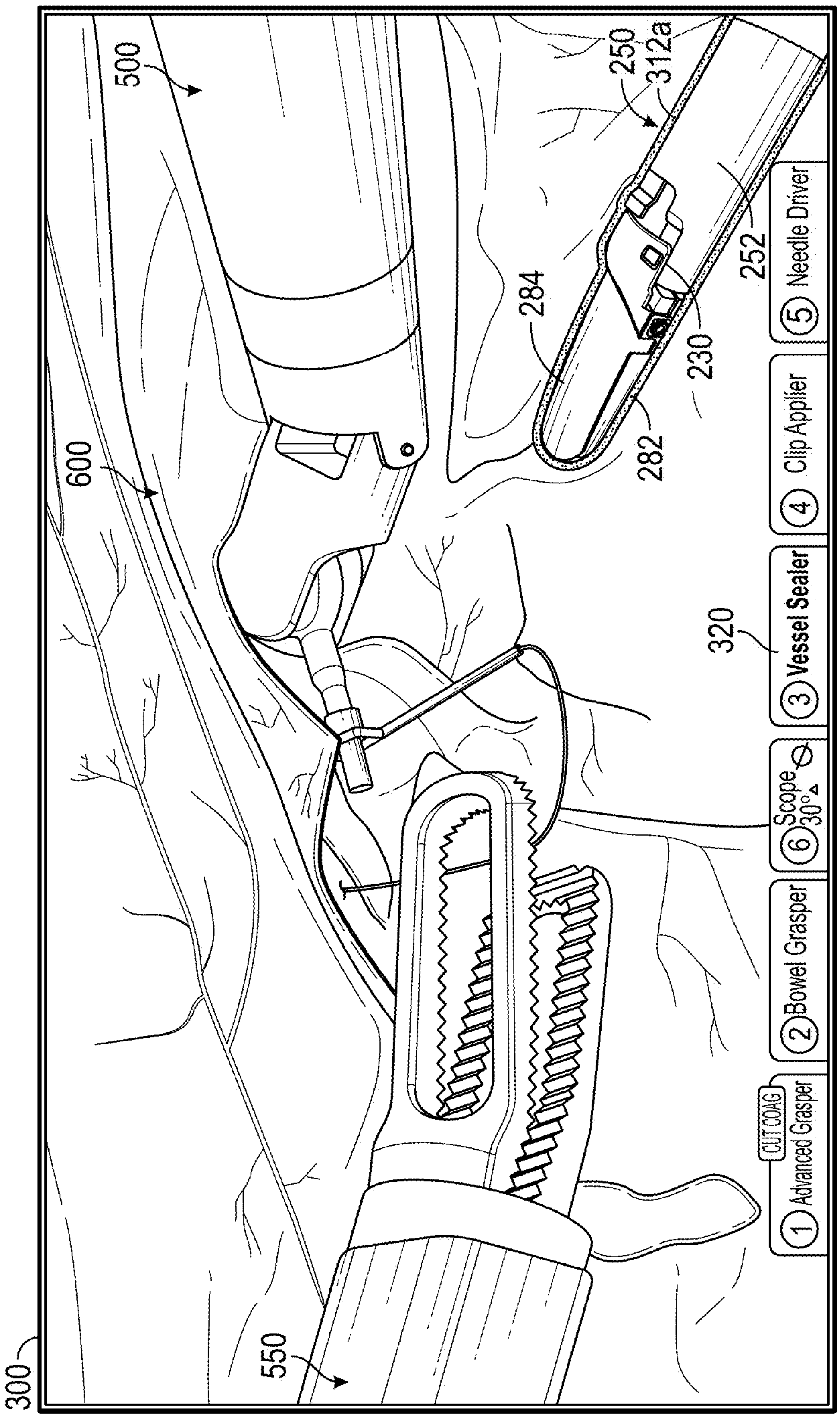

300
500
600
550
250
312a
284
252
230
282
320
CUT COAG
1 Advanced Grasper
2 Bowel Grasper
6 Scope 30°
3 Vessel Sealer
4 Clip Applier
5 Needle Driver

FIG. 24A

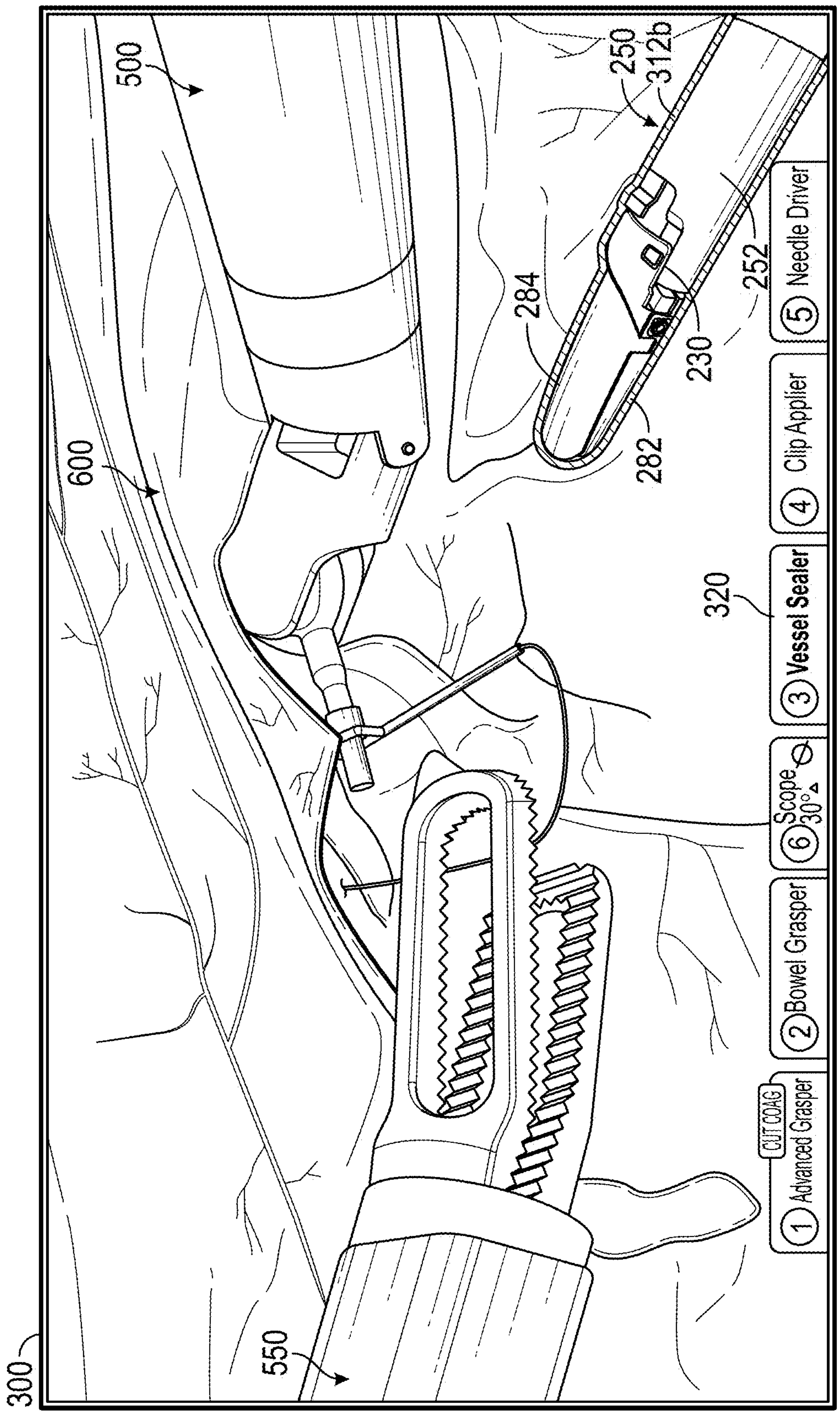

300
500
600
550
250
312b
284
252
230
282
320
CUT COAG
1 Advanced Grasper
2 Bowel Grasper
6 Scope 30°
3 Vessel Sealer
4 Clip Applier
5 Needle Driver

FIG. 24B

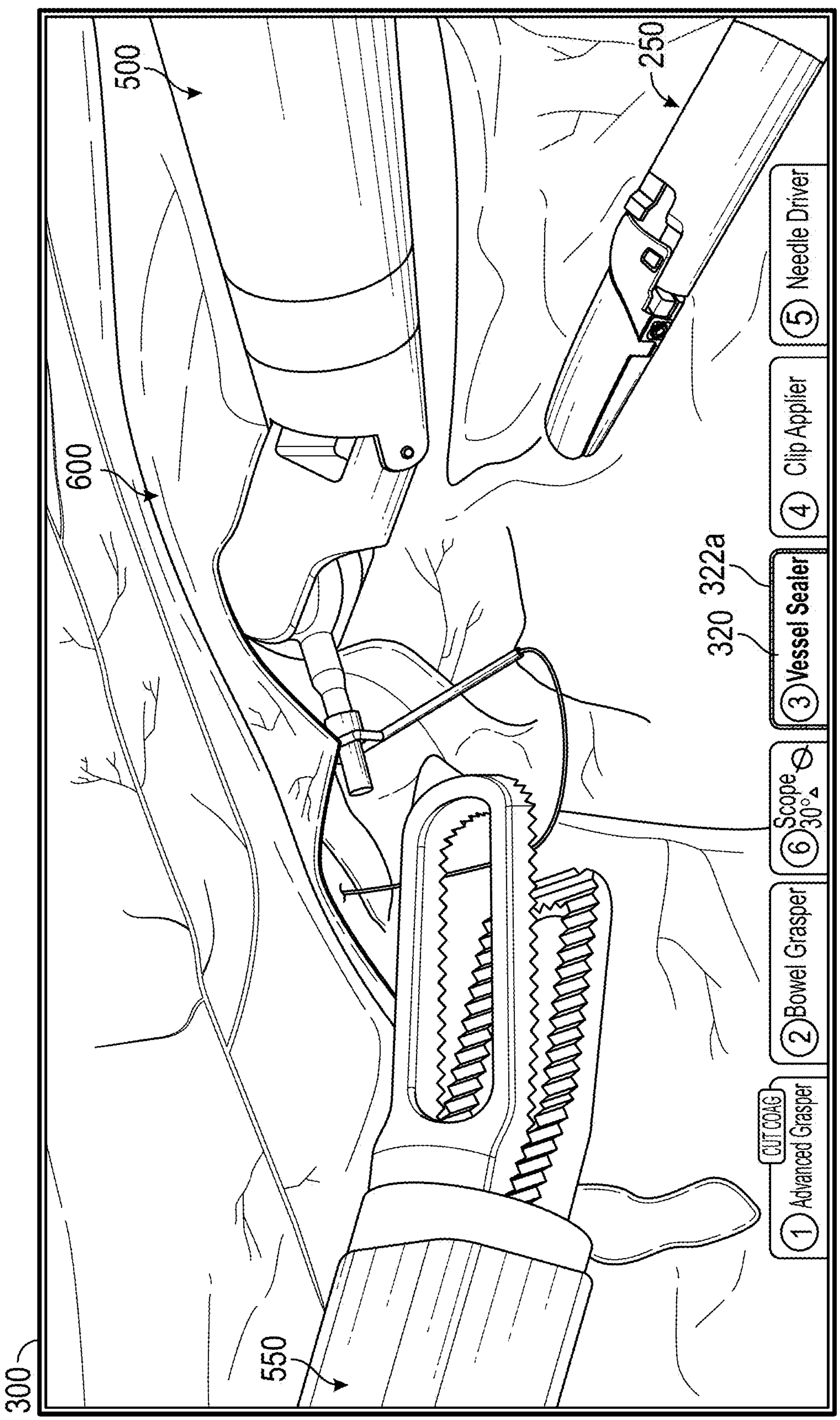

300
500
250
600
550
320
322a
CUT COAG
1 Advanced Grasper
2 Bowel Grasper
6 Scope 30°
3 Vessel Sealer
4 Clip Applier
5 Needle Driver

FIG. 25A

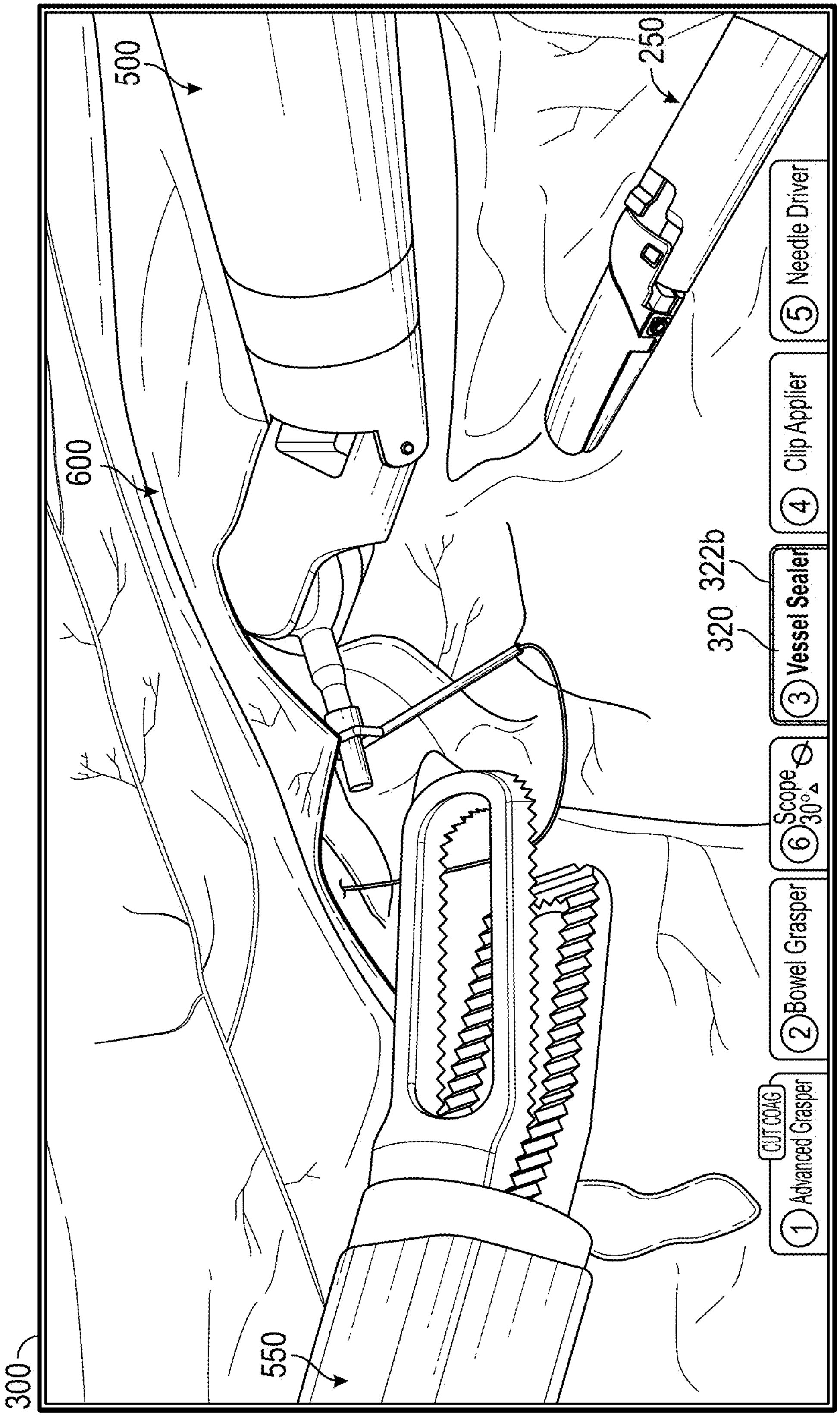

300
500
250
600
550
320
322b
CUT COAG
1 Advanced Grasper
2 Bowel Grasper
6 Scope 30°
3 Vessel Sealer
4 Clip Applier
5 Needle Driver

FIG. 25B

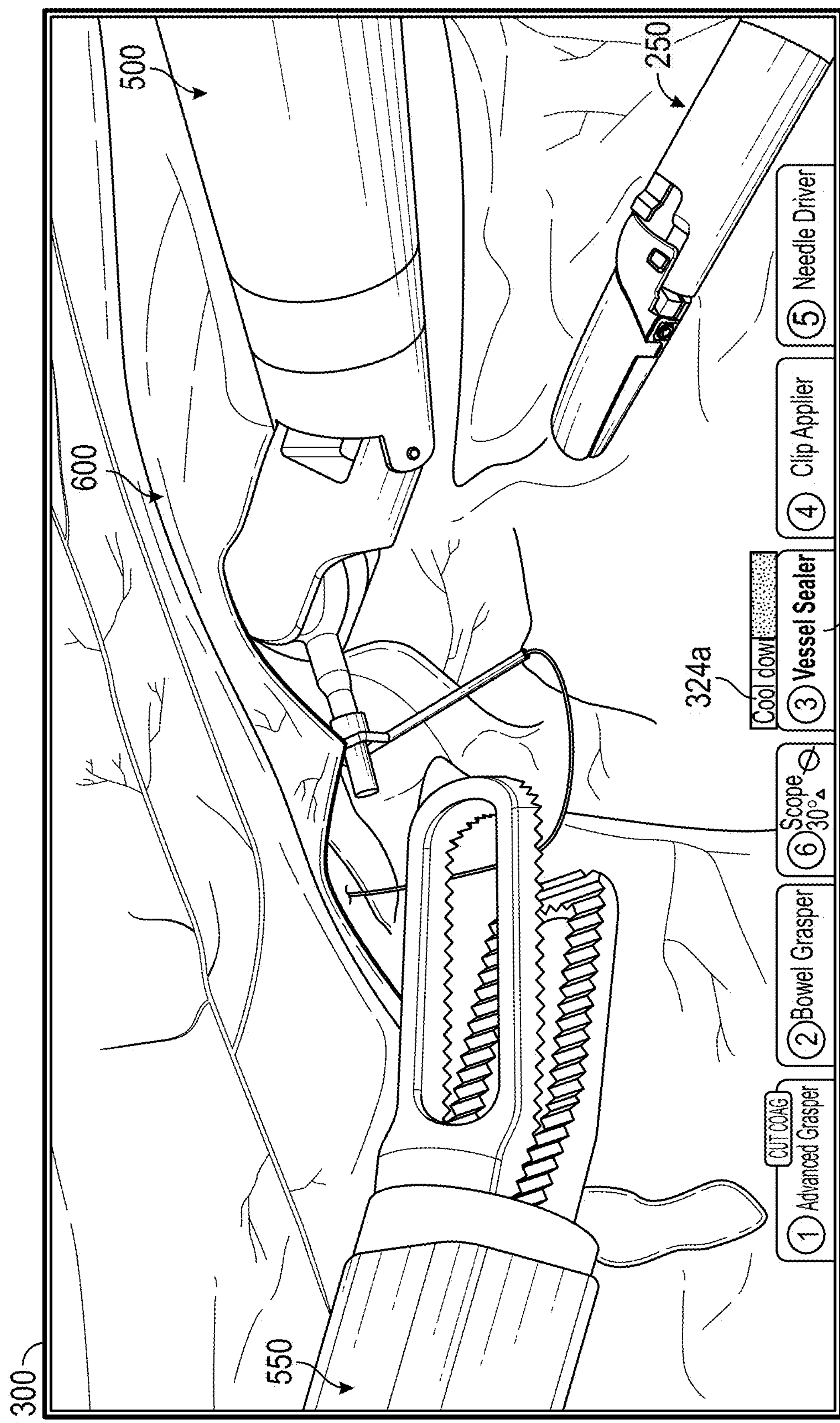

300
500
250
600
550
324a
320
Cool dow
CUT COAG
1 Advanced Grasper
2 Bowel Grasper
6 Scope 30°
3 Vessel Sealer
4 Clip Applier
5 Needle Driver

FIG. 26A

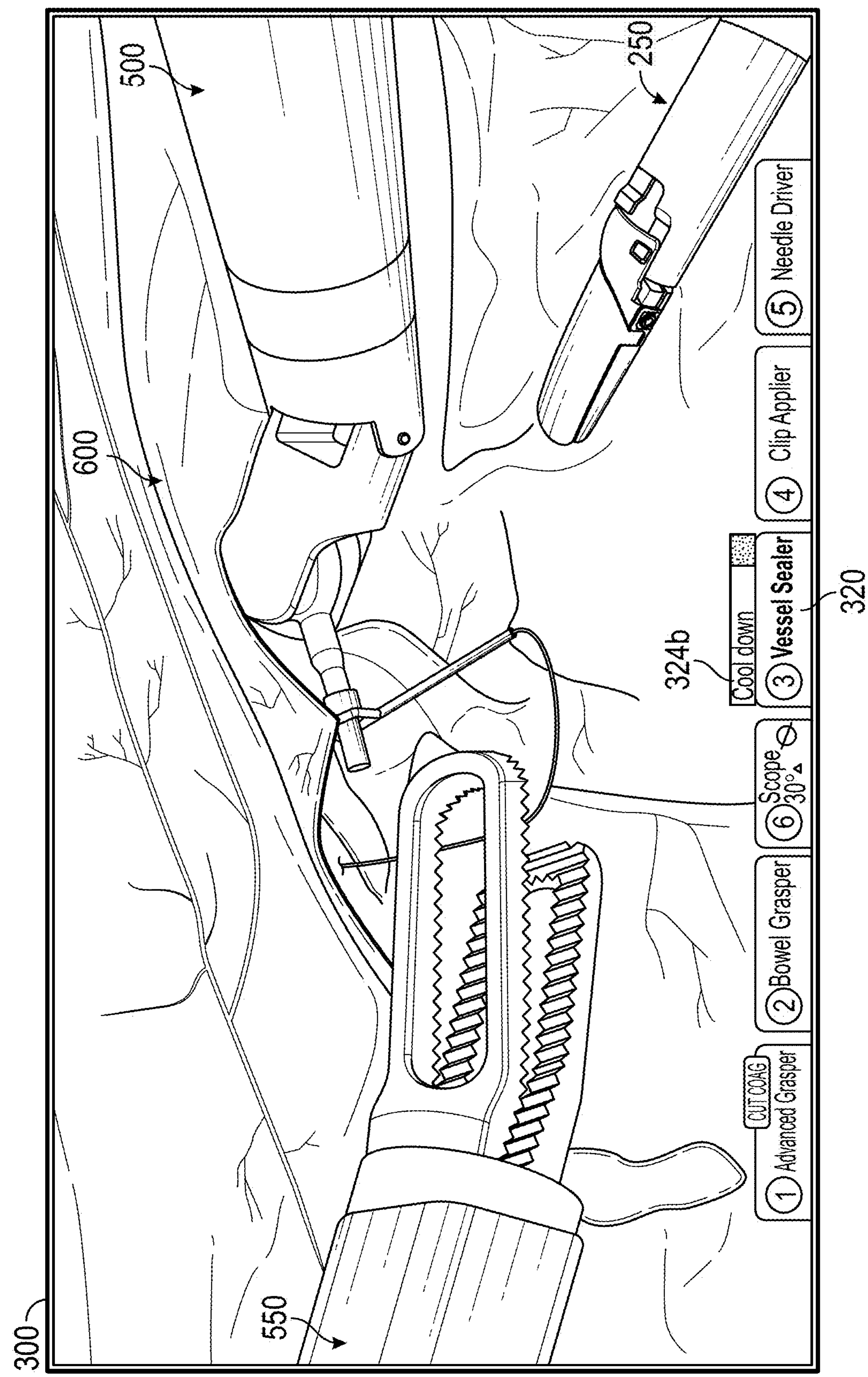

300
500
250
600
324b
Cool down
3 Vessel Sealer
320
4 Clip Applier
5 Needle Driver
6 Scope 30°
2 Bowel Grasper
CUT COAG
1 Advanced Grasper
550

FIG. 26B

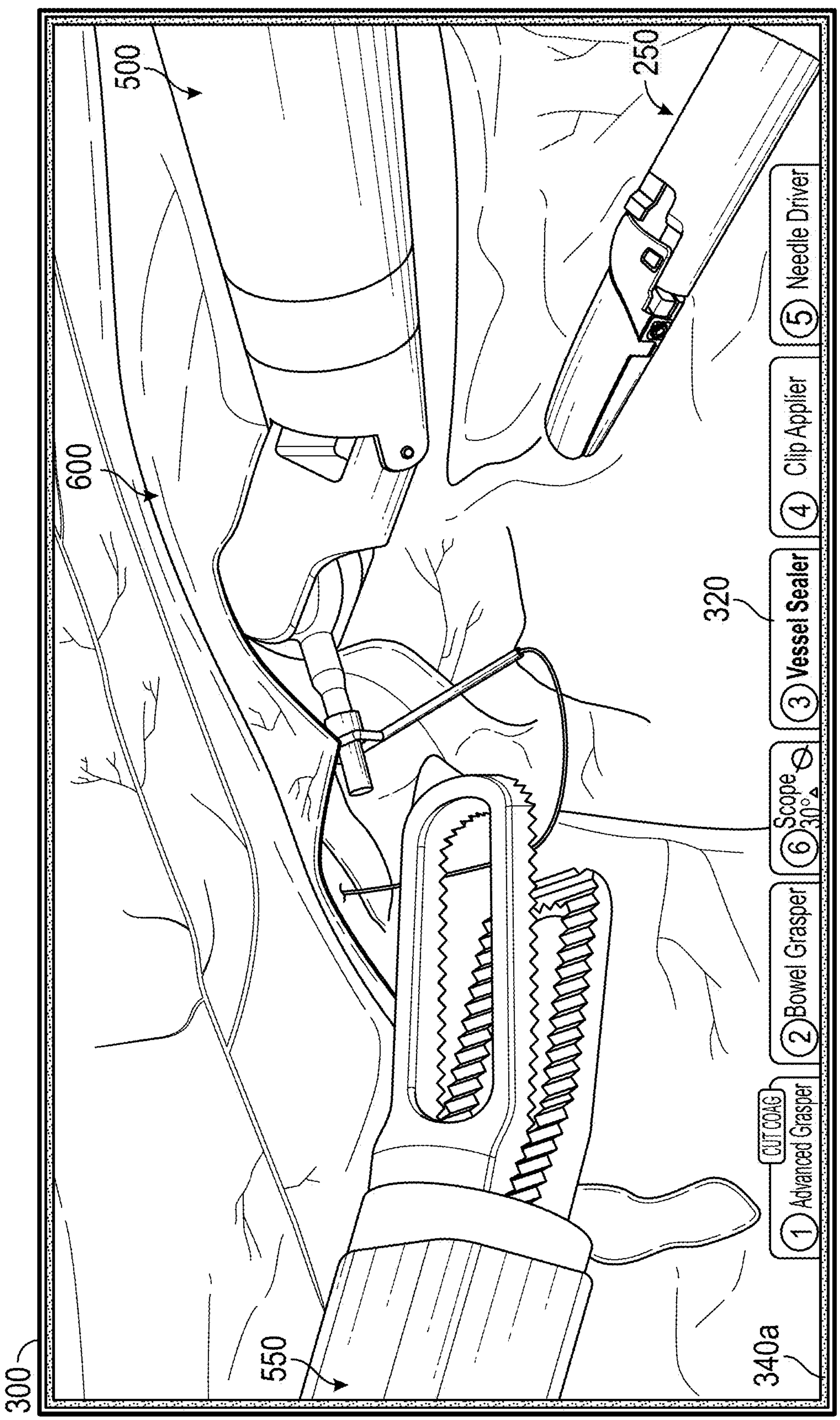

500
250
600
320
550
300
340a
CUT COAG
1 Advanced Grasper
2 Bowel Grasper
6 Scope 30°
3 Vessel Sealer
4 Clip Applier
5 Needle Driver

FIG. 27A

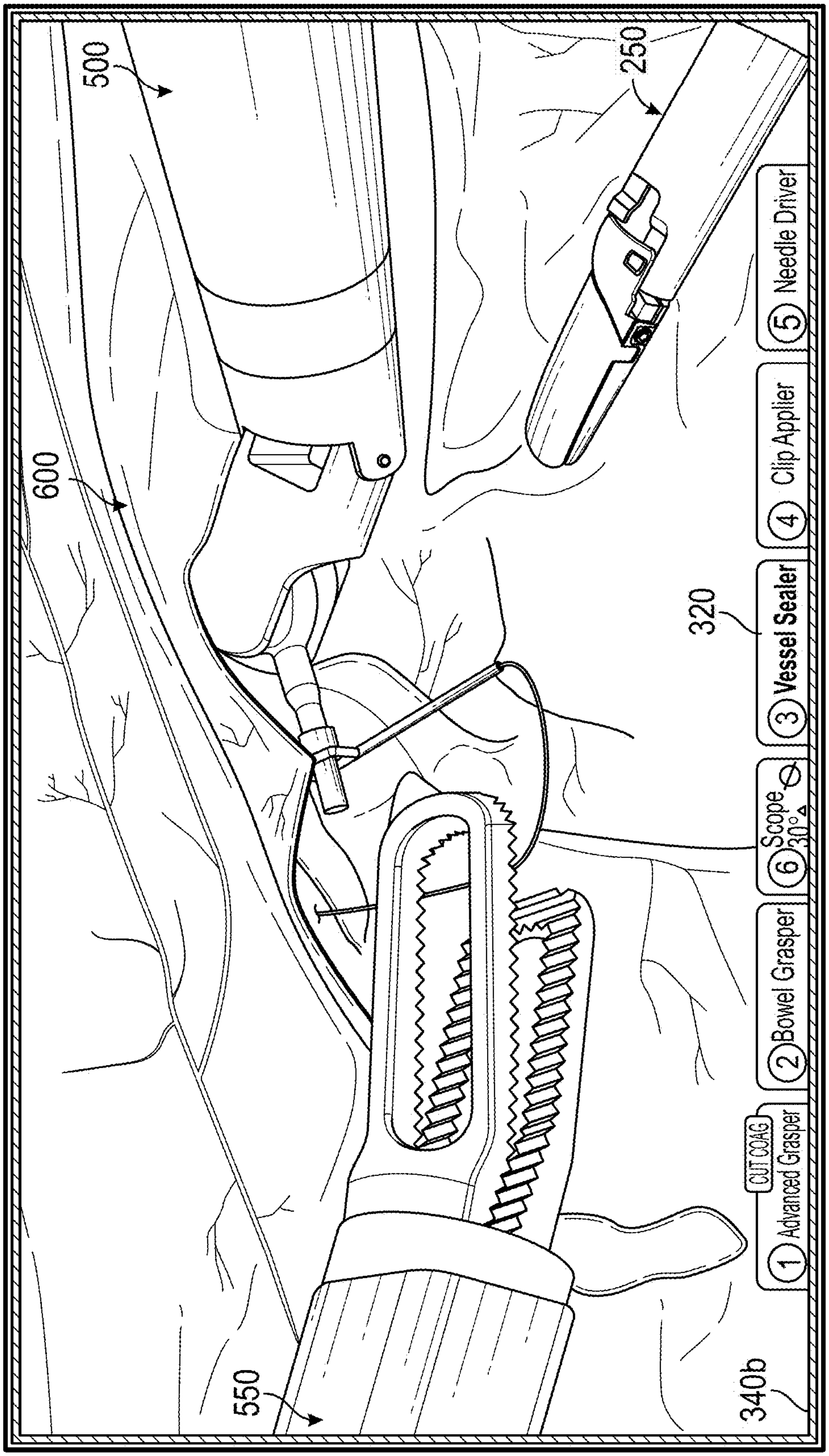

500
250
600
320
550
340b
CUT COAG
1 Advanced Grasper
2 Bowel Grasper
6 Scope 30°
3 Vessel Sealer
4 Clip Applier
5 Needle Driver

FIG. 27B

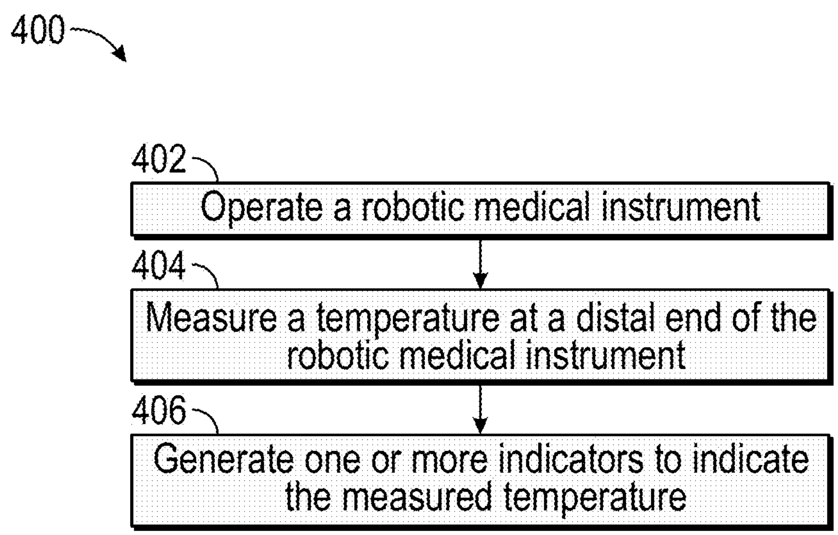

400
402
Operate a robotic medical instrument
404
Measure a temperature at a distal end of the robotic medical instrument
406
Generate one or more indicators to indicate the measured temperature

FIG. 28

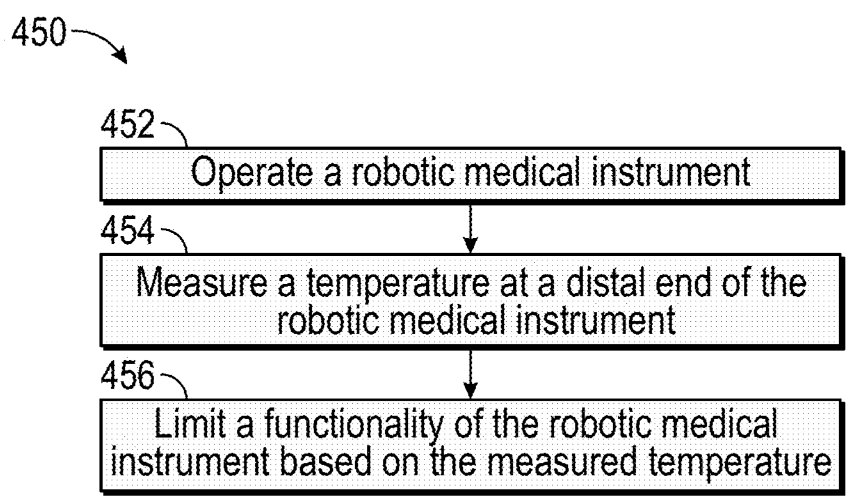

450
452
Operate a robotic medical instrument
454
Measure a temperature at a distal end of the robotic medical instrument
456
Limit a functionality of the robotic medical instrument based on the measured temperature

FIG. 29

SYSTEMS AND METHODS OF COMMUNICATING THERMAL INFORMATION FOR SURGICAL ROBOTIC DEVICES

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims the benefit of U.S. Provisional Application No. 62/994,178, filed Mar. 24, 2020, which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] This application is directed to robotic medical systems, and more particularly to heat indicators configured for use with robotic medical systems.

BACKGROUND

[0003] Medical procedures, such as laparoscopy or endoscopy, may involve accessing and visualizing an internal region of a patient. In a laparoscopic procedure, for example, a medical instrument can be inserted into an internal region through a laparoscopic access port. Robotically-enabled medical system can be used to perform such medical procedures. The robotically-enabled medical systems may include several robotic components, including, for example, robotic arms, robotic instrument manipulators, and robotic medical instruments, such as robotically controllable laparoscopes or endoscopes. The robotically-enabled medical systems can be controlled using a user console that may include one or more hand operated inputs as well as one or more foot operated inputs.

SUMMARY

[0004] The systems, methods and devices of this disclosure each have several innovative aspects, no single one of which is solely responsible for the desirable attributes disclosed herein.

[0005] In one aspect, a robotic medical system is provided. The robotic medical system can include a medical instrument including a distal end configured to be inserted into a patient and apply heat to tissue within the patient. The robotic medical system can further include a robotic manipulator engaged with the medical instrument and configured to operate the medical instrument. The robotic medical system can also include a temperature sensor configured to take one or more temperature readings of the medical instrument. The robotic medical system can include a viewer configured to display an image of the medical instrument and an image overlay conveying information indicative of a temperature of the medical instrument. The information conveyed by the image overlay can be based on the one or more temperature readings taken by the temperature sensor. In some configurations, the image overlay can be displayed over at least a portion of the image of the medical instrument. In some configurations, the image overlay is displayed over at least the distal end of the medical instrument of the image.

[0006] In some configurations, the medical instrument further includes a wrist. The image overlay can be displayed over at least the wrist of the medical instrument of the image. The image overlay can be displayed around at least a portion of the image of the medical instrument. The image overlay can be displayed around a second image overlay associated with the medical instrument.

[0007] The second image overlay can convey a state or an identity of the medical instrument. The image overlay can include a temperature meter indicating a temperature of the medical instrument.

[0008] The image overlay can be capable of displaying multiple colors. The multiple colors can include a first color indicating that the medical instrument is heated and a second color indicating that the medical instrument is cooled. The image overlay can display multiple colors that continually transition from the first color to the second color. The image overlay can display the first color until the medical instrument reaches a temperature threshold. The image overlay can display the second color once the medical instrument reaches the temperature threshold. In some configurations, the image overlay can include a number indicating the temperature of the medical instrument. The image overlay can include a time until the medical instrument reaches a temperature threshold.

[0009] In some configurations, the viewer is on a physician console. In some configurations, the viewer is on a tower. In some configurations, the viewer is on the medical instrument.

[0010] In some configurations, the information can be based on a direct measurement of temperature of the distal end of the medical instrument. In some configurations, the medical instrument can include a wrist. The information can be based on a direct measurement of temperature of the wrist of the medical instrument. The image overlay can convey information based on known characteristics of the medical instrument including one or more of a firing time, a thermal decay constant, and an external body temperature. In some configurations, the temperature sensor is located within the medical instrument.

[0011] In another aspect, a method of controlling a robotic medical instrument can be provided. The method can include operating the robotic medical instrument with a robotic manipulator engaged with the robotic medical instrument. The method can further include measuring a temperature at a distal end of the robotic medical instrument. The method can further include limiting a functionality of the robotic medical instrument based on the measured temperature.

[0012] In some configurations, the method can further include displaying an image of the robotic medical instrument and an image overlay that conveys information regarding the measured temperature. The functionality can be limited until the measured temperature falls below a temperature threshold. In some configurations, limiting the functionality can include limiting a speed of the robotic medical instrument. In some configurations, limiting the functionality can include preventing actuation of the robotic medical instrument. In some configurations, the method can further include generating one or more of a visual, audible, or haptic alarm to indicate the measured temperature. The alarm can indicate the temperature is above a temperature threshold.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] 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.

[0014] FIG. **1** illustrates an embodiment of a cart-based robotic system arranged for diagnostic and/or therapeutic bronchoscopy.

[0015] FIG. **2** depicts further aspects of the robotic system of FIG. **1**.

[0016] FIG. **3** illustrates an embodiment of the robotic system of FIG. **1** arranged for ureteroscopy.

[0017] FIG. **4** illustrates an embodiment of the robotic system of FIG. **1** arranged for a vascular procedure.

[0018] FIG. **5** illustrates an embodiment of a table-based robotic system arranged for a bronchoscopic procedure.

[0019] FIG. **6** provides an alternative view of the robotic system of FIG. **5**.

[0020] FIG. **7** illustrates an example system configured to stow robotic arm(s).

[0021] FIG. **8** illustrates an embodiment of a table-based robotic system configured for a ureteroscopic procedure.

[0022] FIG. **9** illustrates an embodiment of a table-based robotic system configured for a laparoscopic procedure.

[0023] FIG. **10** illustrates an embodiment of the table-based robotic system of FIGS. **5-9** with pitch or tilt adjustment.

[0024] 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**.

[0025] FIG. **12** illustrates an alternative embodiment of a table-based robotic system.

[0026] FIG. **13** illustrates an end view of the table-based robotic system of FIG. **12**.

[0027] FIG. **14** illustrates an end view of a table-based robotic system with robotic arms attached thereto.

[0028] FIG. **15** illustrates an exemplary instrument driver.

[0029] FIG. **16** illustrates an exemplary medical instrument with a paired instrument driver.

[0030] 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.

[0031] FIG. **18** illustrates an instrument having an instrument-based insertion architecture.

[0032] FIG. **19** illustrates an exemplary controller.

[0033] 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.

[0034] FIG. **21**A illustrates a first example of a robotic system that includes one or more indicators.

[0035] FIG. **21**B illustrates a second example of a robotic system that includes one or more indicators.

[0036] FIG. **22** illustrates a perspective view of a distal portion of a medical instrument configured to provide resistive heating.

[0037] FIGS. **23**A, **23**B, **24**A, and **24**B illustrate examples of a viewer that includes one or more heat indicators over a representation of a distal portion of a medical instrument.

[0038] FIGS. **25**A, **25**B, **26**A, and **26**B illustrate examples of a viewer that includes one or more indicators regarding heat for a medical instrument.

[0039] FIGS. **27**A and **27**B illustrate examples of a viewer that includes one or more heat indicators around a perimeter of the viewer.

[0040] FIG. **28** is a flow chart depicting an example method for implementing indicators regarding heat for a robotic medical system.

[0041] FIG. **29** is a flow chart depicting an example method for controlling a robotic medical instrument.

DETAILED DESCRIPTION

1. Overview

[0042] 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 endoscopic procedures, the system may be capable of performing bronchoscopy, ureteroscopy, gastroscopy, etc.

[0043] 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.

[0044] 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.

[0045] 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. 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.

[0046] 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.

[0047] 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 independently of each other.

[0048] 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.

[0049] 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.

[0050] 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.

[0051] 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 the tower **30**. In some embodiments, irrigation and aspiration capabilities may be delivered directly to the endoscope **13** through separate cable(s).

[0052] 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**.

[0053] The tower **30** may also include support equipment for the sensors deployed throughout the robotic system **10**. For example, the tower **30** may include optoelectronics 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 optoelectronics 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.

[0054] 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 the system **10** are generally designed to provide both robotic controls as well as preoperative 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 the system **10**, as well as to 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**.

[0055] 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 **11**, the support for controls, optics, fluidics, and/or navigation may be provided through a separate cable.

[0056] FIG. **2** provides a detailed illustration of an embodiment of the cart **11** 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**.

[0057] 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 **17** 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 the robotic arms **12** to be angled in a variety of configurations.

[0058] 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 the 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.

[0059] 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**.

[0060] 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 **12**. Each of the robotic arms **12** may 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. Having redundant degrees of freedom allows 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.

[0061] The cart base **15** balances the weight of the column **14**, carriage **17**, and robotic 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 **11**. For example, the cart base **15** includes rollable wheel-shaped casters **25** that allow for the cart **11** 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.

[0062] Positioned at the vertical end of the 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 preoperative and intraoperative data. Potential preoperative data on the touchscreen **26** may include preoperative plans, navigation and mapping data derived from preoperative computerized tomography (CT) scans, and/or notes from preoperative patient interviews. Intraoperative 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 **16** from the side of the column **14** opposite the 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 the cart **11**.

[0063] 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.

[0064] 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**.

[0065] FIG. **4** illustrates an embodiment of a robotically-enabled system **10** 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.

[0066] 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 bronchoscopic 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 the table **38**.

[0067] 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 independently of the other carriages. While the 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 **36** 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.

[0068] The robotic arms **39** may be mounted on the carriages **43** 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 the table **38** (as shown in FIG. **6**), on opposite sides of the table **38** (as shown in FIG. **9**), or on adjacent sides of the table **38** (not shown).

[0069] The column **37** structurally provides support for the table **38**, and a path for vertical translation of the carriages **43**. Internally, the column **37** may be equipped with lead screws for guiding vertical translation of the carriages, and motors to mechanize the translation of the carriages **43** based the lead screws. The column **37** may also convey power and control signals to the carriages **43** and the robotic arms **39** mounted thereon.

[0070] The table base **46** serves a similar function as the cart base **15** in the 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.

[0071] With continued reference to FIG. **6**, the system **36** may also include a tower (not shown) that divides the functionality of the system **36** between the table and the 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 the 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 **46** for potential stowage of the robotic arms **39**. 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 preoperative 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.

[0072] 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 the 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 robotic 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.

[0073] FIG. **8** illustrates an embodiment of a robotically-enabled table-based system configured for a ureteroscopic 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.

[0074] 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.

[0075] 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 robotic arms **39** maintain the same planar relationship with the table **38**. To accommodate steeper angles, the column **37** may also include telescoping portions **60** that allow vertical extension of the column **37** to keep the table **38** from touching the floor or colliding with the table base **46**.

[0076] 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.

[0077] 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 upper 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.

[0078] 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**.

[0079] 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.

[0080] 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**.

[0081] 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.

[0082] 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**.

[0083] 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.

[0084] 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.

[0085] The end effectors of the system's robotic arms may comprise (i) an instrument driver (alternatively referred to as "instrument drive mechanism" or "instrument device manipulator") that incorporates 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.

[0086] FIG. **15** illustrates an example instrument driver. Positioned at the distal end of a robotic arm, instrument driver **62** comprises 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 independently 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.

[0087] 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 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.

[0088] 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 the 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 the drive outputs **74** to the 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**.

[0089] 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 bending section that may be articulated and bent based on torque received from the drive outputs **74** of the instrument driver **75**.

[0090] Torque from the instrument driver **75** is transmitted down the elongated shaft **71** using tendons along the elongated 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 the distal end of the elongated shaft **71**, where tension from the tendon causes the grasper to close.

[0091] 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 bending section, torque exerted on the drive inputs **73** would be transmitted down the tendons, causing the softer, bending section (sometimes referred to as the articulable section or region) to bend or articulate. Along the non-bending 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 therebetween 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 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.

[0092] In endoscopy, the elongated shaft **71** houses a number of components to assist with the robotic procedure. The shaft **71** may comprise 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 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 **71**.

[0093] 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.

[0094] 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 **71**. 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 **71** during an endoscopic procedure.

[0095] 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 **80**. 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 that 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**.

[0096] 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, the instrument shaft **88** extends from the center of the 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**.

[0097] 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.

[0098] 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**.

[0099] 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.

[0100] 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.

[0101] 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.

[0102] 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.

[0103] 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**.

[0104] 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.

[0105] 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.

[0106] 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 preoperative 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 preoperative 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.

[0107] 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 **11** shown in FIGS. **1-4**, the beds shown in FIGS. **5-14**, etc.

[0108] 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).

[0109] The various input data **91-94** are now described in greater detail. Preoperative mapping may be accomplished through the use of the collection of low dose CT scans. Preoperative 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.

[0110] In some embodiments, the instrument may be equipped with a camera to provide vision data (or image data) **92**. The localization module **95** may process the vision data **92** to enable one or more vision-based (or image-based) location tracking modules or features. For example, the preoperative model data **91** 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. Intraoperatively, 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.

[0111] 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.

[0112] 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.

[0113] 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 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 intraoperatively "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 preoperative 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.

[0114] 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 preoperative calibration. Intraoperatively, 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.

[0115] 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.

[0116] 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**.

[0117] 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. Indicators for Robotic Medical Devices

[0118] Robotic medical systems, such as those described above with reference to FIGS. **1-20** and others, can include one or more indicators or indicator devices.

[0119] For example, a robotic medical system can include one or more indicators (such as visual, audible, or haptic indicators, among others) which can be configured to communicate or provide information about the system to a user or other medical personnel in an operating room.

[0120] Such indicators can be particularly useful for robotic medical systems that include a plurality of robotically controlled moveable components. In particular, the robotic medical systems can include medical instruments that change in temperature. The indicators can be configured to provide various functions as will be described below, including, for example, providing thermal information regarding the robotic system and/or components thereof. In some examples, other information may also be conveyed, such as information related to the identity or type of the medical instrument or related to a state of the medical instrument.

[0121] The indicators can be configured to provide or communicate thermal information about the system and/or its components. In some examples, the indicators can be configured to provide information related to a temperature state of the system or component(s) thereof. For example, an indicator can communicate that one or more components of the system is at an increased temperature. The indicator can serve to notify users in the vicinity of the system about the temperature of a component, so that the user knows to wait before moving the component or to wait before delivering additional energy to the component. This can advantageously prevent contact at unacceptable temperatures between the component and the patient, user, or other parts of the system. This can increase safety for those using these components delivering heat or energy. As will be described in more detail below, the indicators can advantageously be communicated in a number of ways and positioned in various components of the robotic system.

[0122] FIGS. **21**A and **21**B illustrate examples of robotic systems **200** that may include one or more indicators. As shown in FIG. **21**A, a user **202** may utilize or interact with the robotic system **200**, which can include, among other things, a tower console **204** and a medical instrument **250** attached to and controlled by one or more robotic arms (not shown). As shown in FIG. **21**B, the robotic system **200** can include a viewer **206** and a medical instrument **250** attached to and controlled by one or more robotic arms (not shown). In some embodiments, the viewer **206** can be part of a surgeon or physician console. In some embodiments, the viewer **206** can be on a tower. In some embodiments, the viewer **206** can be on or part of the medical instrument **250**. The medical instrument **250** can include a distal end configured to be inserted into a patient and apply heat to tissue within the patient. The medical instrument **250** can be controlled by a robotic manipulator (not shown) which is engaged with the medical instrument **250** and which can be configured to operate the medical instrument **250**. The system **200** can be similar in some respects to the systems **10**, **100**, **140**A described above. For example, with reference to FIGS. **1-4**, the one or more robotic arms **12** of system **10** can engage with and control the medical instrument **250**.

[0123] The robotic system **200** can include a temperature sensor configured to take one or more temperature readings of the medical instrument **250**. The temperature sensor can be positioned in various places in the system **200**. In some examples, the temperature sensor can be located within or near the medical instrument **250**. In some examples, the temperature sensor can be configured to take a direct measurement of temperature of the distal end of the medical instrument **250**. The distal end can include, for example, one or more of an end effector, jaws, a wrist, and/or a portion of a shaft of the medical instrument **250**. In an example where the medical instrument **250** includes a wrist, the temperature measurement can be based on a direct measurement of the temperature of the wrist of the medical instrument **250**. In some examples, the temperature measurement can be based on a direct measurement of the temperature of various parts of the medical instrument **230**, such as the end effector, the jaws, and/or the shaft.

[0124] The temperature data from the temperature sensor can be received by one or more components of the robotic system **200**, such as, for example, the tower console **204**, the viewer **206** and/or other systems (s) in communication with the robotic system **200**. For example, the tower console **204** or viewer **206** can include a screen or display configured to display one or more indicators. The one or more indicators can convey information related to a temperature of the medical instrument **250**, based on the one or more temperature readings taken by the temperature sensor. The viewer **206** can be at various places within the robotic system **200**. In some examples, the viewer **206** can be a screen or a display that is part of a physician/user console, a tower, a cart, and/or the medical instrument **250** itself.

[0125] As discussed below, the display can include a rendering of an image or representation (graphical or otherwise) of the medical instrument **250**. The display can also include an image overlay over the image of the medical instrument **250**. The display can also include an indicator in the form of an image overlay that conveys information based on the one or more temperature readings taken by the temperature sensor(s).

[0126] The medical instrument **250** may comprise a number of medical instruments. For example, the medical instrument **250** can be used for a variety of surgical tasks such as dissection, cutting, ligation, and/or sealing. The medical instrument **250** can perform these functions by applying thermal energy to tissue. The medical instrument **250** can includes jaws, which are heated by electrical current, and in turn deliver thermal energy to the tissue. Energy devices that act in this manner include monopolar electrocautery instruments and advanced energy instruments, such as vessel sealers. A common issue with these types of medical instruments is that there is a typically a cool-down period associated with each firing of the medical instrument, as the end effectors of the instrument need to fully disperse the generated heat before the next contact with tissue. This can limit the speed or frequency with which the medical instrument can be used, since the user may have to wait for the medical instrument to cool before attempting the next firing. This can also lead to serious consequences for the patient, including inadvertent injury to adjacent structures or vessel rupture if the medical instrument is moved incorrectly or inadvertently before the instrument is adequately cooled. The indicators described herein are advantageously provided to alert a surgeon of when a medical instrument **250** has been adequately cooled.

[0127] FIG. **22** illustrates a top perspective view of a distal portion of one embodiment of a medical instrument **250** capable of resistive heating. The medical instrument **250** can include a multi-functional grasper and cutter including a shaft **252**, a wrist **230**, and an end effector including an upper jaw **282** and a lower jaw **284**. At least one of the upper jaw **282** and lower jaw **284** includes a pad (e.g., upper pad **286**, lower pad **288**) formed in part of a ferrous material that allows resistive heat to be generated. In this example, the instrument **250** is capable of multiple functions, including sealing and cutting, simply by modifying the temperature of the upper and lower pads **286**, **288**, thereby advantageously reducing the need for a physical cutting blade. In an alternative example, a physical cutting blade (not shown) can also be provided with the upper and lower pads **286**, **288** if desired. The elongated shaft **252** can be coupled to an instrument handle (not shown). The wrist **230** can move in multi-degrees of freedom. For example, in the present example, the wrist **230** is capable of moving in both the pitch and yaw dimensions of movement.

[0128] The end effector includes an upper jaw **282** and a lower jaw **284** configured to, among other things, grasp tissue. The upper jaw **282** has an upper pad **286** and a conductive line **292** adjacent to the upper pad **286**. Likewise, the lower jaw **284** has a lower pad **288** and a conductive line **294** adjacent to the lower pad **288**. In some examples, the upper pad **286** and lower pad **288** can be formed entirely of a ferrous material. In other examples, the upper pad **286** and the lower pad **288** can be formed of a non-ferrous material that is coated at least in part by a ferrous material. In some examples, the conductive lines **292**, **294** can form a loop or coil that extends substantially around a perimeter of the upper and lower pads **286**, **288**. In other examples, the conductive lines **292**, **294** are not in the form of a loop or coil, but is simply a straight, linear, wavy, or zig-zagged line that extends adjacent the pads **286**, **288**.

[0129] Current can be delivered through the conductive lines **292**, **294** from a power source (not shown) to generate heat within the upper and lower pads **286**, **288**. Current is delivered through the conductive lines **292**, **294**, thereby generating heat in the upper and lower pads **286**, **288** via magnetic induction. While the instrument described is heated at the end effector or jaws, medical instruments can be heated in multiple areas, including the multi degree of freedom wrist **230** or shaft **252**. Advantageously, the heat can be monitored and modulated via a processor or controller, as described above, thereby allowing for different functions, such as cauterization, hemostasis or cutting. One skilled in the art will appreciate that the instrument embodiment in FIG. **22** is just one example of a type of instrument capable of generating heat via resistive heating, and that there are other ways for instruments to generate heat, such as by electrosurgery and laser technology. In some embodiments, heat can be generated on and around an instrument (e.g., around nearby tissue) via harmonic oscillations or vibrations. In some embodiments, a harmonic instrument can vibrate, thereby causing frictional heat to be generated between the instrument and adjacent tissue.

[0130] To avoid risk of injury to a patient, the medical instrument **250** after heating should be cooled prior to engaging tissue again or prior to firing the medical instrument **250** again. In some examples, the medical instrument **250** should be cooled to a temperature, such as approximately 75, 70, 65, 60, 55, 50, 45, 40, 35 or 30 degrees Celsius. In some examples, a certain temperature and/or time between firings can be set as threshold for subsequent activation of the medical instrument.

[0131] As previously described, the medical instrument **250** can include a temperature sensor. The temperature information can be captured by direct measurement of the temperature of the end effector of the medical instrument. The temperature can also be determined based on inputs, such as known characteristics of the medical instrument, including, e.g., firing time, thermal decay constant(s), external or intracorporeal body temperature, or combinations thereof. In some embodiments, a sensor (e.g., an infrared, CCD, CMOS, or the like) can be coupled to one of the tools (e.g., the laparoscope). In an embodiment in which the sensor (e.g., infrared sensor) is attached to a laparoscope, the laparoscope is capable of sensing temperature of a multiple of sites within the view of the camera.

[0132] The system can use indicators to inform a user, such as a clinician, when the medical instrument is or will be available for safe use. Note that while the indicator(s) can be used and illustrated with respect to the end effector of the medical instrument, the indicator(s) can also be used and illustrated with respect to the wrist, shaft, or anywhere else on the instrument that may be heated. The indicators can include be communicated in a variety of ways, such as visually, audibly, haptically, or any combination thereof. In some examples, the indicators can be communicated visually and positioned on a graphical user interface or on the instrument itself. Other locations for the indicators are also possible, such as on a patient table or bed, a cart, or one or more robotic arms.

[0133] The illustrated positions of the indicators are provided by way of example, not limitation. Further, not all indicators need be included in all embodiments. For example, in some embodiments, one or more of the indicators may be omitted from the viewer **300**. Features and functionality of the visual indicators will be described in this section with reference to the example embodiments illustrated in FIGS. **23-27**. The illustrated embodiments are provided by way of example and illustration and are not intended to be limiting. Upon consideration of this disclosure, one of skill in the art will appreciate that other configurations and embodiments, which are within the scope of this disclosure for systems with indicators are possible. Further, several notable advantages of indicators configured to display thermal information for use with robotic medical systems will be described below. Not all of the described advantages need be provided by every embodiment, and the indicators may also provide advantages that are not described herein.

[0134] FIGS. **23**A and **23**B illustrate exemplary embodiments of a viewer **300** that may include one or more indicators. In the illustrated embodiment, as will be explained in further detail below, the viewer **300** can be configured to display, among other things, an image or representation of a medical instrument **250** with one or more indicators regarding a status of the medical instrument **250**, such as, e.g., a heat or temperature level of a distal portion of the medical instrument **250**. In the illustrated embodiment, the distal portion of the medical instrument **250** comprises a pair of jaws **282**, **284** configured to deliver heat and/or clamp together. In the illustrated embodiment, the indicators comprise visual indicators and take the form of a color-coded image overlay **310** on top of the jaws of the medical instrument **250**.

[0135] The viewer **300** can be configured to allow the user to view images of a treatment site **600** from one or more imaging devices (e.g., cameras) of the robotic system in order to facilitate control of the system to perform a robotic medical procedure. For example, a robotically-controllable endoscope of the robotic system can include a camera positioned at a distal tip thereof. The user can view an image from the camera of the endoscope in the viewer **300** in order to facilitate control of the endoscope and/or other components of the robotic medical system. As another example, the robotic system may include one or more cameras laparoscopically or endoscopically inserted into a patient. The user can view images from the inserted cameras in order to facilitate control of one or more additional robotically-controlled medical instruments, such as one or more additional laparoscopically inserted medical instruments, such as the medical instruments **250**. **500**, **550** as shown. The viewer **300** can comprise a screen for viewing the images from the one or more cameras. In some embodiments, the viewer **300** includes a stereographic or stereoscopic viewer.

[0136] With continued reference to FIGS. **23**A and **23**B, illustrated is an embodiment of a viewer **300** configured to display/render an image or representation of at least a portion of a medical instrument **250** alongside other tools or instruments **500**, **550** at a treatment site **600**. The viewer **300** can also display, for example, an indicator in the form of an image overlay **310** displayed over the image of the medical instrument **250**. Although the illustrated examples of FIGS. **23**A and **23**B show an image overlay **310** displayed over the representations of the jaws **282**, **284** of the medical instrument **250**, the image overlay **310** can be displayed over other portions of the representation of the medical instrument **250**, such as anywhere on the distal end of the medical instrument **250**. In addition to or alternatively, the image overlay **310** may be displayed over other parts of the representation of the medical instrument **250**, such as the representation of the wrist **230** or the representation of the shaft **252**.

[0137] In FIGS. **23**A and **23**B, the image overlay **310** is shown as a region of shading over the representations of the end effector **282**, **284**, which can correspond to different colors or patterns, such as flashing, to a user of the viewer **300**. This can be advantageous as the image overlay **310** is displayed over the representation of the portion of the medical instrument **250** of interest, as the jaws **282**, **284** of the medical instrument **250** are the portion of the medical instrument **250** that applies heat. This allows the information conveyed by the image overlay **310** to be displayed directly on the image or representation of the medical instrument for which it is related.

[0138] FIG. **23**A shows a first image overlay or indicator **310***a* of a first color or pattern and FIG. **23**B shows a second image overlay or indicator **310***b* of a second color or pattern. In some examples, the different colors or patterns of indicators **310***a*, **310***b* correspond to different temperatures of the medical instrument **250**. For example, an indicator **310***a*, **310***b* of a first color (e.g., green) can indicate the temperature is cool or below a certain temperature threshold, while an indicator **310***a*, **310***b* of a second color (e.g., red) different from the first color can indicate the temperature is hot or above a certain temperature threshold. In some examples, a pattern of flashing, such as variations in frequency, can indicate a temperature of the medical instrument **230**. In some examples, the opacity of the indicator **310***a*, **310***b* can indicate a temperature of the medical instrument **250**. For example, a more opaque color of the indicator **310***a*, **310***b* can indicate the temperature is high, while a lower opacity of the color of the indicator **310***a*, **310***b* can indicate the temperature is low. The temperature may be considered high when it is above a certain threshold. The temperature may be considered low when it is below a certain threshold. The threshold can be based on a user input, a user preference, the patient, the type of procedure, the type of instrument, the type of functionality being performed by the medical instrument, or any other number of factors.

[0139] As noted above, the system can include one or more controllers configured to be operated by the user in order to provide control of various aspects or components of the robotic medical system. The one or more controllers can include gimbals or pedals. Examples of such controllers **182** have been described above with reference to FIG. **19**. In related aspects, one or more of the controllers can be configured to selectively couple and control medical instruments. The one or more controllers can be configured to allow a user to fire or activate a thermal/heat (e.g., cauterizing, sealing, etc.) feature of a medical instrument. The controllers can be configured to perform or activate different functions of the instruments (e.g., cut, grasp, coagulate, seal, etc.). Additional features and functionality of the controllers **182** have been described above with reference to FIG. **19**, which illustrates one embodiment thereof. Other embodiments of handheld controllers are also possible, including controllers that include keyboards, touchpads, buttons, joysticks, mice, etc.

[0140] As described above, the system **200** may be configured to control more than one medical instruments as well as more than one modalities of each of the medical instruments. For example, as shown in FIGS. **23**A-**23**B, there may be a first medical instrument **250**, a second medical instrument **500**, and a third medical instrument **550** at a treatment site **600**. FIGS. **23**A-**23**B also show a menu or series of tabs, each associated with the different medical instruments or with the various modalities of the medical instruments. Each medical instrument or particular modality of the medical instrument can have a tab or an associated image overlay that indicates the state, type, or identity of the medical instrument (e.g. "Vessel Sealer"). For example, a series of tabs are shown in FIGS. **23**A-**23**B, including the "Vessel Sealer" tab **320** which is associated with the medical instrument **250**.

[0141] In some examples, the menu or series of tabs may be image overlays positioned on an image or representation of a treatment site **600** within a patient of the viewer **300**. The associated image overlay or tab of a certain medical instrument can be bolded, highlighted, enlarged, or otherwise differentiated when a user input (e.g. controller **182**) is selectively coupled to the associated medical instrument. For example, the "Vessel Sealer" tab **320** can be bolded when the medical instrument **250** is selectively coupled to a user input. In some examples, the tab associated with the vessel sealer may be highlighted, bolded, enlarged, or otherwise differentiated to indicate the vessel sealer instrument is active, actuated, in motion, or heated. In some examples, each of the series of tabs may be selectable or clickable, where selecting or clicking a particular tab, the associated medical device can be selectively coupled to a user input. The menu or series of tab can be positioned anywhere on the viewer **300**. As shown in the illustrated example in FIGS. **23**A-**23**B, the menu or series of tab can be positioned on the bottom side of the viewer **300**.

[0142] In FIGS. **24**A-**24**B, the viewer **300** is shown including an image of a medical instrument **250**. The image overlay **310** may be a region or an outline of shading around a portion of the representation of the medical device **250**. Similar to FIGS. **23**A-**23**B, the image overlay **310** may have different shading or patterns (such as described above) to indicate different temperatures of the medical instrument **250**. As shown in FIG. **24**A, a first image overlay **310***a* is positioned around the representation of the jaws **282**, **284**, the wrist **230**, and the shaft **252** to indicate a first temperature. Similarly, in FIG. **24**B, a second image overlay **310***b* of a different color or pattern is positioned around the representation of the jaws **282**, **284**, the wrist **230**, and the shaft **252** to indicate a second temperature, different from the first temperature.

[0143] In FIGS. **25**A-**25**B, the viewer **300** is shown including an image or representation of the medical instrument **250**. The image overlay **322** may be a region or outline of shading around a second image overlay **320** associated with the medical instrument **250**. In some examples, the image overlay **322** can be positioned over the second image overlay **320** associated with the medical instrument **250**. The image overlay **322** can be positioned around or over the associated image overlay **320** to indicate a temperature of the associated medical instrument. As shown in FIG. **25**A, a first image overlay **322***a* is positioned partially around a perimeter of the associated image overlay **320** to indicate a first temperature. Similarly, in FIG. **25**B, a second image overlay **322***b* of a different color or pattern is positioned around a perimeter of the associated image overlay **320** to indicate a second temperature, different from the first temperature. This position of the image overlay **322** can be advantageous as the second overlay **320** can remain in a constant position on the viewer **300**, regardless of the position of the medical instrument **250**. This can allow an observer to quickly determine the temperature of the device without first locating where the device is positioned on the viewer **300**. This allows the information conveyed by the image overlay **322** to be communicated on other indicators associated with the medical instrument **250**.

[0144] As shown in FIGS. **26**A-**26**B, a combination of text and colors or shading can be used to indicate the temperature of the medical instrument **250**. In FIG. **26**A, the image overlay **322** is positioned on top of the second image overlay **320**. The image overlay **324***a* can be shown as a progress bar, where shading of the progress bar indicates how much of the cool down period remains or how high the temperature is of the medical instrument **250**. In FIG. **26**B, the image overlay **324***b* is shown with less shading in the progress bar, indicating the cool down period is nearly complete and the temperature is almost cooled down.

[0145] In some examples, the indicators can be displayed or communicated unassociated with the medical instrument. In FIGS. **27**A-**27**B, the viewer **300** is shown including an image **350** of the medical instrument **250**. The image overlay **340** may be a region of shading around the perimeter of the viewer **300**. In some examples, the image overlay **340** may be a region of shading of a partial perimeter (e.g. a single side, the top and bottom, the sides) of the viewer **300**. In some examples, such as shown in FIGS. **27**A-**27**B, the image overlay **340** may be a region of shading around the entire perimeter of the viewer **300**. This type of overlay may be advantageous as its increased size may increase the visibility of the image overlay **340** to a user observing the screen. This may allow an observer to determine the temperature of the medical device **250**, even when looking other parts of the viewer **300**, such as at other medical devices. In FIG. **27**A, the first image overlay **340***a* is positioned around the entire perimeter of the viewer **300** to indicate a first temperature of the medical instrument. In FIG. **27**B, the second image overlay **340***b* is positioned around the entire perimeter of the viewer **300** to indicate a second temperature of a medical instrument.

[0146] Furthermore, although only one indicator is shown in each of the illustrated embodiments below, other numbers of indicators are also possible. For example, the indicator **310** shown in FIGS. **23**A-**23**B, the indicator **322** shown in FIG. **25**A-**25**B, or the indicator **340** shown in FIGS. **27**A-**27**B can be shown simultaneously.

[0147] Furthermore, although visual indicators are displayed in these figures, other types of indicators can be used in combination with or in lieu of the visual indicators. For example, audio indicators can include various tones or volumes to indicate the temperature of the medical instrument. The audio indicators can be positioned in various positions in the system, such as at a tower console, a head-in viewers (2D or 3D), operating room monitors, console monitors, touchscreens, tower consoles, user input displays, or patient side interfaces.

[0148] Similarly, a haptic indicator may be used, which can include different patterns of vibration or resistance to indicate the temperature of the medical instrument. For example, an instrument handle, an instrument, or a user input (such as a gimbal, pedal, or controllers such as controller **182**) can vibrate when the temperature of the medical instrument has reached a certain threshold. In another example, the user input or medical instrument can provide resistance until the temperature of the medical instrument has reached a certain threshold. The user input can also include indicators related to the thermal information of the medical instrument. In some examples, while a user input is selectively coupled to a medical instrument **250** that is configured to deliver heat, the user input can be configured to provide haptic indicators to the user to indicate the medical instrument **250** is at or above a certain temperature. For example, the controller **182** can vibrate or provide a haptic pattern to indicate the temperature is above or below a threshold. The user input can also provide haptic resistance if the temperature is above a threshold, thus preventing the user from moving the coupled medical instrument until the temperature falls below a temperature threshold. The user input can provide haptic feedback that a medical instrument **250** is sufficiently cooled to move or engage tissue. The user input can also provide haptic feedback that the medical instrument is ready to or is not ready to be fired or heated.

[0149] The indicators described herein can be considered “dynamic” because, in some examples, the indicators can change based on a variety of factors, including, for example, a user input, a state of the robotic system, a state of a component of the robotic system (such as a state of a robotic arm, a state of a robotic medical instrument, etc.), and/or a type of medical procedure being performed, among other factors. In some examples, the system is configured to determine a state of the robotic system and adjust the dynamic indicators accordingly based on the determined state. In some examples, the indicators can be used to indicate when a medical instrument has changed from one state to another (e.g., from a first temperature to a second temperature or from a non-operational state to an operational state). Thus, in certain situations, the indicators on the viewer **300** may display in one way, and in different situations, the indicators on the viewer **300** may display in a different way. For example, the indicators on the viewer **300** can be displayed around the image of the medical instrument when the controllers **182** are selectively coupled to the medical instrument. This offers improved functionality and control over previous systems, which have generally relied on a user's expertise and judgement.

[0150] In some examples, the indicators can be visual indicators, such as image overlays, as described above. The visual indicator can also be on a viewer as described herein (e.g. the viewers **300** as shown in FIGS. **23**A-**23**B, **24**A-**24**B, **25**A-**25**B, **26**A-**26**B, or **27**A-**27**B). The image overlays can be positioned on an image of a medical instrument and/or an treatment site, which may be a live feed or a representative model or depiction. In some examples, the indicators can be other types of visual indicators (such as lights, screens, or other displays) that can communicate information to a user. Visual indicators can be, for example, in the form of direct lighting, up-lighting, back-lighting, LED panels, screens, or any combination thereof. In some embodiments, the visual indicators can be configured to change patterns (e.g., a blinking or flashing pattern) and/or change intensity or brightness.

[0151] The visual indicators can be positioned in various places. In some examples, the indicators can be displayed on viewers, which may be a display or screen for displaying text, images or other symbols. The viewers as described can be positioned on a number of locations, such as a head-in viewers (2D or 3D), operating room monitors, console monitors, touchscreens, tower consoles, user input displays, or patient side interfaces. In some examples, the visual indicators can be displayed directly on a medical instrument **250**, such as by a ring of light positioned on or within the medical instrument **250**. The indicators can be directly on the medical instrument **250**, such as the distal end, wrist **230**, or shaft **252** of the medical instrument **250**. The medical instrument **250** can also include a screen configured to displaying text or other symbols. The medical instrument **250** can include lights positioned on the medical instrument **250**. Further, a ring or light can be positioned in any number of locations in the robotic system, such as on a user input, a controller, a robotic arm, an instrument base, or a bed rail. Other visual indicators can include light emitting diodes, lasers, or moveable colored markers. For example, the medical instrument **250** may include an associated light, which may be positioned anywhere on the medical instrument **250**, such as the wrist **230** or distal shaft **252**. The associated light may be a ring light or a light positioned on a surface of the medical instrument **250**. The color or pattern of the light may indicate a temperature of the medical instrument **250**. In some examples, a viewer (such as viewers **300** as shown in FIGS. **23**A-**23**B, **24**A-**24**B, **25**A-**25**B, **26**A-**26**B, or **27**A-**27**B) may then display an image of a medical instrument **250** which includes a visual indicator directly on the medical instrument **250**.

[0152] Further, although only one viewer **300** is shown in each of the illustrated embodiments in FIGS. **23**A-**23**B, **24**A-**24**B, **25**A-**25**B, **26**A-**26**B, or **27**A-**27**B, other numbers of viewers are also possible. The indicators can be configured to update and display information contextually based on a variety of factors related to the robotic system as described. Different shading or cross-hatching has been used to illustrate different indicators that can be provided by the indicators (e.g., indications of different colors).

[0153] The indicators can convey information related to the temperature of the medical instrument in a variety of ways. The indicators can be capable of displaying multiple colors or patterns. In some examples, a first color or pattern can be used to indicate the medical instrument is heated and a second color or pattern can be used to indicate the medical instrument is cooled. In some examples, opacity, intensity, or brightness of the colors or patterns can also be used to indicate temperature. In some examples, the indicator can display multiple colors or patterns that continually transition from a first color or pattern to a second color or pattern. In some examples, the indicator can display a first color or pattern until the medical instrument reaches a temperature threshold and a second color or pattern reaches the temperature threshold.

[0154] In one example, the indicator can start with one color (e.g., red) and then continually change color until a safe color (e.g., green) is reached. In another example, the indicator can start with one color (e.g., red) and then only change to a safe color (e.g., green) when a desired temperature is reached. In addition, it is possible to add a temperature number (e.g., 70 degrees) adjacent to the visual indicators that can change.

[0155] In some examples, the indicator can include text (e.g. "cool down") to indicate the progress of the temperature of the medical instrument. For example, the indicator can include a temperature meter to indicate the temperature of the medical instrument. The indicator can also include a number indicating the temperature of the medical instrument. The indicator can include a time until the medical instrument is estimated to reach a temperature threshold. The indicator can also include a time that has elapsed since the medical instrument has been fired to provide resistive heat.

[0156] In addition, while the type of communication can be visual, audible, or haptic, these types of communications can also be combined. For example, an indicator can go from red to green, and upon reaching green, an audible signal is generated to the clinician or a corresponding haptic vibration can be generated in the medical instrument or controller.

[0157] The indicator may be communicated at various times. In some examples, the indicator can be communicated at all times. In some examples, the indicator may be communicated when a medical instrument is selectively engaged or coupled with a user input. In other examples, the indicator may be communicated when the medical instrument has been fired or activated to deliver heat. The indicator may be communicated when other instruments are activated. The indicator may be communicated when a temperature of a medical instrument is above, below, or is at a certain threshold. This threshold may comprise or otherwise relate to the threshold temperature at which the medical instrument is ready to activated or may be a different threshold.

[0158] Different types of indicators may be used together, e.g., simultaneously. For example, when a visual indicator is changed from one pattern or color to another pattern or color, it can be accompanied by an audio indicator or a change in audio indicator from a first tone to a second tone. In some examples, different types of visual indicators can be used, such as multiple image overlays or image overlay and lights.

[0159] FIG. **28** illustrates an example method **400** for implementing indicators on a robotic medical system as described herein. The method **400** begins at block **402**, which includes operating a robotic medical instrument. As described above, medical instruments can be engaged with and controlled by a robotic manipulator. As described above, the medical instrument can include a jaws a distal end, which can be heated by electrical current to deliver thermal energy to tissue. Operating the robotic medical instrument can include delivering energy to tissue at a treatment site. For example, an operator can control an energy or heat delivery device to navigate to a desired target area within a patient, grasp tissue at the desired target area, and activate or fire the medical instrument to deliver energy or heat for one or more steps of a medical procedure (such as, e.g., cutting or sealing).

[0160] At block **404**, the method **400** includes determining a temperature at a distal end of the robotic medical instrument. In some examples, the temperature of the distal end of the robotic medical instrument can be measured by a temperature sensor. As described herein, the temperature sensor can be placed in various positions in the system, such as at the distal end of the medical instrument to directly measure the temperature. In some examples, the temperature can be measured directly at the jaws, the wrist, or the shaft of the medical instrument. In some examples, the temperature can also be based on other variables, such as known characteristics of the medical instrument, including firing time, thermal decay constant, or external or intracorporeal body temperature. In some examples, the temperature can be compared to a threshold. For example, the threshold can be a predetermined temperature at which the medical instrument is safe to engage tissue or fire again. In some examples, the threshold can be 60 degrees Celsius. In some examples, the threshold can be about 75, 70, 65, 55, 50, 45, 40, 35 or 30 degrees Celsius.

[0161] At block **406**, the method **400** includes generating one or more indicators to indicate the determined temperature. As described above, the one or more indicators can be visual, haptic, or audible or any combination thereof. For example, in some examples, the indicators can be visually displayed on a viewer (e.g., as shown in FIGS. **23**A-**23**B, **24**A-**24**B, **25**A-**25**B, **26**A-**26**B, or **27**A-**27**B). In some examples, the one or more indicators can include an image overlay that conveys information regarding the determined or measured temperature, the image overlay can be display on an image or representation of the medical instrument. The indicators can convey information related to the measured temperature, such as the temperature value itself, if the temperature is above or below a threshold, or the time to allow the medical instrument to cool before it is ready for activation.

[0162] FIG. **29** illustrates an example method **450** for controlling a robotic medical instrument. The method **450** begins at block **452**, which includes operating a robotic medical instrument. The robotic medical instrument can be operated in a number of different ways, such as those described above.

[0163] At block **454**, the method **450** includes determining at temperature at a distal end of the robotic medical instrument. The temperature can be determined in a number of different ways, such as those described above.

[0164] At block **456**, the method **450** includes limiting a functionality of the robotic medical instrument based on the determined temperature from block **454**. For example, functionality can be limited or resistive. In some examples, limiting a functionality of the robotic medical instrument can be considered haptic feedback. For example, the robotic medical instrument can resist movement as a form of limited functionality, which can also cause resistance in the controller being operated by a user. The functionality can be limited after a certain amount of time or until the determined temperature falls below a temperature threshold. In some embodiments, limiting a functionality of the robotic medical instrument can also include turning on or off the instrument, or modifying its ability to generate energy.

[0165] In some examples, a feature of the instrument can be adjusted or modified based on the determined temperature. For example, an availability of the feature of the instrument may be reduced or modified based on the determined temperature. This limited functionality may be temporary, such as based on the determined temperature or based on a predetermined amount of time. The functionality or feature to be limited can include the speed, direction, movement of the robotic medical instrument. In some examples, limiting functionality can include preventing actuation of the robotic medical instrument, such as preventing movement of the jaws or portion of the medical instrument or preventing firing of the medical instrument.

[0166] In some examples, a controller or processor of the system can receive a signal including the determined temperature of the distal end of the robotic medical instrument. The controller or processor may then determine the determined temperature is above or below a certain threshold. Based on this determination, the controller or processor may then generate and send a signal to limit the functionality of the medical instrument. In some examples, the signal may be sent to the medical instrument to prevent movement, actuation, heat generation, activation, or any other features of the medical instrument. In some examples, the signal may be sent to a user input, such as a controller, to prevent a user from moving, actuating, or activating the medical instrument with the user input. In some examples, the signal may be sent to a user input to generate haptic resistance of the user input. For example, haptic resistance in the user input can prevent or inhibit movement of the user input (and thereby preventing or inhibiting movement of the medical instrument).

[0167] Furthermore, although limiting functionality and generating indicators are described in different methods, these features may be used simultaneously. For example, an indicator in the form of a visual or audible alarm can be generated while functionality of the medical instrument is limited when the temperature is above a certain threshold.

3. Implementing Systems and Terminology

[0168] Implementations disclosed herein provide systems, methods and apparatus associated with indicators configured to provide information for use with robotic medical systems.

[0169] 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.

[0170] Any phrases referencing specific computer-implemented processes/functions 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.

[0171] 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.

[0172] 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.

[0173] 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."

[0174] 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 robotic medical system, comprising:

a medical instrument comprising a distal end configured to be inserted into a patient and apply heat to tissue within the patient;

a robotic manipulator engaged with the medical instrument and configured to operate the medical instrument;

a temperature sensor configured to take one or more temperature readings of the medical instrument; and

a viewer configured to display an image of the medical instrument and an image overlay conveying information indicative of a temperature of the medical instrument,

wherein the information conveyed by the image overlay is based on the one or more temperature readings taken by the temperature sensor.

2. The robotic medical system of claim **1**, wherein the image overlay is displayed over at least a portion of the image of the medical instrument.

3. The robotic medical system of claim **2**, wherein the medical instrument further comprises a wrist, and wherein the image overlay is displayed over at least the wrist of the medical instrument of the image.

4. The robotic medical system of claim **1**, wherein the image overlay is displayed around a second image overlay associated with the medical instrument.

5. The robotic medical system of claim **4**, wherein the second image overlay conveys a state or an identity of the medical instrument.

6. The robotic medical system of claim **1**, wherein the image overlay comprises a temperature meter indicating a temperature of the medical instrument.

7. The robotic medical system of claim **1**, wherein the image overlay is capable of displaying multiple colors.

8. The robotic medical system of claim **7**, wherein the multiple colors comprise a first color indicating that the medical instrument is heated, and wherein the multiple colors comprise a second color indicating that the medical instrument is cooled.

9. The robotic medical system of claim **8**, wherein the image overlay displays the first color until the medical instrument reaches a temperature threshold, wherein the image overlay displays the second color once the medical instrument reaches the temperature threshold.

10. The robotic medical system of claim **1**, wherein the image overlay comprises a number indicating the temperature of the medical instrument.

11. The robotic medical system of claim **1**, wherein the information is based on a direct measurement of temperature of the distal end of the medical instrument.

12. The robotic medical system of claim **1**, wherein the medical instrument further comprises a wrist, and wherein the information is based on a direct measurement of temperature of the wrist of the medical instrument.

13. The robotic medical system of claim **1**, wherein the image overlay conveys information based on known characteristics of the medical instrument including one or more of a firing time, a thermal decay constant, and an external body temperature.

14. The robotic medical system of claim **1**, wherein the temperature sensor is located within the medical instrument.

15. A method of controlling a robotic medical instrument, the method comprising:

operating the robotic medical instrument with a robotic manipulator engaged with the robotic medical instrument;

measuring a temperature at a distal end of the robotic medical instrument; and

limiting a functionality of the robotic medical instrument based on the measured temperature.

16. The method of claim **15**, further comprising displaying an image of the robotic medical instrument and an image overlay that conveys information regarding the measured temperature.

17. The method of claim **15**, wherein the functionality is limited until the measured temperature falls below a temperature threshold.

18. The method of claim **17**, wherein limiting the functionality comprises limiting a speed of the robotic medical instrument.

19. The method of claim **17**, wherein limiting the functionality comprises preventing actuation of the robotic medical instrument.

20. The method of claim **15**, further comprising generating one or more of a visual, audible, or haptic alarm to indicate the measured temperature.

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