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(54) **MULTIFUNCTIONAL OPERATIONAL COMPONENT FOR ROBOTIC DEVICES**

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(58) **Field of Classification Search**

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See application file for complete search history.

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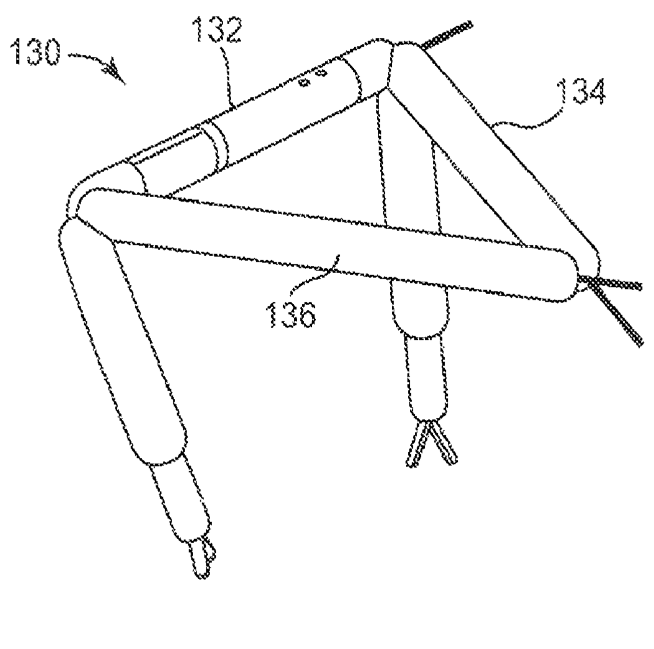
(57) **ABSTRACT**

The various embodiments disclosed herein relate to modular medical devices, including various devices with detachable modular components and various devices with pivotally attached modular components. Additional embodiments relate to procedures in which various of the devices are used cooperatively. Certain embodiments of the medical devices are robotic in vivo devices.

**20 Claims, 26 Drawing Sheets**



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continuation of application No. 14/202,353, filed on Mar. 10, 2014, now Pat. No. 9,179,981, which is a continuation of application No. 12/324,364, filed on Nov. 26, 2008, now Pat. No. 8,679,096, which is a continuation-in-part of application No. 12/192,779, filed on Aug. 15, 2008, now Pat. No. 8,974,440, and a continuation-in-part of application No. 11/766,683, filed on Jun. 21, 2007, now Pat. No. 8,968,332, and a continuation-in-part of application No. 11/966,741, filed on Dec. 28, 2007, now Pat. No. 9,579,088.

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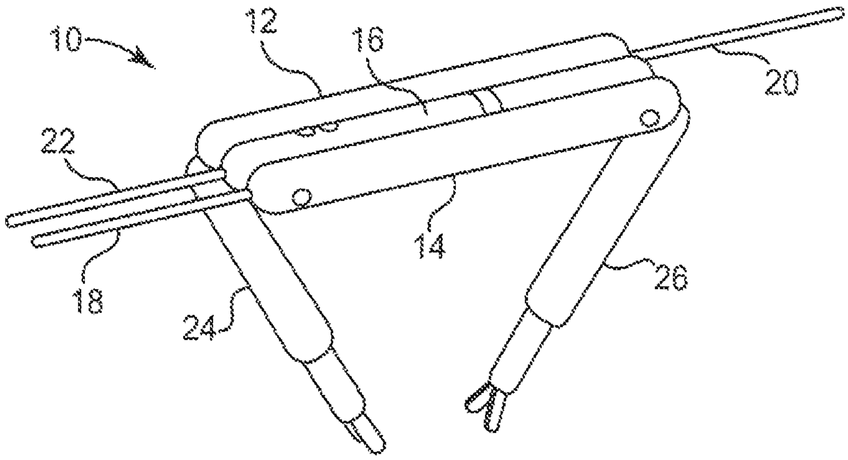


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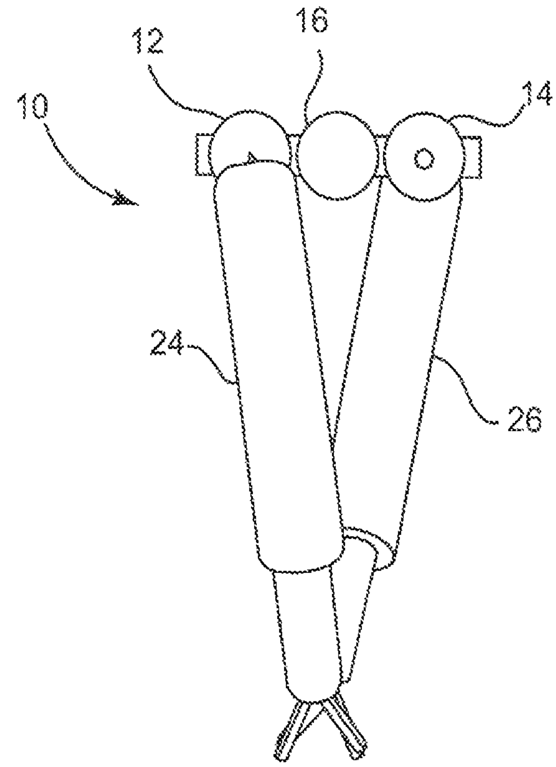


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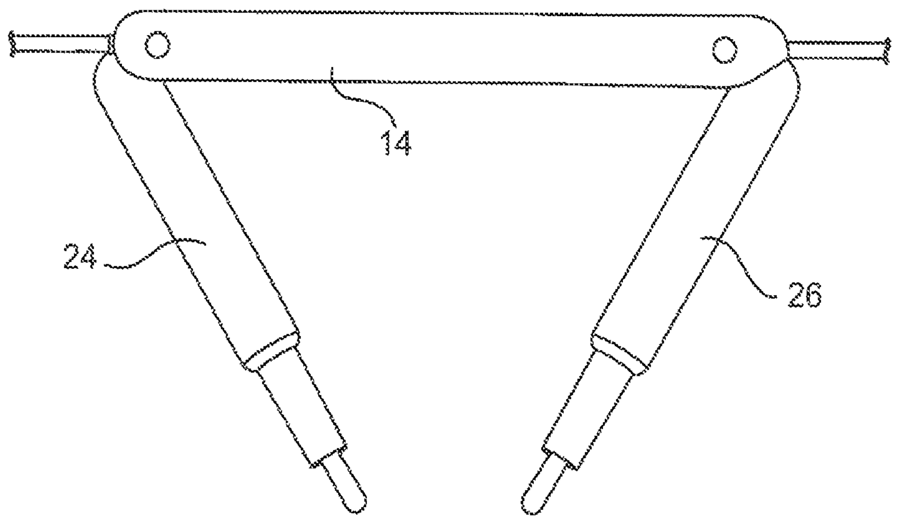
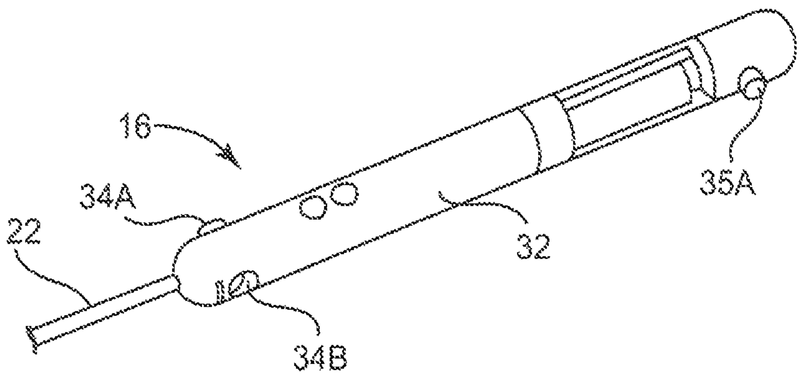


Fig. 1C



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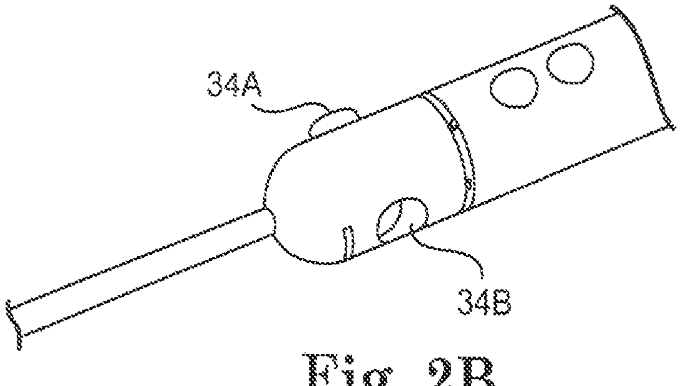

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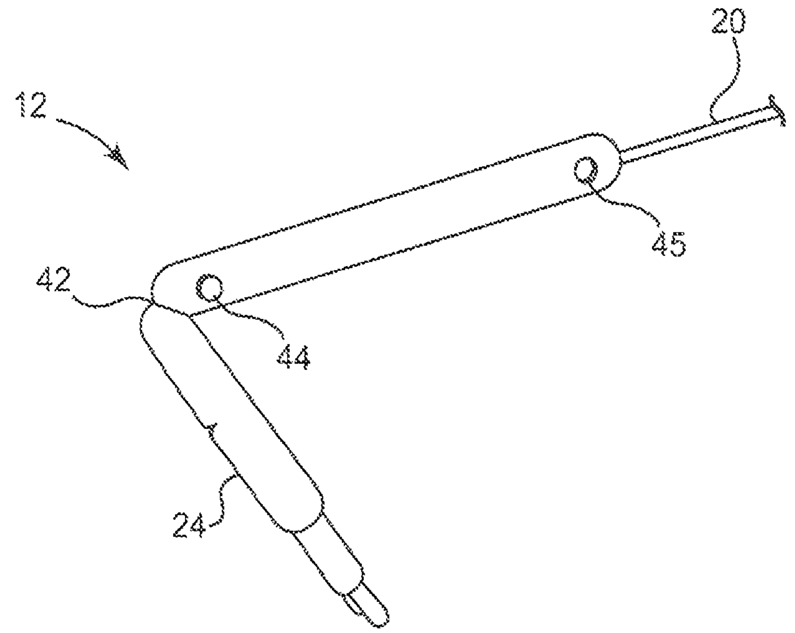



Fig. 3

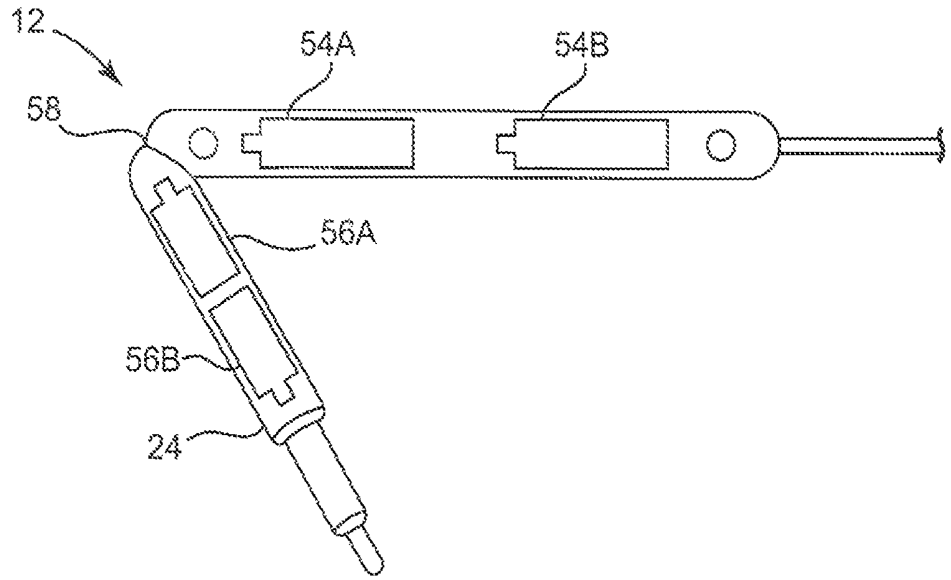



Fig. 4

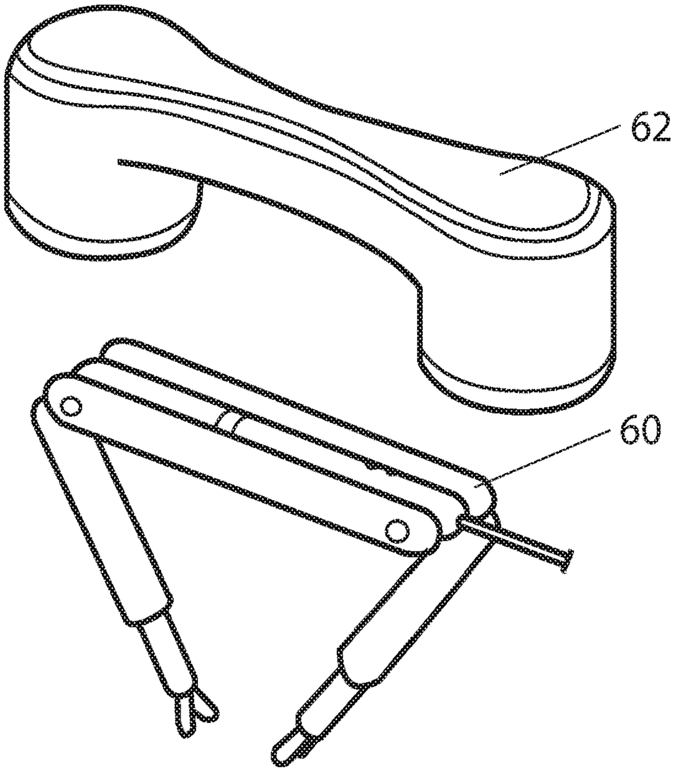



Fig. 5A

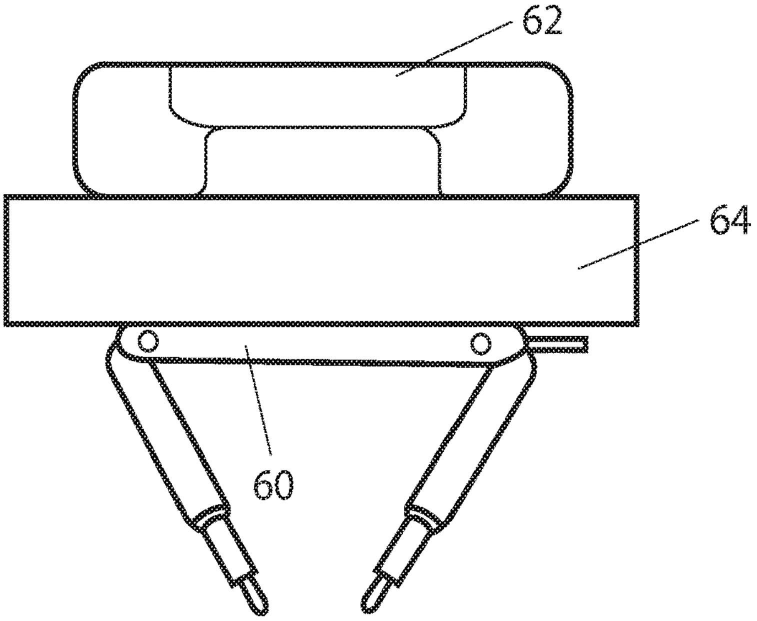
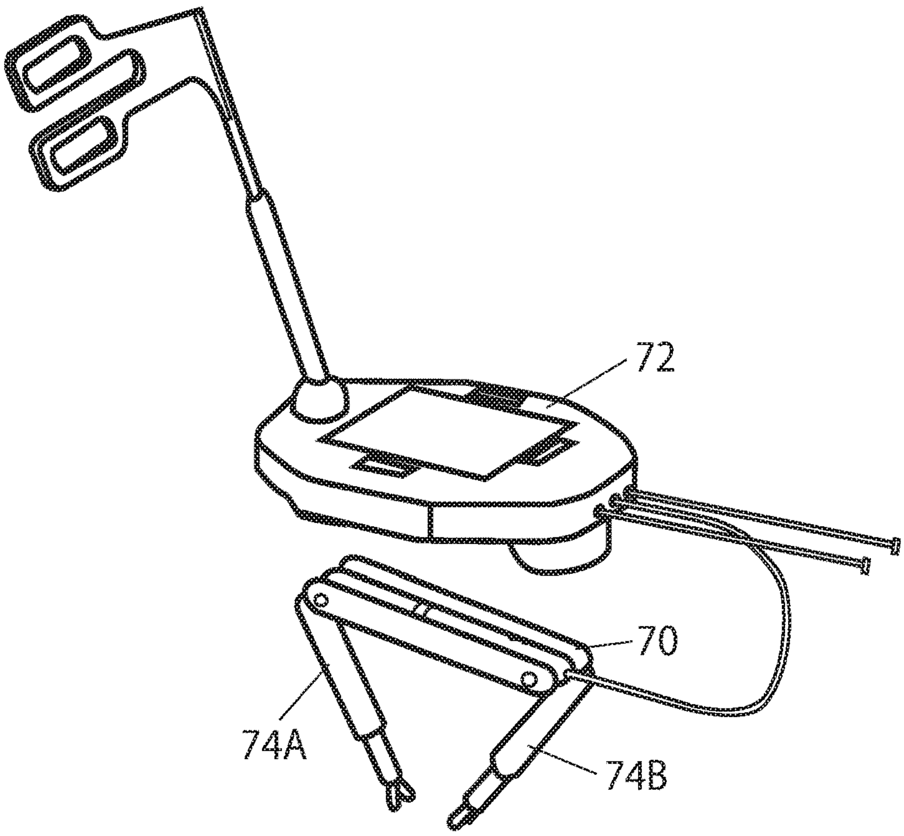



Fig. 5B

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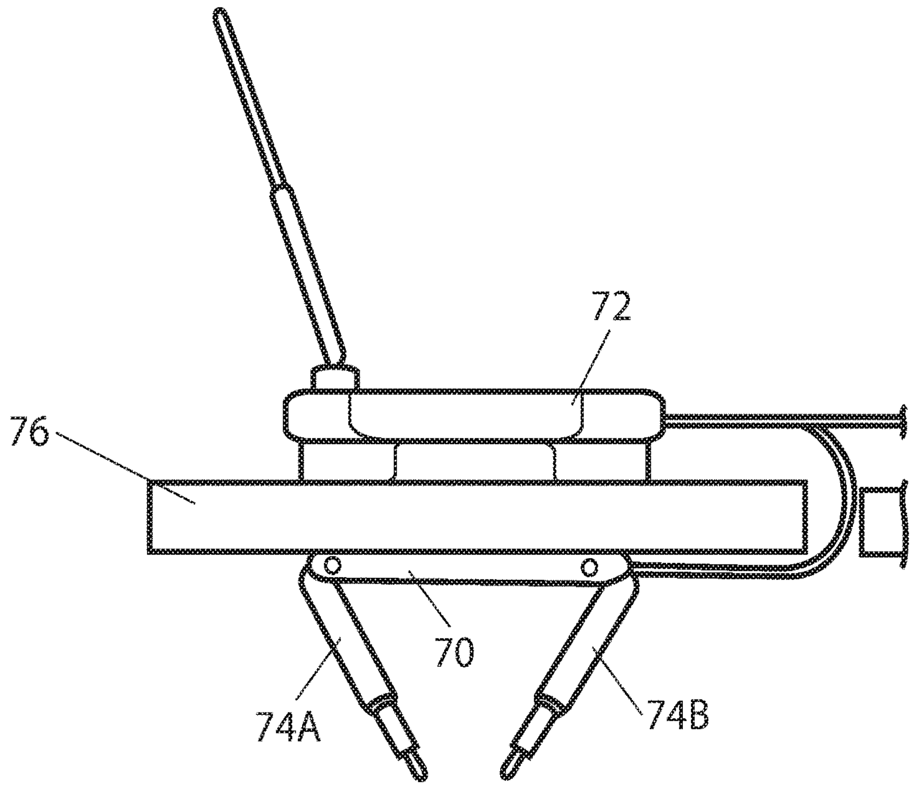


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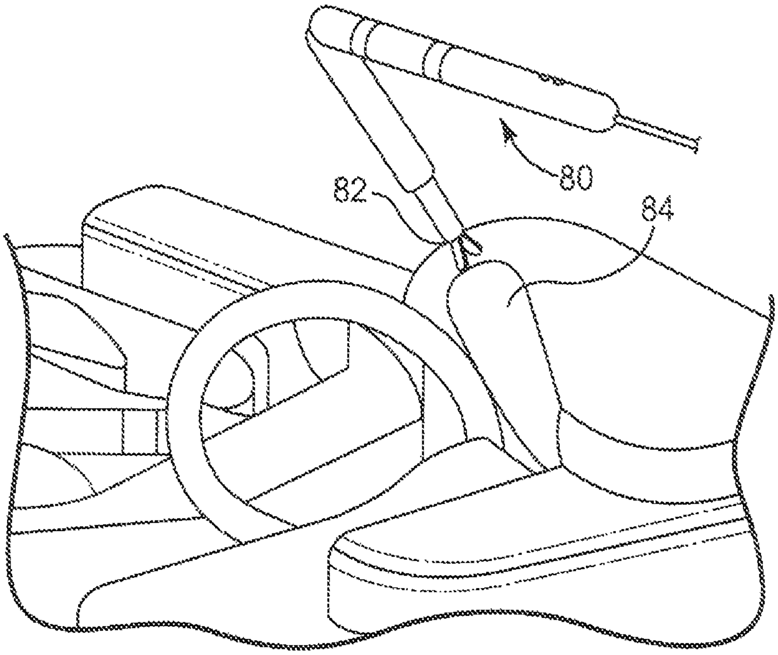


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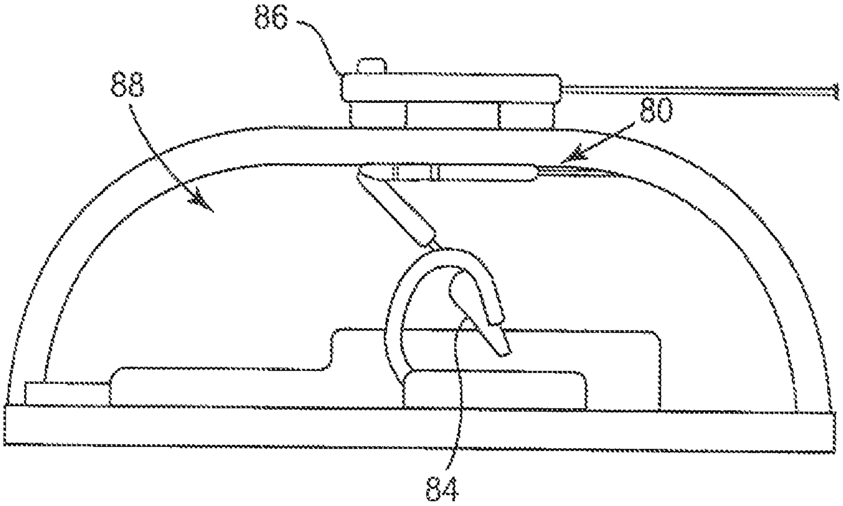


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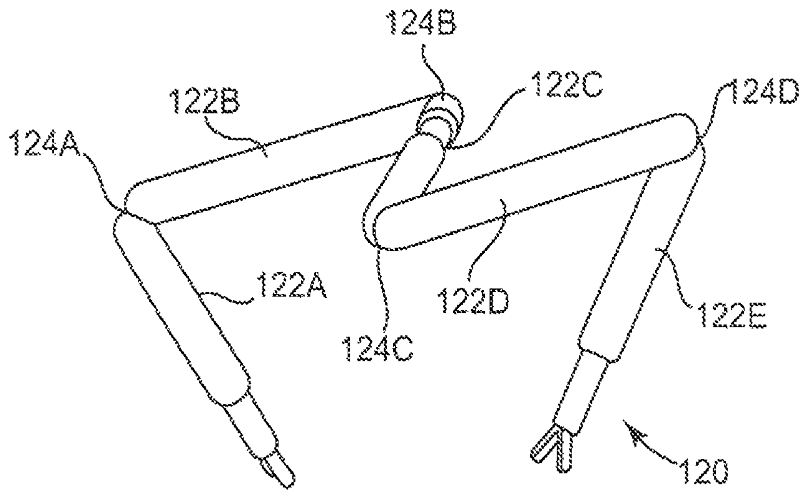
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Fig. 8A

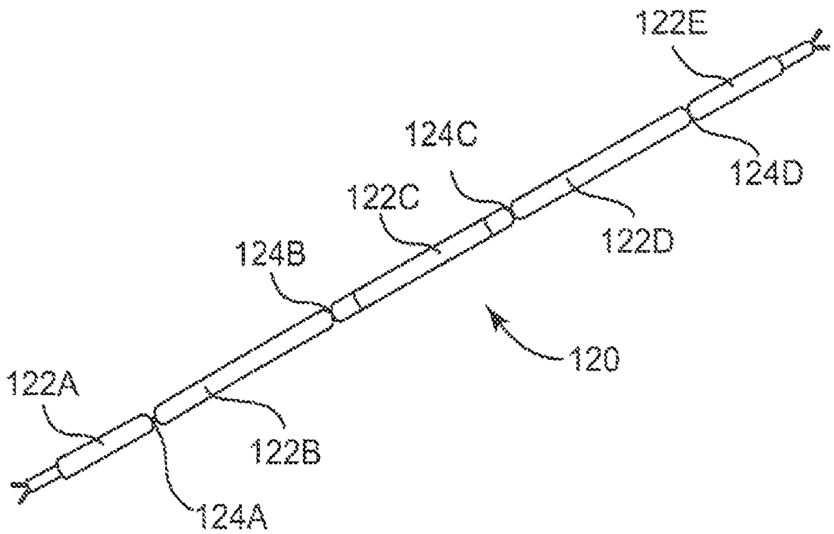
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Fig. 8B

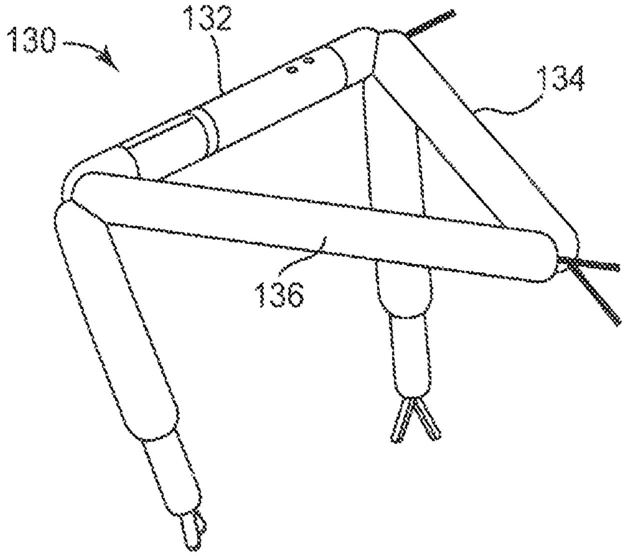



Fig. 9

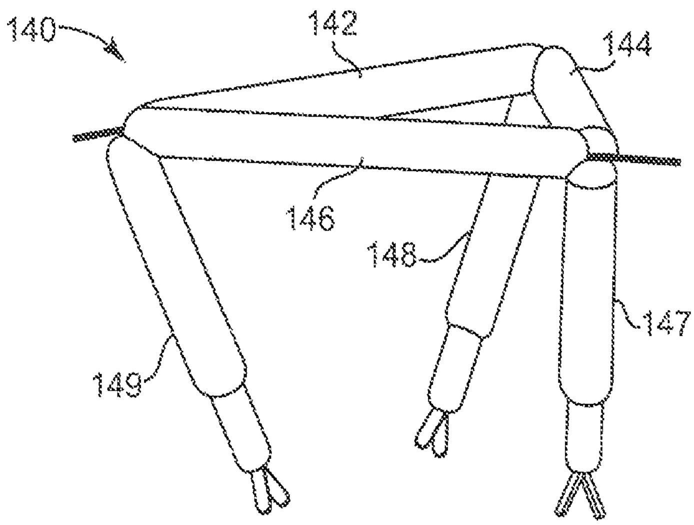
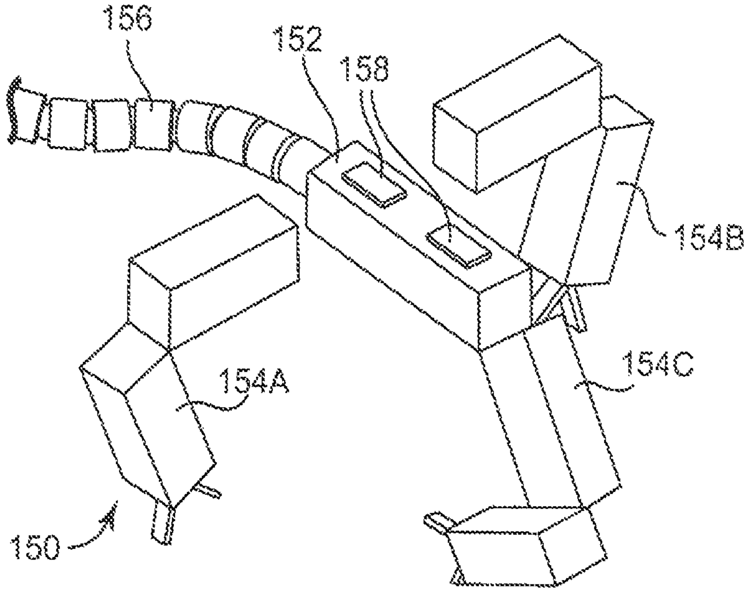



Fig. 10

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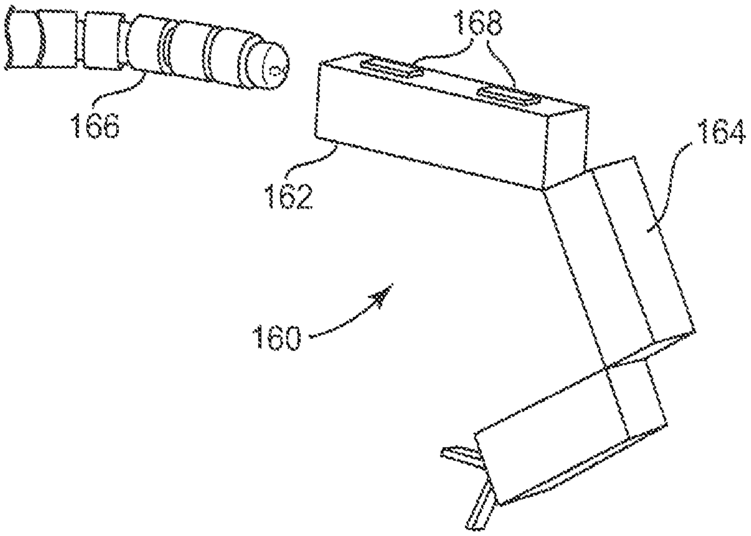


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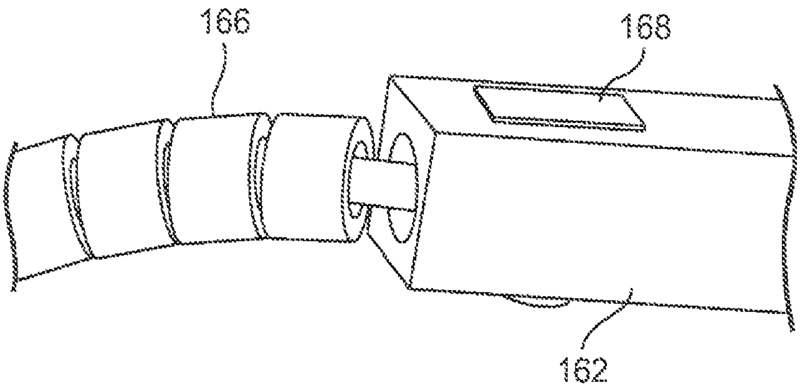


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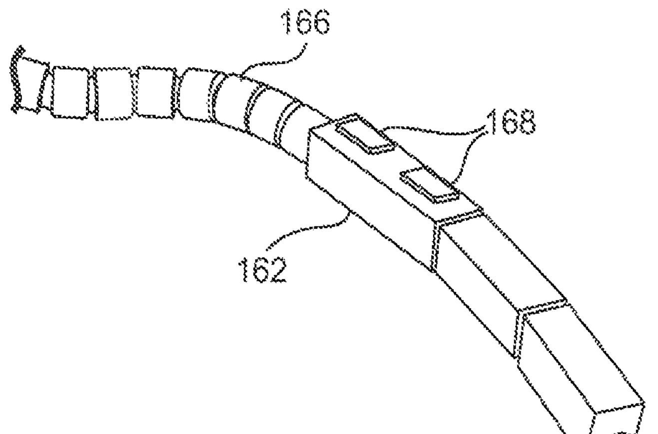



Fig. 12C

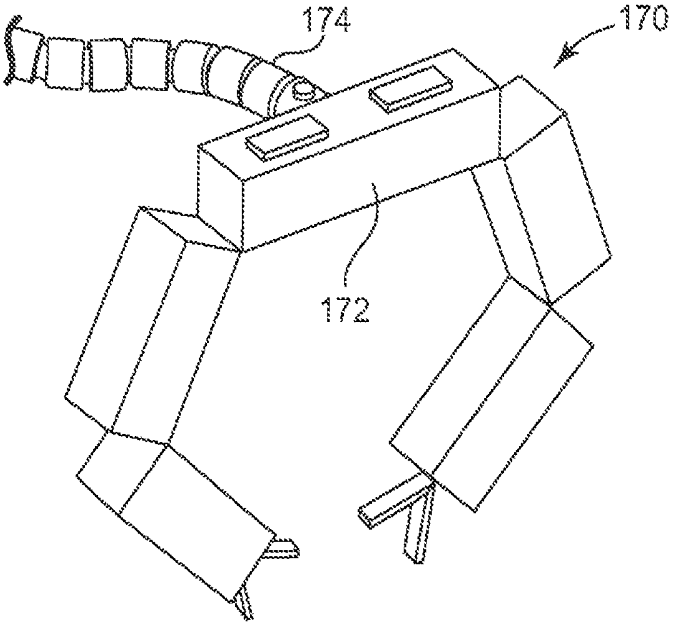



Fig. 13

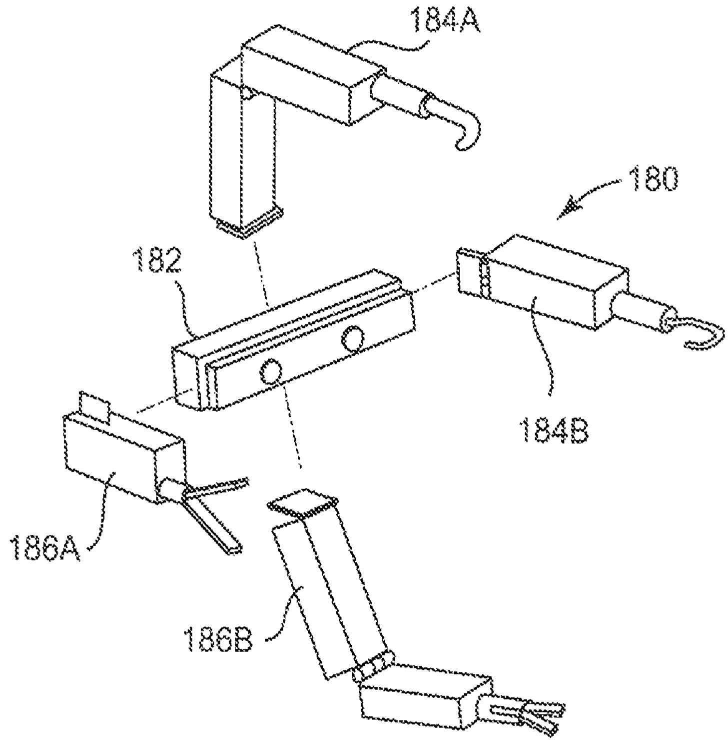
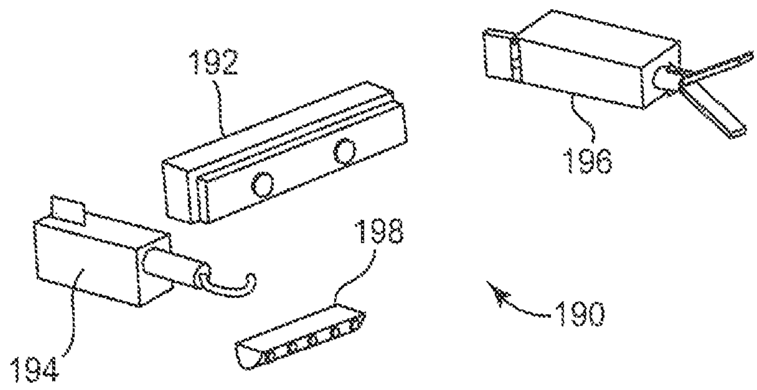



Fig. 14

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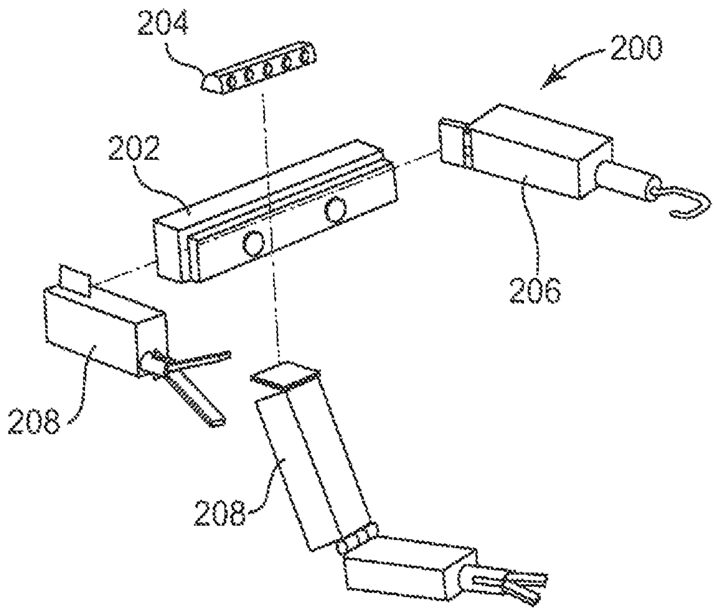


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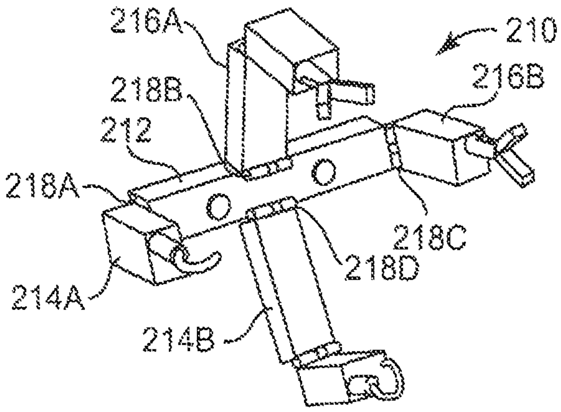


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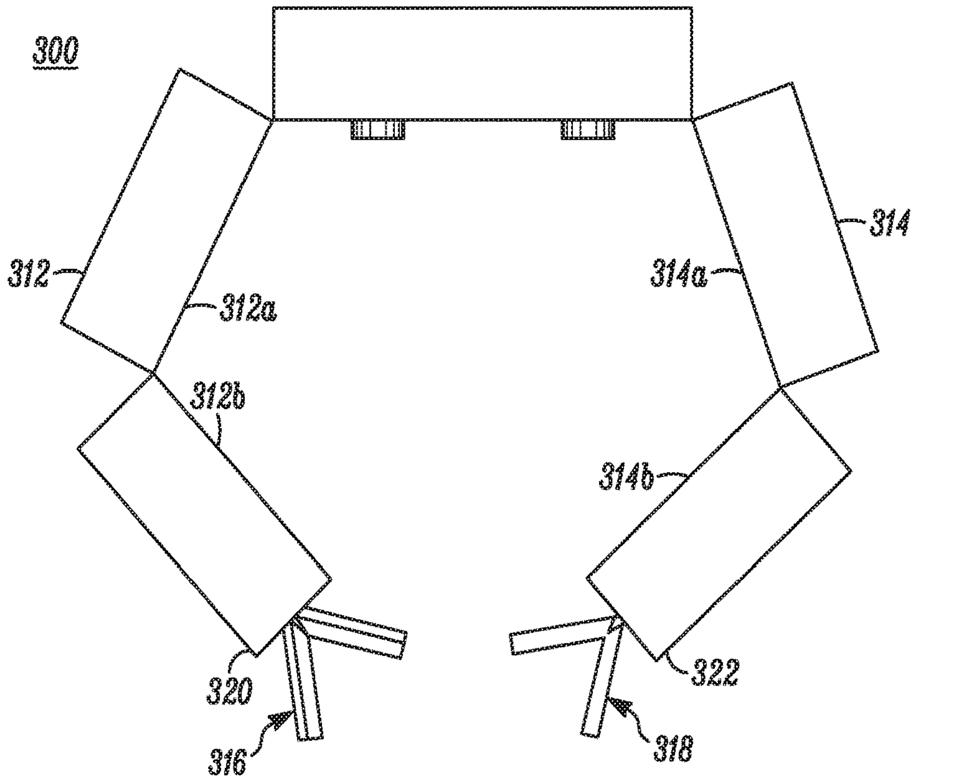


FIG. 18A

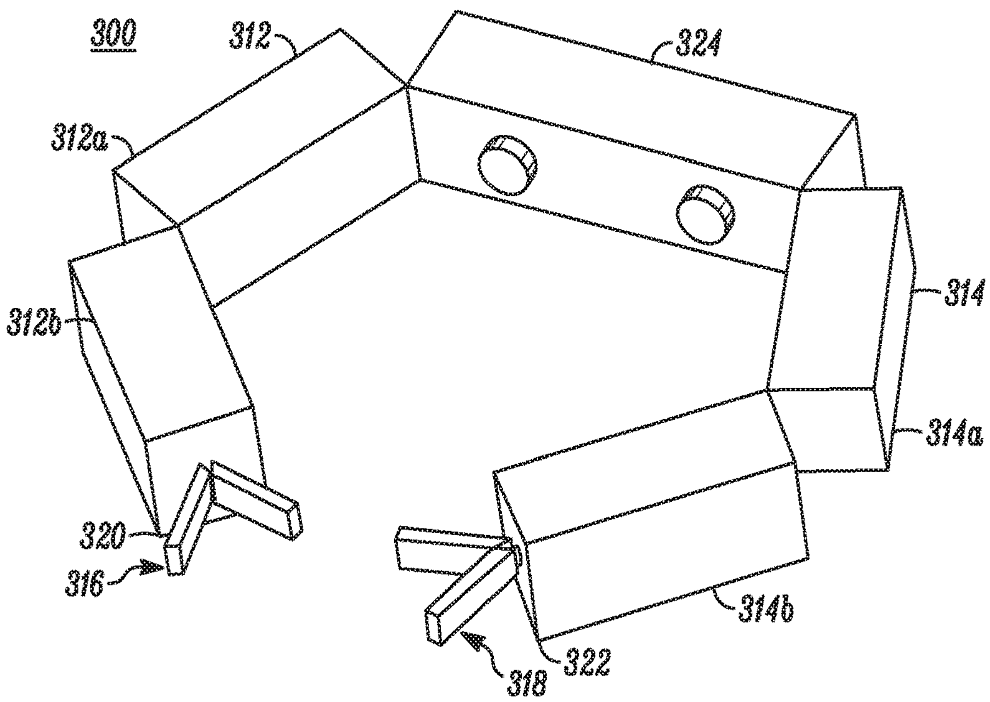


FIG. 18B

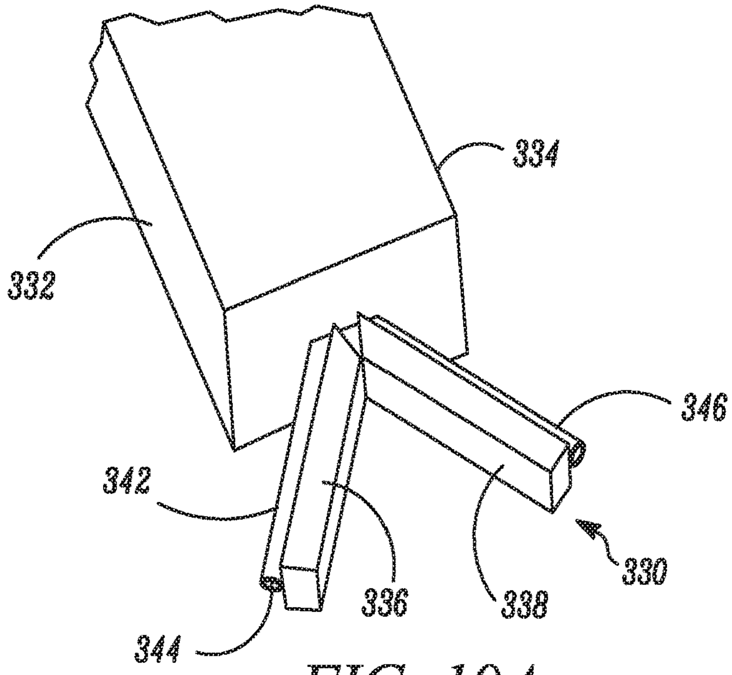


FIG. 19A

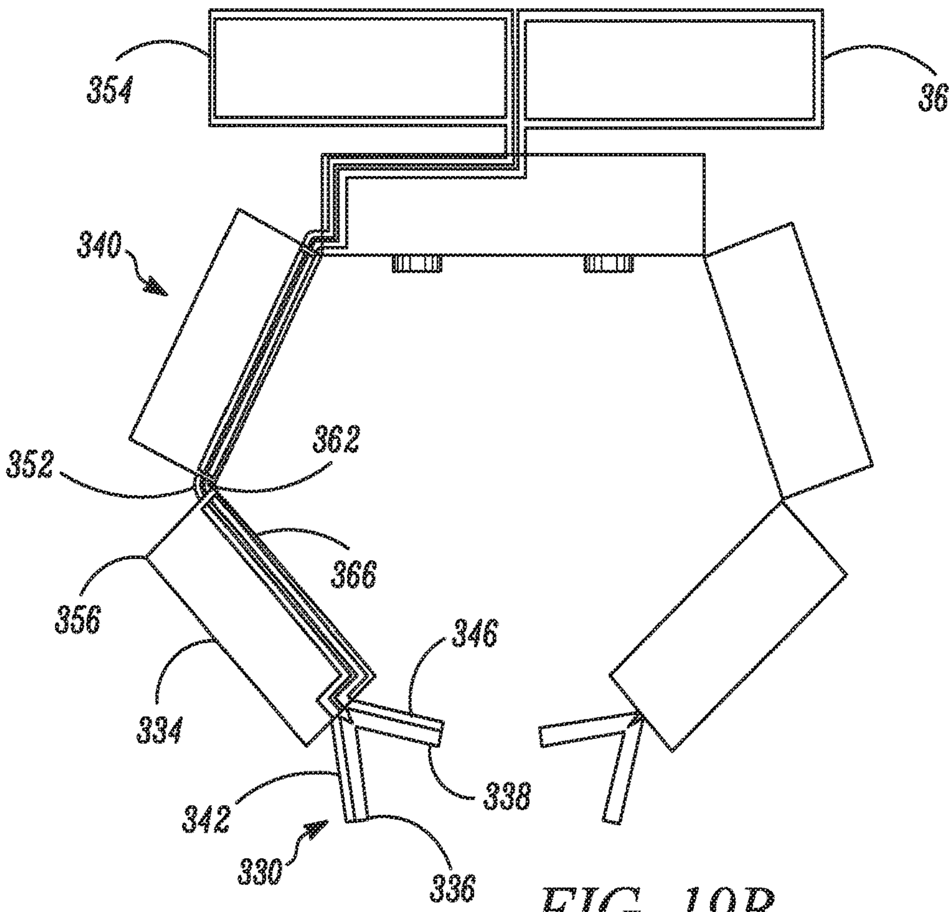


FIG. 19B

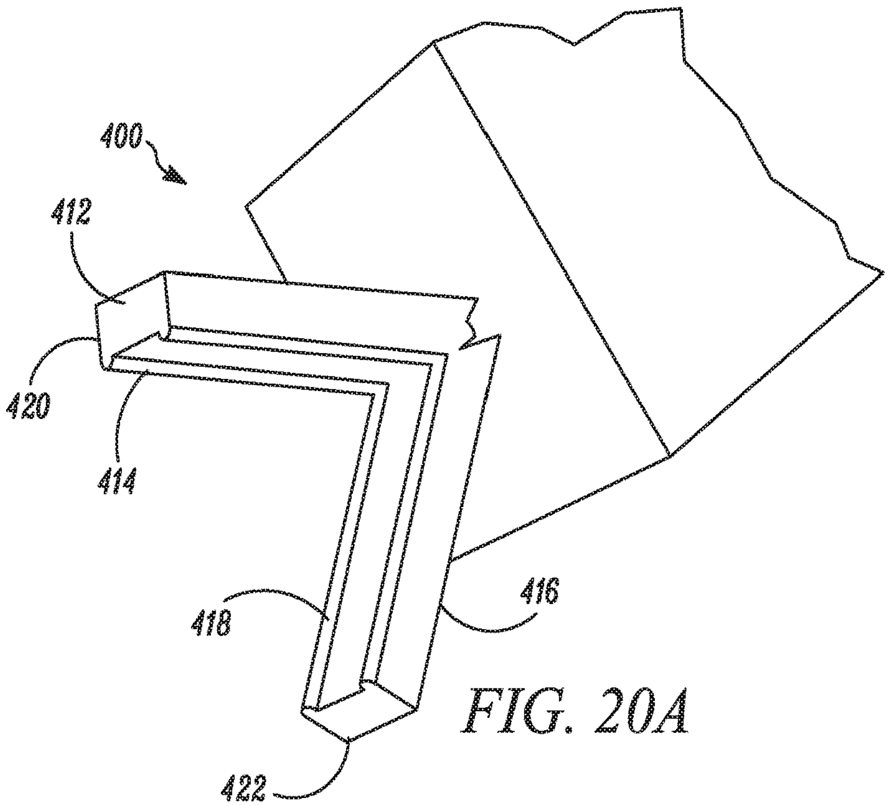


FIG. 20A

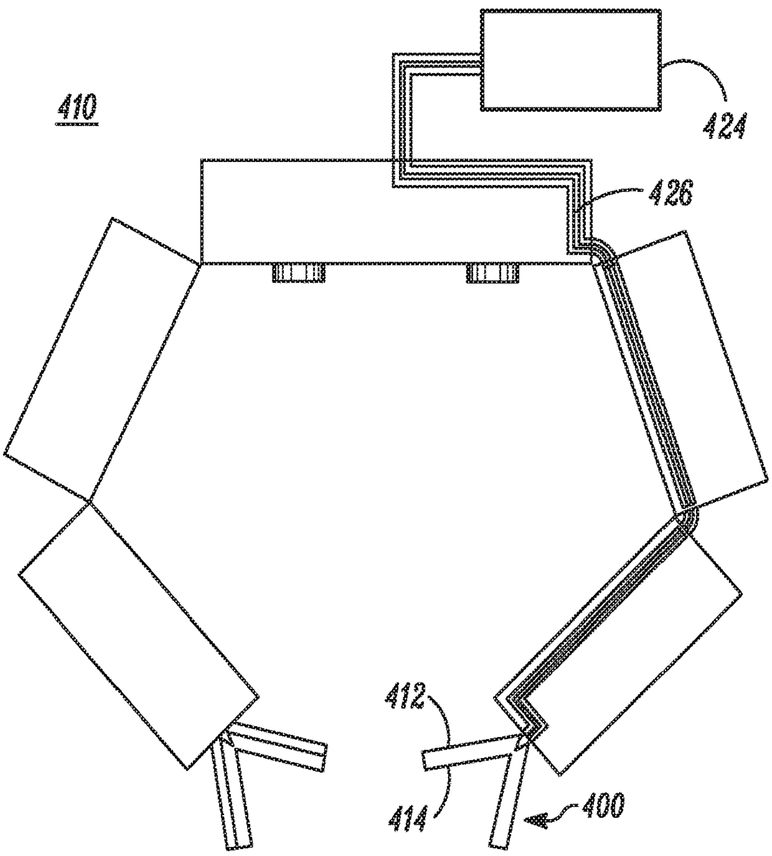


FIG. 20B

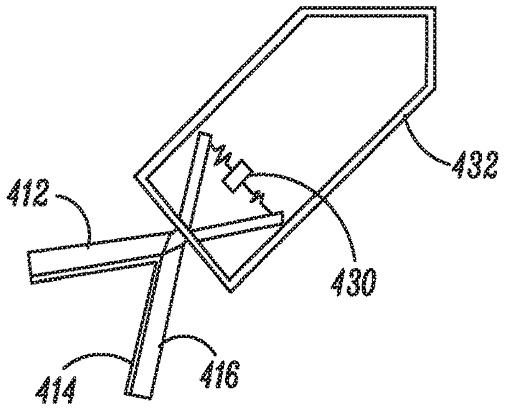


FIG. 20C

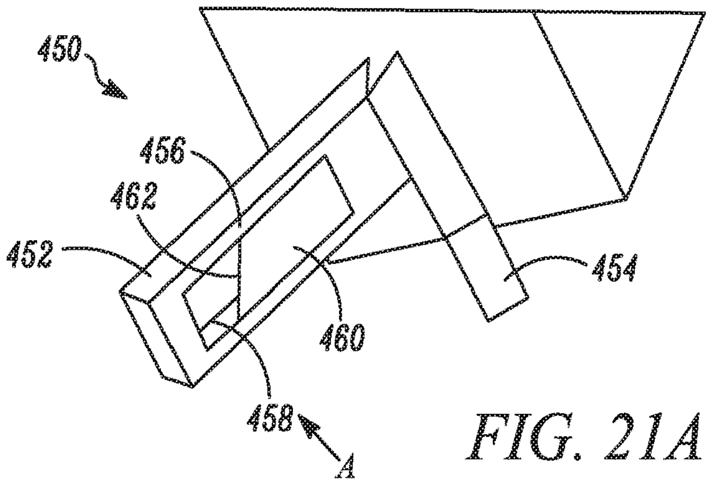


FIG. 21A

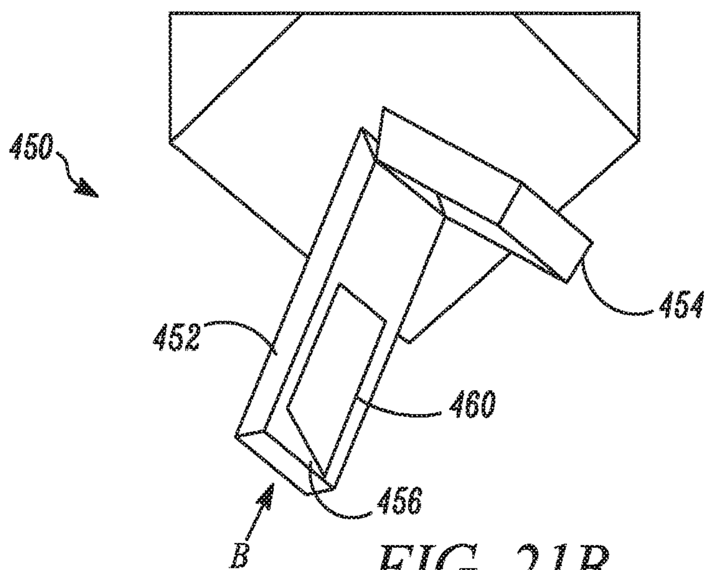


FIG. 21B

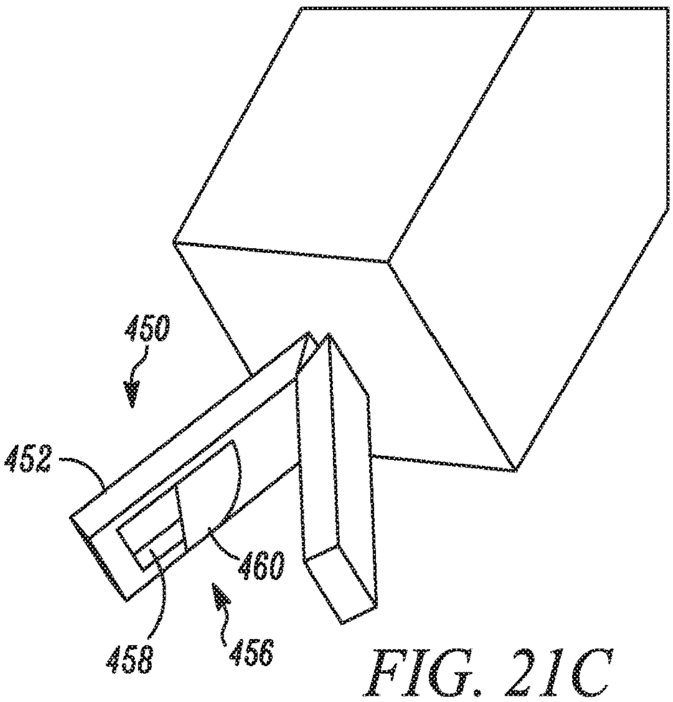


FIG. 21C

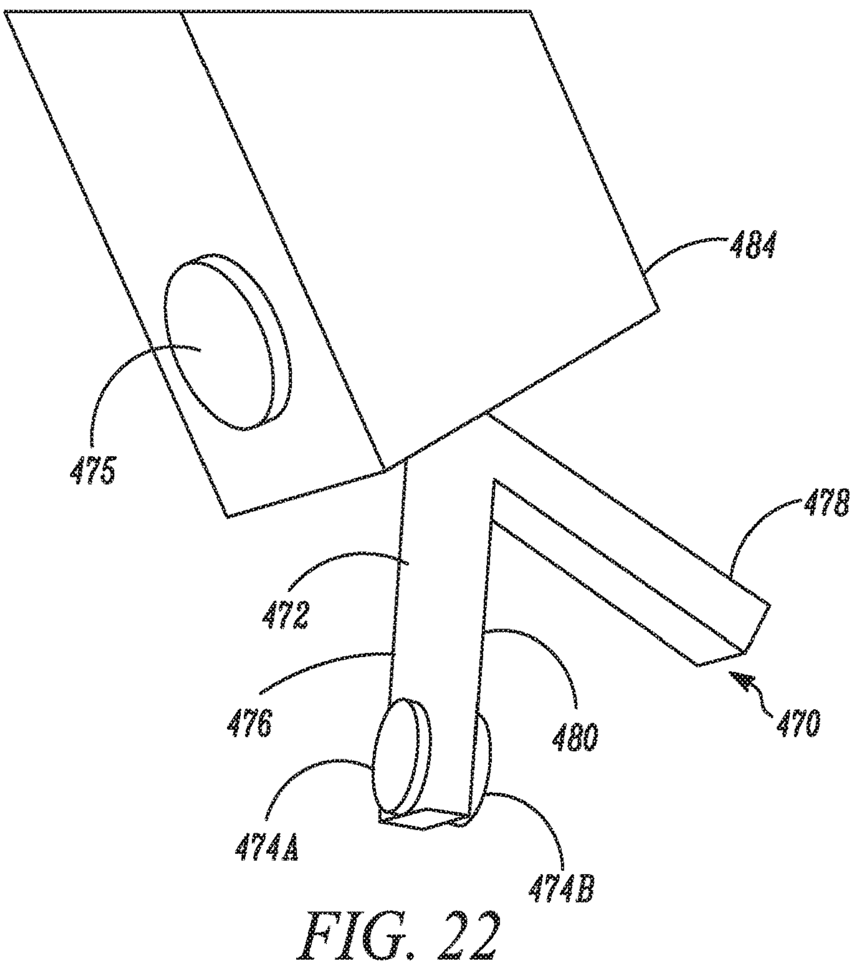


FIG. 22

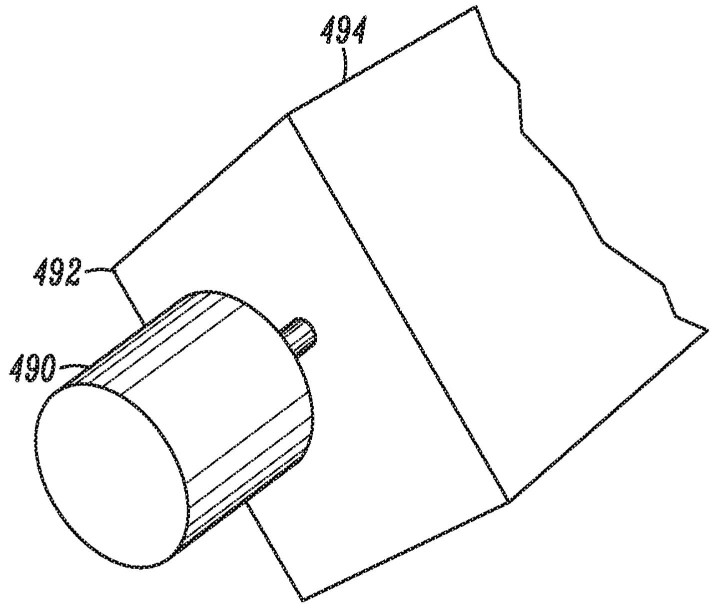


FIG. 23

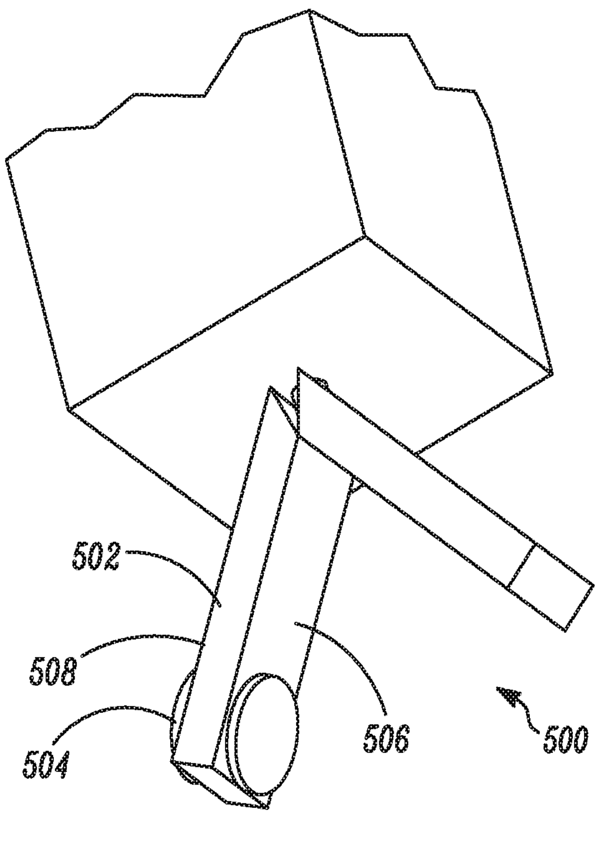


FIG. 24

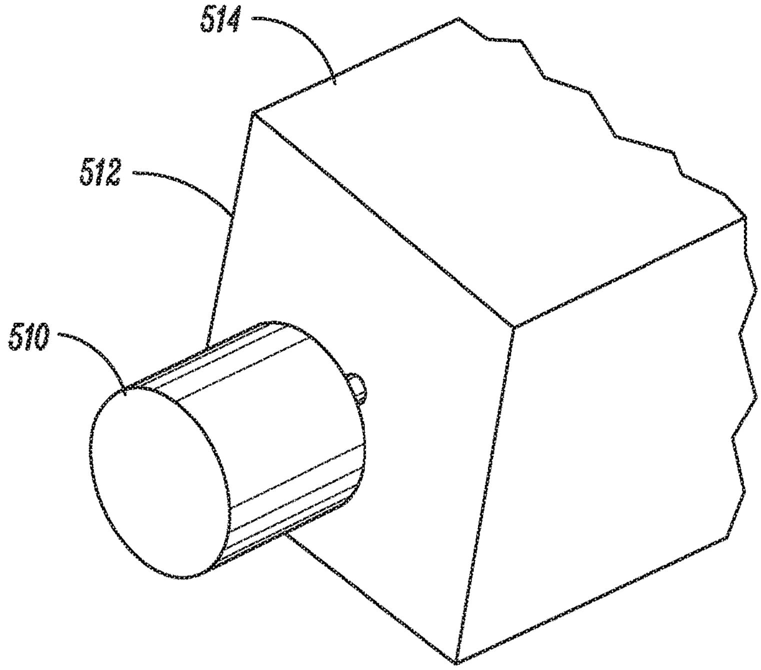


FIG. 25

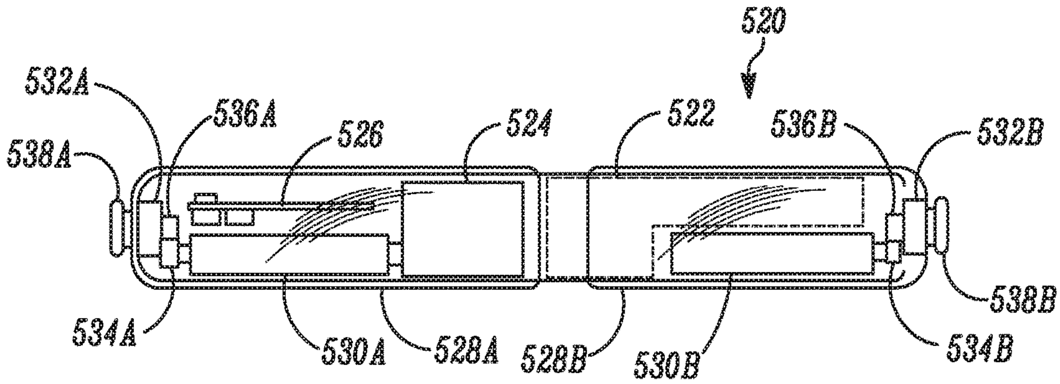


FIG. 26A

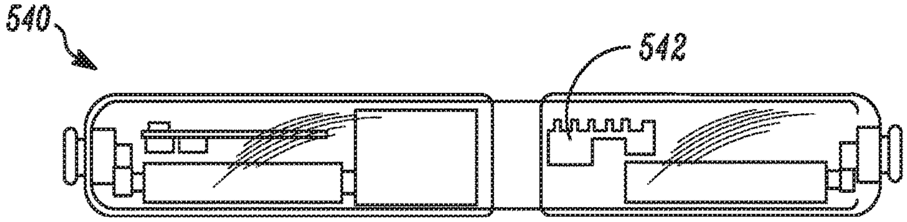


FIG. 26B

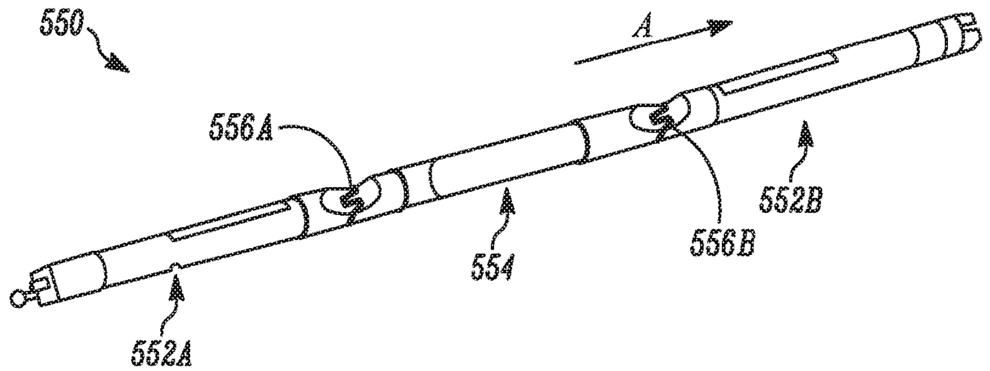


FIG. 27A

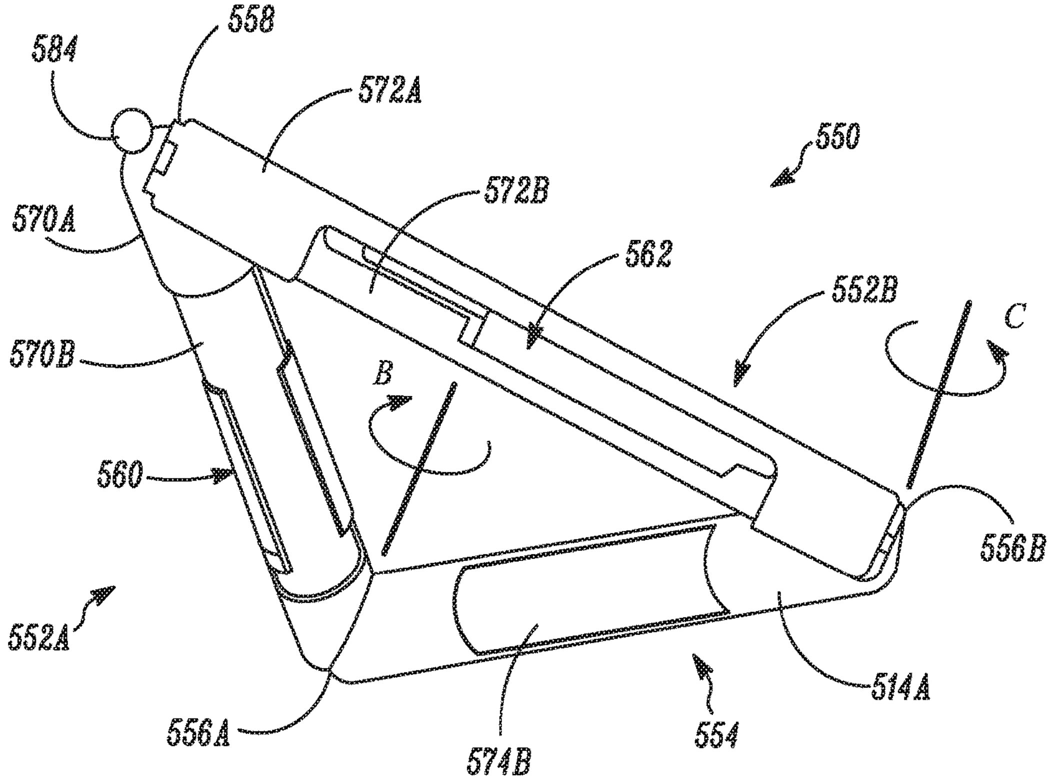


FIG. 27B

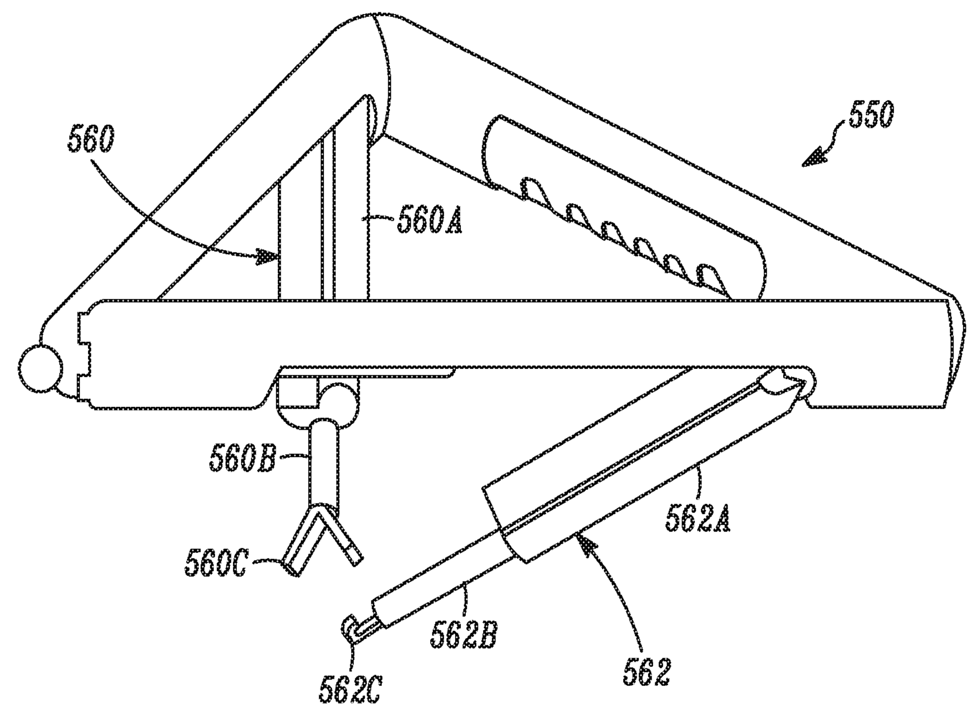


FIG. 28A

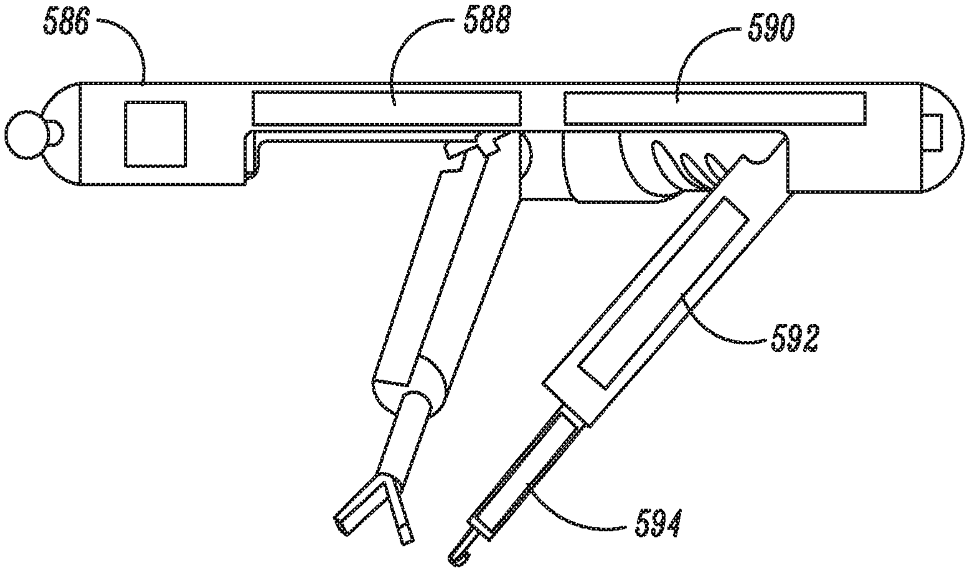


FIG. 28B

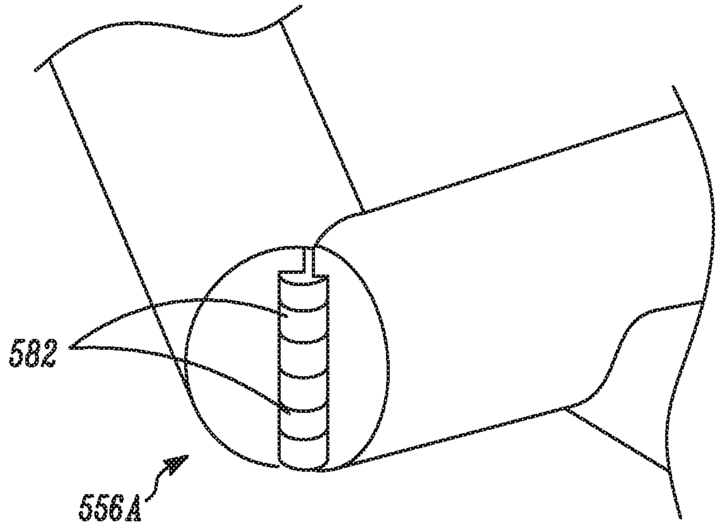


FIG. 28C

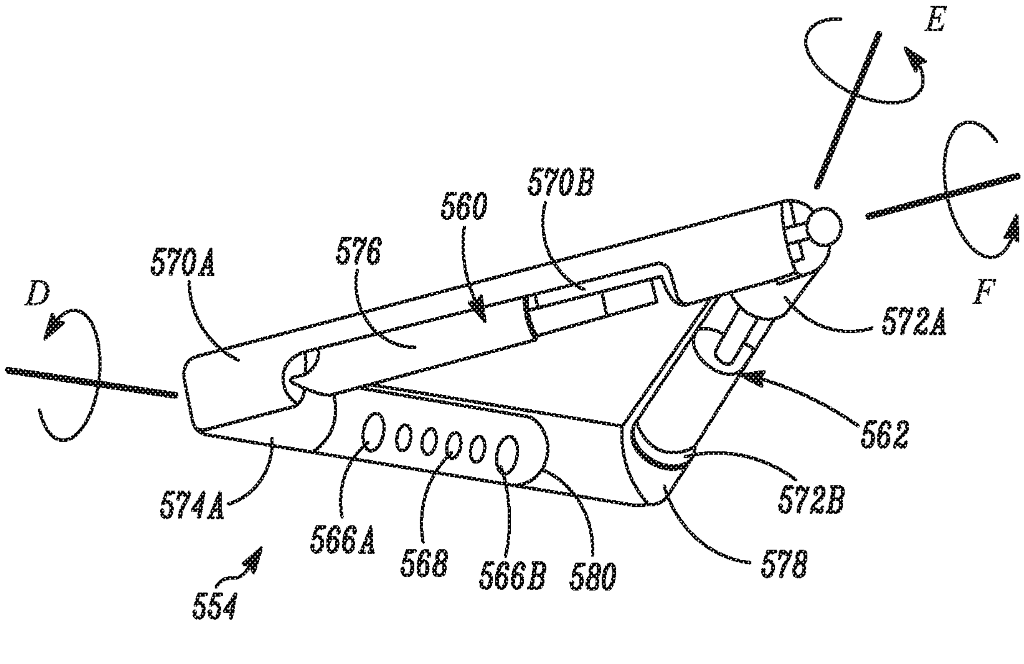


FIG. 29

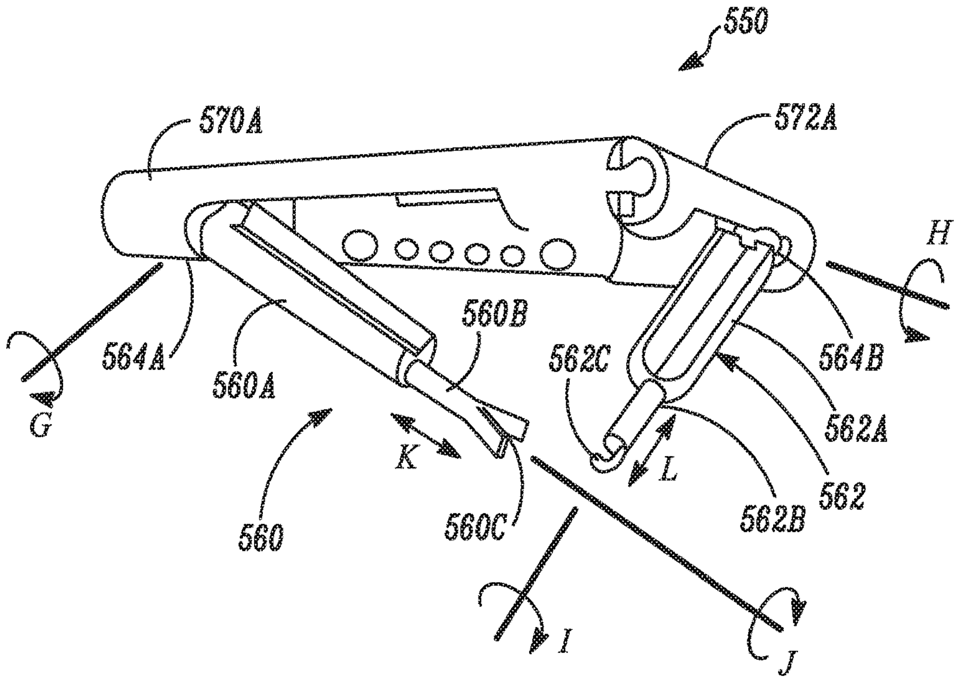
550
570A
572A
H
564B
562C
560B
564A
560A
562A
G
K
L
562
560
560C
562B
I
J

FIG. 30

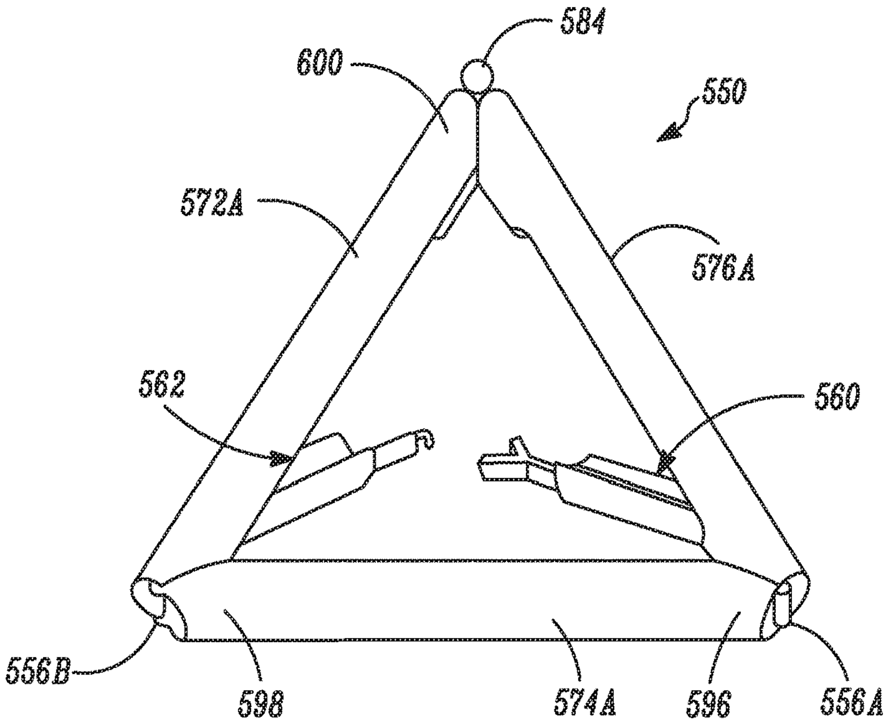
584
600
550
572A
576A
562
560
556B
598
574A
596
556A

FIG. 31

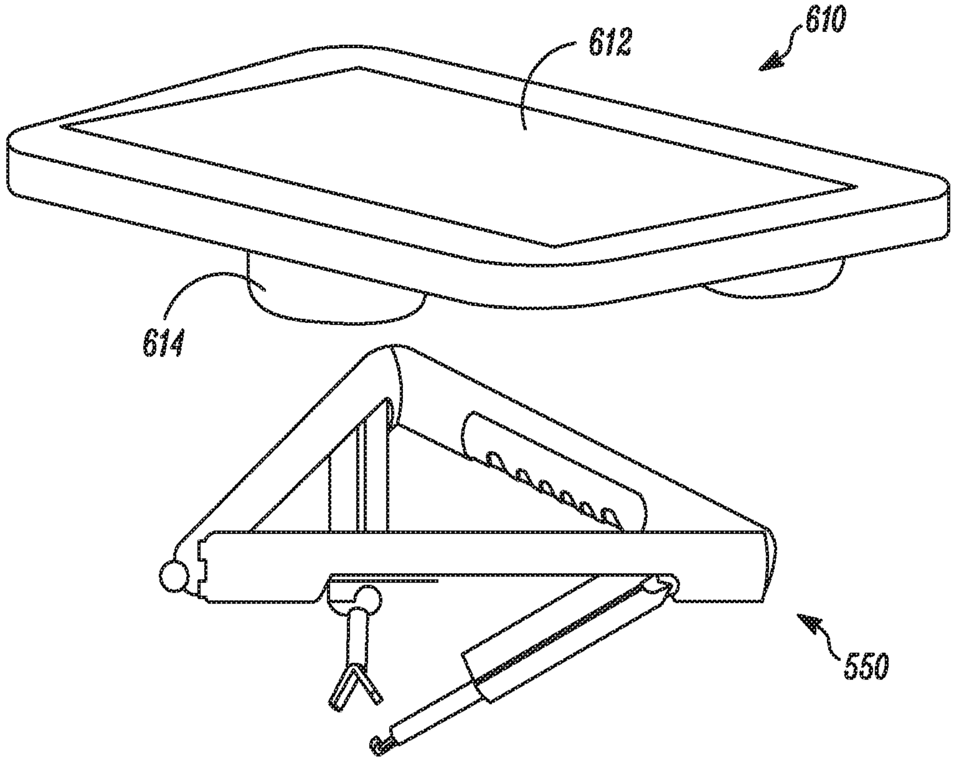


*FIG. 32*

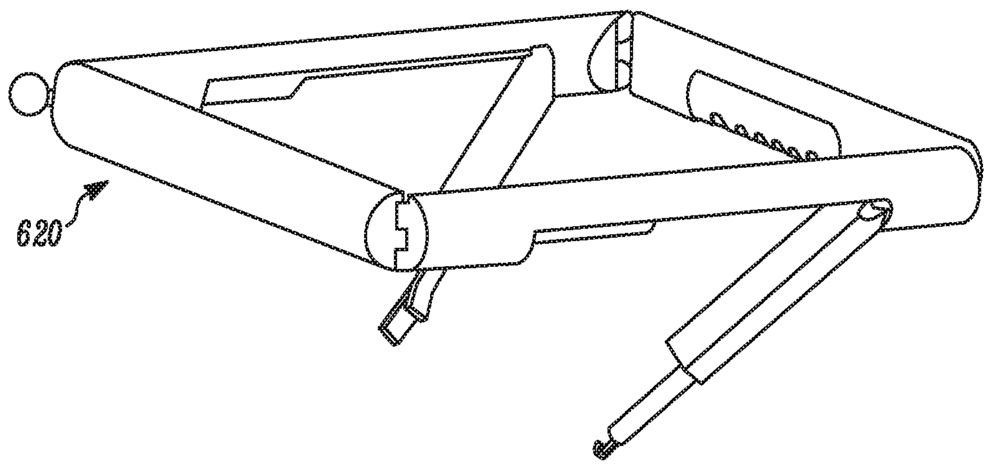


*FIG. 33*

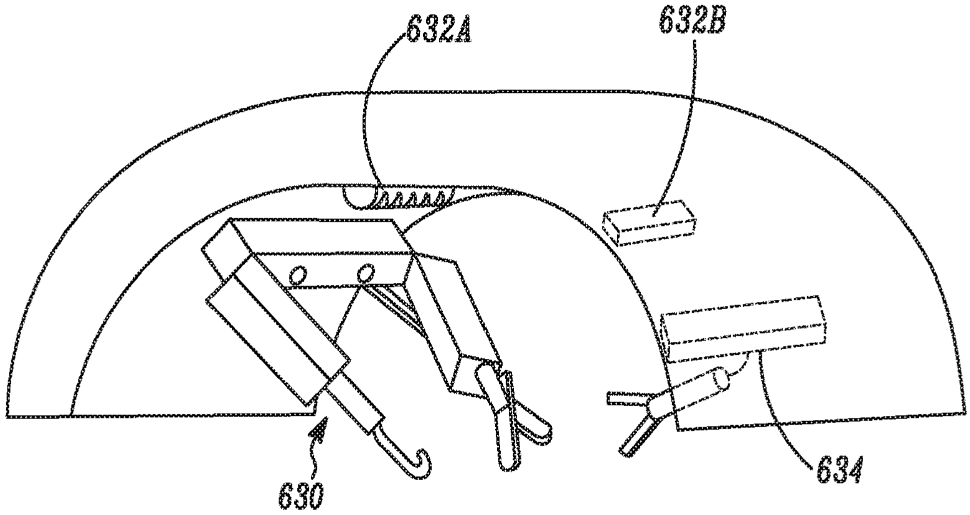


FIG. 34

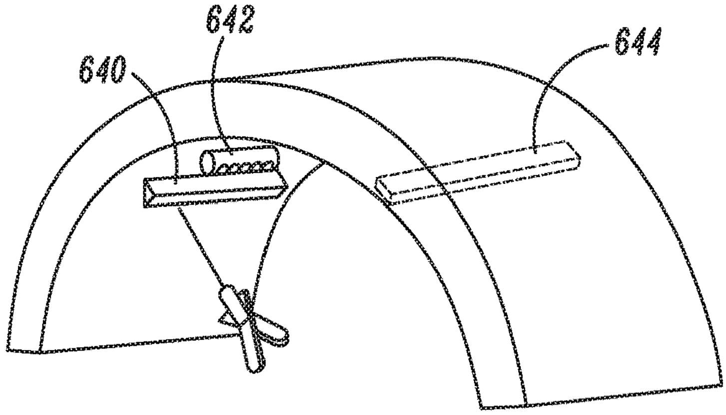


FIG. 35

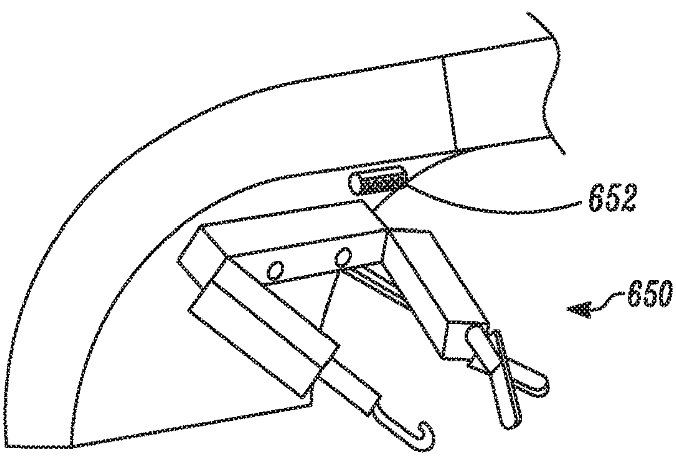


FIG. 36

# MULTIFUNCTIONAL OPERATIONAL COMPONENT FOR ROBOTIC DEVICES

## CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims priority as a continuation of U.S. application Ser. No. 14/936,234, filed Nov. 9, 2015 and entitled "Multifunctional Operational Component for Robotic Devices," which claims priority as a continuation of U.S. application Ser. No. 14/202,353, filed Mar. 10, 2014 and entitled "Multifunctional Operational Component for Robotic Devices," which issued on Nov. 10, 2015 as U.S. Pat. No. 9,179,981, which claims priority as a continuation of U.S. application Ser. No. 12/324,364, filed Nov. 26, 2008 and entitled "Multifunctional Operational Component for Robotic Devices," which issued on Mar. 25, 2014 as U.S. Pat. No. 8,679,096, which claims priority to U.S. Application 60/990,086, filed Nov. 26, 2007 and entitled "Multifunctional Operational Component," all of which are hereby incorporated herein by reference in their entireties. Additionally, U.S. application Ser. No. 12/324,364 is a continuation-in-part of U.S. application Ser. No. 12/192,779, filed Aug. 15, 2008 and entitled "Modular and Cooperative Medical Devices and Related Systems and Methods," which issued on Mar. 10, 2015 as U.S. Pat. No. 8,974,440, which claims priority to U.S. Application 60/956,032, filed Aug. 15, 2007, U.S. Application 60/990,076, filed Nov. 26, 2007, U.S. Application 60/990,106, filed Nov. 26, 2007, U.S. Application 61/025,346, filed Feb. 1, 2008, and U.S. Application 61/030,617, filed Feb. 22, 2008, all of which are hereby incorporated herein by reference in their entireties. Further, U.S. application Ser. No. 12/324,364 is a continuation-in-part of U.S. application Ser. No. 11/766,683, filed on Jun. 21, 2007 and entitled "Magnetically Coupleable Robotic Devices and Related Methods," which issued on Mar. 3, 2015 as U.S. Pat. No. 8,968,332, which claims priority to U.S. Application 60/815,741, filed Jun. 22, 2006, U.S. Application 60/845,608, filed Sep. 29, 2006, U.S. Application 60/868,030, filed Nov. 30, 2006, U.S. Application 60/884,792, filed Jan. 12, 2007, and U.S. Application 60/888,182, filed Feb. 5, 2007, all of which are hereby incorporated herein by reference in their entireties. In addition, U.S. application Ser. No. 12/324,364 is a continuation-in-part of U.S. application Ser. No. 11/966,741, filed Dec. 28, 2007 and entitled "Methods, Systems, and Devices for Surgical Visualization and Device Manipulation," which claims priority to U.S. Application 60/890,691, filed Feb. 20, 2007, U.S. Application 60/956,032, filed Aug. 15, 2007, and U.S. Application 60/983,445, filed Oct. 29, 2007, all of which are hereby incorporated herein by reference in their entireties.

## GOVERNMENT SUPPORT

This invention was made with government support under Grant No. R21EB5663-2, awarded by the National Institute of Biomedical Imaging and Bioengineering within the National Institutes of Health. Accordingly, the government has certain rights in the invention.

## FIELD OF THE INVENTION

The embodiments disclosed herein relate to various medical devices and related components, including robotic and/or in vivo medical devices and related components. Certain embodiments include various modular medical devices, including modular in vivo and/or robotic devices. In particular, certain embodiments relate to modular medical devices including various functional and/or multifunctional operational components. Further embodiments relate to methods of operating the above devices, including methods of using various of the devices cooperatively.



## BACKGROUND OF THE INVENTION

Invasive surgical procedures are essential for addressing various medical conditions. When possible, minimally invasive procedures such as laparoscopy are preferred.

However, known minimally invasive technologies such as laparoscopy are limited in scope and complexity due in part to 1) mobility restrictions resulting from using rigid tools inserted through access ports, and 2) limited visual feedback. Known robotic systems such as the da Vinci® Surgical System (available from Intuitive Surgical, Inc., located in Sunnyvale, Calif.) are also restricted by the access ports, as well as having the additional challenges of being very large, very expensive, unavailable in most hospitals, and having limited sensory and mobility capabilities.

## BRIEF SUMMARY OF THE INVENTION

One embodiment disclosed herein relates to a modular medical device or system having at least one modular component configured to be disposed inside a cavity of a patient. The modular component has a body, an operational component, and a coupling component. In a further embodiment, the modular component can be coupled at the coupling component to a second modular component. In a further alternative, a third modular component can be coupled to the first and second modular components.

Another embodiment disclosed herein relates to a modular medical device or system having a body configured to be disposed inside a cavity of a patient. The device also has at least a first modular component coupleable to the body, the first modular component having a first operational component. In another embodiment, the device also has a second modular component coupleable to the body, the second modular component having a second operational component. In further alternatives, the device can also have third and fourth modular components or more.

In certain embodiments, the operational component can be a multi-functional operational component. If more than one multi-functional operational component is provided, the multi-functional operational components can be the same as or different from one another. According to one embodiment, a multi-functional operational embodiment includes a first arm having any one of an irrigation component, a suction component, a cautery component, a biopsy component, a sensor component, or a treatment module and a second arm. In some embodiments, the second arm can also include any one of an irrigation component, a suction component, a cautery component, a biopsy component, a sensor component, or a treatment module.

Yet another embodiment disclosed herein relates to a modular medical device or system having a first modular component, a second modular component, and a third modular component. In one embodiment, the three modular components are pivotally connected to each other in a triangular configuration. In this embodiment, the first and third components can be coupled together at a releasable mating connection. According to one embodiment, each of the modular components has an inner body and an outer body, wherein the inner body is rotatable in relation to the outer body. In addition, each modular component has an operational component associated with the inner body. In accordance with another implementation, each of the inner and outer bodies comprise an opening, and each of the inner bodies is rotatable to position the inner and outer openings in communication, whereby the operational components are accessible. In a further alternative, each pivotal connection of the device or system has a mechanism configured to urge the mating or coupling connections at the ends of the first and third components into contact. Alternatively, the device has four modular components that are pivotally connected to each other in a quadrangular configuration. In further alternatives, additional modular components can be pivotally connected to each other.

While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. As will be realized, the invention is capable of modifications in various obvious aspects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a perspective view of a modular medical device, according to one embodiment.

FIG. **1**B is a side view of the modular medical device of FIG. **1**A.

FIG. **1**C is a front view of the modular medical device of FIG. **1**A.

FIG. **2**A depicts a perspective view of a modular component, according to one embodiment.

FIG. **2**B depicts a close-up perspective view of a portion of the modular component of FIG. **2**A.

FIG. **3** is a perspective view of another modular component, according to another embodiment.

FIG. **4** is a front cutaway view of another modular component, according to a further embodiment.

FIG. **5**A is a perspective view of a modular medical device control system, according to one embodiment.

FIG. **5**B is a front cutaway view of the system of FIG. **5**A.

FIG. **6**A is a perspective view of a modular medical device control and visualization system, according to one embodiment.

FIG. **6**B is a front cutaway view of the system of FIG. **6**A.

FIG. **7**A is a perspective cutaway view of a modular medical device control and visualization system, according to another embodiment.

FIG. **7**B is a front cutaway view of the system of FIG. **7**A.

FIG. **8**A is a perspective view of a modular medical device, according to another embodiment.

FIG. **8**B is another perspective view of the device of FIG. **8**A.

FIG. **9** is a perspective view of another modular medical device, according to a further embodiment.

FIG. **10** is a perspective view of a further modular medical device, according to another embodiment.

FIG. **11** is a perspective view of another modular medical device, according to one embodiment.

FIG. **12**A is a perspective view of another modular medical device, according to a further embodiment.

FIG. **12**B is a close-up perspective view of a part of the device of FIG. **12**A.

FIG. **12**C is another perspective view of the device of FIG. **12**A.

FIG. **13** is a perspective view of a further modular medical device, according to another embodiment.

FIG. **14** is a perspective view of the disassembled components of another modular medical device, according to one embodiment.

FIG. **15** is a perspective view of the disassembled components of a further modular medical device, according to another embodiment.

FIG. **16** is a perspective view of the disassembled components of a further modular medical device, according to another embodiment.

FIG. **17** is a perspective view of an assembled modular medical device, according to a further embodiment.

FIG. **18**A is a close-up, schematic view of an operational component according to one embodiment.

FIG. **18**B is a schematic view of a robotic device including the operational component shown in FIG. **18**A.

FIG. **19**A is a close-up, schematic view of an operational component according to one embodiment.

FIG. **19**B is a schematic view of a robotic device including the operational component shown in FIG. **19**A.

FIG. **20**A is a close-up, schematic view of an operational component according to one embodiment.

FIG. **20**B is a schematic view of a robotic device including the operational component shown in FIG. **20**A.

FIG. **20**C is a close-up schematic view of an operational component according to an embodiment.

FIGS. **21**A-**21**C are close-up, schematic views of an operational component according to various embodiments.

FIG. **22** is a close-up, schematic view of an operational component according to an embodiment.

FIG. **23** is a close-up, schematic view of an operational component according to one embodiment.

FIG. **24** is a close-up, schematic view of an operational component according to one embodiment.

FIG. **25** is a close-up, schematic view of an operational component according to one embodiment.

FIG. **26**A is a front view of a modular medical device with a payload space, according to one embodiment.

FIG. **26**B is another front view of the device of FIG. **26**A.

FIG. **27**A is a perspective view of a modular medical device, according to another embodiment.

FIG. **27**B is a perspective bottom view of the device of FIG. **27**A.

FIG. **28**A is a perspective top view of the device of FIG. **27**A.

FIG. **28**B is a perspective side view of the device of FIG. **27**A.

FIG. **28**C is a perspective close-up view of a portion of the device of FIG. **27**A.

FIG. **29** is a perspective bottom view of the device of FIG. **27**A.

FIG. **30** is a perspective side view of the device of FIG. **27**A.

FIG. **31** is a top view of the device of FIG. **27**A.

FIG. **32** is a perspective view of modular medical device control and visualization system, according to one embodiment.

FIG. **33** is a perspective view of a modular medical device, according to one embodiment.

FIG. **34** is a perspective cutaway view of various medical devices operating cooperatively in a body cavity, according to one embodiment.

FIG. **35** is a perspective cutaway view of various medical devices operating cooperatively in a body cavity, according to another embodiment.

FIG. **36** is a perspective cutaway view of various medical devices operating cooperatively in a body cavity, according to a further embodiment.

## DETAILED DESCRIPTION

The various systems and devices disclosed herein relate to devices for use in medical procedures and systems. More specifically, various embodiments relate to various modular or combination medical devices, including modular in vivo and robotic devices and related methods and systems, while other embodiments relate to various cooperative medical devices, including cooperative in vivo and robotic devices and related methods and systems.

It is understood that the various embodiments of modular and cooperative devices and related methods and systems disclosed herein can be incorporated into or used with any other known medical devices, systems, and methods.

For example, the various embodiments disclosed herein can be incorporated into or used with any of the medical devices and systems disclosed in copending U.S. applications Ser. No. 11/932,441 (filed on Oct. 31, 2007, and entitled "Robot for Surgical Applications"), Ser. No. 11/695,944 (filed on Apr. 3, 2007, and entitled "Robot for Surgical Applications"), Ser. No. 11/947,097 (filed on Nov. 27, 2007, and entitled "Robotic Devices with Agent Delivery Components and Related Methods), Ser. No. 11/932,516 (filed on Oct. 31, 2007, and entitled "Robot for Surgical Applications"), Ser. No. 11/766,683 (filed on Jun. 21, 2007, and entitled "Magnetically Coupleable Robotic Devices and Related Methods"), Ser. No. 11/766,720 (filed on Jun. 21, 2007, and entitled "Magnetically Coupleable Surgical Robotic Devices and Related Methods"), Ser. No. 11/966,741 (filed on Dec. 28, 2007, and entitled "Methods, Systems, and Devices for Surgical Visualization and Device Manipulation"), Ser. No. 12/171,413 (filed on Jul. 11, 2008, and entitled "Methods and Systems of Actuation in Robotic Devices"), 60/956,032 (filed on Aug. 15, 2007), 60/983,445 (filed on Oct. 29, 2007), 60/990,062 (filed on Nov. 26, 2007), 60/990,076 (filed on Nov. 26, 2007), 60/990,086 (filed on Nov. 26, 2007), 60/990,106 (filed on Nov. 26, 2007), 60/990,470 (filed on Nov. 27, 2007), 61/025,346 (filed on Feb. 1, 2008), 61/030,588 (filed on Feb. 22, 2008), and 61/030,617 (filed on Feb. 22, 2008), all of which are hereby incorporated herein by reference in their entireties.

Certain device implementations disclosed in the applications listed above can be positioned within a body cavity of a patient, including certain devices that can be positioned against or substantially adjacent to an interior cavity wall, and related systems. An "in vivo device" as used herein means any device that can be positioned, operated, or controlled at least in part by a user while being positioned within a body cavity of a patient, including any device that is positioned substantially against or adjacent to a wall of a body cavity of a patient, further including any such device that is internally actuated (having no external source of motive force), and additionally including any device that may be used laparoscopically or endoscopically during a surgical procedure. As used herein, the terms "robot," and "robotic device" shall refer to any device that can perform a task either automatically or in response to a command.

Certain implementations disclosed herein relate to modular medical devices that can be assembled in a variety of configurations.

FIGS. **1A-1C** depict an exemplary "combination" or "modular" medical device **10**, according to one embodiment. For purposes of this application, both "combination device" and "modular device" shall mean any medical device having modular or interchangeable components that can be arranged in a variety of different configurations. The combination device **10** shown in FIGS. **1A-1C** has three modular components **12**, **14**, **16** coupled or attached to each other. More specifically, the device **10** has two robotic arm modular components **12**, **14** and one robotic camera modular component **16** disposed between the other two components **12**, **14**. In this implementation, the modular component **16** contains an imaging component (not shown) and one or more lighting components (not shown), while each of the other modular components **12**, **14** have an arm **24**, **26** respectively and do not contain any lighting or imaging components. That is, in this embodiment, the modular component **16** is a modular imaging and lighting component **16** while the two modular components **12**, **14** are modular arm components **12**, **14**. In the resulting configuration, the components **12**, **14**, **16** are coupled or attached to each such that the camera component **16** is disposed between the two modular arm components **12**, **14**. As will be discussed in further detail below, this configuration of the components **12**, **14**, **16** is merely one of several possible configurations of such modular components.

In accordance with one embodiment, the strategic positioning of various operational components in the combination device **10** in FIGS. **1A-1C** results in an optimization of the volume in each of the individual components **12**, **14**, **16**. That is, the space in modular components **12**, **14** that would have been required for an imaging component and/or a lighting component is instead utilized for larger and/or more complex actuators or other components. If larger or more complex actuators are utilized in both modular components **12**, **14**, greater force can be applied to each arm **24**, **26**, thereby making it possible for the combination device **10** to perform additional procedures that require greater force.

In comparison to the space optimization advantage of the combination device **10**, a non-combination device must have all the necessary components such as imaging and illumination components in the device body along with the actuators, thereby reducing the space available and requiring that the actuators and other components be small enough such that they all fit in the device together.

According to one alternative embodiment, the additional space available in the combination device **10** created by the space optimization described above could be used to provide for more sophisticated components such as more complex camera focusing mechanisms or mechanisms to provide zoom capabilities. In a further alternative, the various components could be distributed across the modular components **12**, **14**, **16** of the combination device **10** in any fashion. For example, the illumination and imaging components could be both positioned in either modular component **12** or **14**. Alternatively, one of the illumination and imaging components could be disposed in any one of the three modular components **12**, **14**, **16** and the other component could be disposed in one of the other three components **12**, **14**, **16**. It is understood that any possible combination of various components such as illumination, actuation, imaging, and any other known components for a medical device can be distributed in any combination across the modular components of any combination device.

Another advantage of the combination devices such as that shown in FIGS. **1A-1C**, according to one implementation, is the capacity to increase the number of a particular type of component in the device. For example, one embodiment of a combination device similar to the device **10** in FIGS. **1A-1C** could have lighting components on more than one of the modular components **12**, **14**, **16**, and further could have more than one lighting component on any given modular component. Thus, the combination device could have a number of lighting components ranging from one to any number of lighting components that could reasonably be included on the device. The same is true for any other component that can be included in two or more of the modular components.

In accordance with a further embodiment, another possible advantage of the various combination device embodiments disclosed herein relates to the fact that the various separable modular components (instead of one larger device) simplifies insertion because each component separately is shorter and less complex. Thus, each component individually has a smaller cross-section and can be inserted into a body cavity through a smaller incision, port, or any other known delivery device than the larger, non-combination device.

It is understood that, according to various embodiments, a combination device such as the device **10** depicted in FIGS. **1A-1C** could have additional modular components coupled thereto. Thus, the device could have additional arms or other modular components such as, for example, one or more of a sensing modular component, an illumination modular component, and/or a suction/irrigation modular component.

In use, modular components (such as, for example, components **12**, **14**, **16** of FIGS. **1A**, **1B**, and **1C**) are each separately inserted into the target cavity of a patient. Typically, each of the components are inserted through a laparoscopic port, an incision, or a natural orifice. Alternatively, the components are inserted by any known method, procedure, or device. Once each of the desired components (which could range from one to several components) is positioned in the target cavity, the components can be assembled into a combination device such as, for example, the combination device **10** depicted in FIGS. **1A-1C**, by coupling the components together in a desired configuration. After the procedure has been performed, the components of the combination device can be decoupled and each separately removed. Alternatively, once a portion of a procedure is performed, one or more of the components can be decoupled and removed from the cavity and one or more additional components can be inserted into the cavity and coupled to the combination device for one or more additional procedures for which the component replacement was necessary.

The various modular component embodiments disclosed herein can be coupled to create a combination device in a variety of ways. To configure the combination device **10** as shown in FIG. **1A**, the exemplary modular components **12**, **14**, **16** each have four mating or coupling components as best shown in FIGS. **2A**, **2B**, and **3**.

In FIGS. **2A** and **2B**, the modular component **16** provides one example of an attachment mechanism for coupling modular components together. That is, the device **16** has four mating or coupling components **34A**, **34B**, **35A**, (and **35B**, which is not shown) for coupling to other devices or modular components. In this embodiment as best shown in FIG. **2A**, there are two coupling components **34**, **35** at each end of the device **30**, with two components **34A**, **34B** at one end and two more at the other end (depicted as **35A** and another such component on the opposite side of the component **16** that is not visible in the figure). Alternatively, the modular component **16** can have one coupling component, two coupling components, or more than two coupling components.

To better understand the coupling components of this embodiment, FIG. **2B** provides an enlarged view of one end of the device **16**, depicting the male coupling component **34A** and female coupling component **34B**. The male component **34A** in this embodiment is configured to be coupleable with a corresponding female component on any corresponding modular component, while the female component **34B** is configured to be coupleable with a corresponding male component on any corresponding modular component.

It is understood that the mechanical male/female coupling components discussed above are merely exemplary coupling mechanisms. Alternatively, the components can be any known mechanical coupling components. In a further alternative, the coupling components can also be magnets that can magnetically couple with other magnetic coupling components in other modular components. In a further embodiment, the coupling components can be a combination of magnets to help with initial positioning and mechanical coupling components to more permanently couple the two modules.

Returning to the embodiment depicted in FIG. **1A**, two modular components **12**, **14**, each having an arm **24**, **26** (respectively), are coupled to the modular component **16**. FIG. **3** depicts component **12**, but it is understood that the following discussion relating to modular component **12** applies equally to component **14**. Modular component **12** as shown in FIG. **3** has male/female coupling components **44**, **45** that can be coupled to component **16** as discussed above. Alternatively, as discussed above, any known coupling components can be incorporated into this component **12** for coupling with other modular components.

According to one implementation, the arm **24** in the embodiment of FIG. **3** provides the four degrees of freedom ("DOF"). These four degrees of freedom include three rotations and one extension. Two rotations occur about the joint **42**. The third rotation occurs along the axis of the arm **24**. The extension also occurs along the axis of the arm **24**. Alternatively, any known arm implementation for use in a medical device can be used.

FIG. **4** depicts an alternative exemplary embodiment of modular component **12**. In this implementation, the actuator components **54A**, **54B**, **56A**, **56B** are depicted in the component **12**. That is, two actuators **54A**, **54B** are provided in the body of the device **12**, while two additional actuators **56A**, **56B** are provided in the arm **24**. According to one embodiment, actuators **54A**, **54B** are configured to actuate movement of the arm **24** at the shoulder joint **58**, while actuators **56A**, **56B** are configured to actuate movement at the arm **24**. Alternatively, it is understood that any configuration of one or more actuators can be incorporated into a modular component to actuate one or more portions of the component or device.

In accordance with further implementations, it is understood that the various modular components discussed herein can contain any known operational components contained in any non-modular medical device. For example, the modular component **16** has a camera **32** and further can have all of the associated components and/or features of the modular components or medical devices discussed above, including the medical devices and components disclosed in the applications incorporated above.

In the depicted embodiment, the modular component **16** has a connection component or "cable" **22** that can be connected at the other end of the cable **22** to a controller (not shown). Similarly, each of modular components **12**, **14** also can have a connection component (**18**, **20** respectively). In alternative implementations, the combination device **10** could have a single cable connected to one of the modular components. In such implementations, the coupling components also provide for communication connections among the modular components such that power, control signals or commands, video, and any other form of communication can be transported or communicated among the modular components.

In use, the various modular components and combination devices disclosed herein can be utilized with any known medical device control and/or visualization systems, including those systems disclosed in the applications incorporated above. These modular components and combination devices can be utilized and operated in a fashion similar to any medical devices disclosed in those applications. For example, as shown in FIGS. **5**A and **5**B, a combination device or modular component **60** can be utilized with an external magnetic controller **62**. In this embodiment, the device **60** has magnetic components (not shown) that allow the device **60** to be in magnetic communication with the external controller **62**. It is understood that the device **60** can operate in conjunction with the external controller **62** in the same fashion described in the applications incorporated above.

In an alternative use, any of the individual modular components can operate as an independent device as well. That is, it is understood that any individual component can be inserted into a body cavity and operated without coupling it to any other modular components. As such, each modular component can also be considered a separate device.

In another similar example as depicted in FIGS. **6**A and **6**B, a combination device or modular component **70** can be utilized with an external controller and visualization component **72**. In this embodiment, the device **70** has magnetic components (not shown) that allow the device **70** to be in magnetic communication with the external controller **72** and further has arms **74**A, **74**B that can be operated using the controller **72**. It is understood that the device **70** can operate in conjunction with the external component **72** in the same fashion described in the applications incorporated above.

According to one implementation, a modular device can be used for a variety of surgical procedures and tasks including, but not limited to, tissue biopsy and tissue retraction. For example, as shown in FIGS. **7**A and **7**B in accordance with one embodiment, a device **80** having a grasper **82** can be used to retract the gall bladder **84** during a cholecystectomy procedure.

In accordance with one alternative, any of the modular components disclosed herein can be assembled into the combination device prior to insertion into the patient's cavity. One exemplary embodiment of such a combination device is set forth in FIGS. **8**A and **8**B, which depict a combination device **120** having modular components **122**A, **122**B, **122**C, **122**D, **122**E that are coupled to each other using hinge or rotational joints **124**A, **124**B, **124**C, **124**D, **124**E (as best shown in FIG. **8**B). This device **120** as shown can fold together or otherwise be configured after insertion as shown in FIG. **8**A. One advantage of this embodiment, in which the modular components **122**A-**122**E are coupled to each other, is that in vivo assembly of the combination device **120** is simplified.

In a further alternative embodiment as best shown in FIG. **9**, any of the modular components disclosed or contemplated herein are inserted separately into the target cavity and subsequently assembled with the modular components being connected end-to-end (in contrast to a side-by-side configuration similar to that depicted in FIGS. **1**A-**1**C). More specifically, the combination device **130** in FIG. **9** has three modular components **132**, **134**, **136**. One of the components is a camera modular component **132**, while the other two are robotic arm modular components **134**, **136**. These three components **132**, **134**, **136** are connected to form the tripod-like combination device **130** as shown.

In yet another implementation, FIG. **10** depicts another combination device **140** having a generally triangular configuration. That is, the device **140** has three arm modular components **142**, **144**, **146** that are coupled together end-to-end, with each component **142**, **144**, **146** having an arm **148**, **147**, **149**, respectively. In one embodiment, the three-armed robot could be assembled using three one-arm segments as shown in FIG. **10**. Alternatively, the three-armed robot could be assembled by linking three modular bodies end-to-end and coupling an arm component to each linkage of the modular bodies.

Alternatively, additional modular components could be added to a tripod-like combination device such as the devices of FIGS. **9** and **10**. For example, one or more additional modular components could be positioned adjacent and parallel to one or more of the three previously-coupled modular components such that one or more sides of the three sides have a "stacked" configuration with at least two modular components stacked next to each other.

As mentioned above, according to one embodiment, a particularly useful aspect of using modular medical devices during medical procedures, including modular robotic and/or in vivo devices as described herein, is the ability to insert multiple modular components, such as any of the modular components described or contemplated herein, into a patient's body and subsequently assemble these into a more complex combination device in vivo. In one implementation, more than one modular component is inserted or positioned in the patient's body (through a natural orifice or more conventional methods) and then the components are either surgically assembled or self-assembled once inside the patient's body, in a location such as the peritoneal cavity, for example.

Surgical (or procedural) assembly can involve the surgeon attaching the modular components by using standard laparoscopic or endoscopic tools, or could involve the surgeon using specifically developed tools for this purpose. Alternatively, surgical assembly could instead or further include the surgeon controlling a robotic device disposed within the patient's body or exterior to the body to assemble the modular components. Self assembly, on the other hand, can involve the modular components identifying each other and autonomously assembling themselves. For example, in one embodiment of self assembly, the modular components have infrared transmitters and receivers that allow each component to locate attachment points on other components. In another example, each modular component has a system that utilizes imaging to identify patterns on other modular components to locate attachment points on those other components. In a further alternative, assembly could also include both surgical and self-assembly capabilities.

After the surgical procedure is completed, the components are disassembled and retracted. Alternatively, the robotic device or system can be configurable or reconfigurable in vivo to provide different surgical features during different portions of the procedure. That is, for example, the components of the device or devices can be coupled together in one configuration for one procedure and then disassembled and re-coupled in another configuration for another procedure.

One further exemplary embodiment of a suite of modular components is set forth in FIGS. **11-17**. It is understood that such a suite of components can be made available to a surgeon or user, and the surgeon or user can utilize those components she or he desires or needs to create the combination device desired to perform a particular procedure. In one embodiment, since the devices and components are modular, the user (or team) can assemble the procedure-specific robotic device or devices in vivo at the onset of the procedure.

The modular components can include any known procedural or operational component, including any component discussed elsewhere herein (such as those depicted in FIGS. **1A-4**, and/or **8A-10**) or any component disclosed in the applications incorporated above that can be used as modular component. For example, the various modular components depicted in FIGS. **11-17** include a variety of different operational components or other types of components, as will be described in further detail below.

More specifically, FIGS. **11-13** depict various modular combination device embodiments having a body that is coupled to at least one arm component and a lockable tube. For example, FIG. **11** shows a combination device **150** having a body **152** coupled to three operational arm components **154**A, **154**B, **154**C, and a lockable tube **156**. In one aspect, the body **152** can also have at least one magnet **158** (or two magnets as depicted in the figure) that can be used to position the device within the patient's cavity. That is, according to one implementation similar to those described above in relation to other devices, the magnet(s) **158** can be magnetically coupled to an external magnet controller or visualization component to position the device **150**.

The lockable tube **156** can be a reversibly lockable tube as disclosed in U.S. application Ser. No. 12/171,413, filed on Jul. 11, 2008, which is incorporated by reference above. The tube **156** and device **150** can be operated in any fashion as described in that application. Alternatively, the tube **156** can be a flexible tube that can be stabilized or held in place using a series of magnets adjacent to or near the flexible tube or a series of needles inserted through the external wall of the patient's body. For example, magnets can be positioned in one or more of the modular components of the flexible tube. In use, one or more magnets are positioned externally with respect to the target cavity in such a fashion as to position the tube and/or robotic device into the desired location.

In use, as also described in the above-incorporated application, a reversibly lockable tube and robotic device (such as, for example, the tube **156** and device **150** depicted in FIG. **11**) can be used together to accomplish various tasks. That is, the tube can be operably coupled to the device (as shown in FIG. **11**, for example) and contain any required connection components such as connections for hydraulic, pneumatic, drive train, electrical, fiber optic, suction, or irrigation systems, or any other systems or connections that require physical linkages between the device positioned in the patient's body and some external component or device. In one embodiment, the robotic device is first positioned at the desired location in the patient's body and then the tube is inserted and connected to the device. Alternatively, the robotic device can be coupled to the tube prior to insertion, and then both the device and the tube are inserted into the patient's body and the device is then positioned at the desired location.

FIGS. **12**A-**12**C depict another embodiment of a combination device coupled to a lockable tube. More specifically, FIGS. **12**A, **12**B, and **12**C depict a combination device **160** having a body **162** coupled to one operational arm component **164** and a lockable tube **166**. As with the device in FIG. **11**, the body **162** has two magnets **168** that can be used in conjunction with an external magnet controller to position the device **160** and tube **166** as desired by the user. Alternatively, the body **162** can have one magnet or more than two magnets. In addition, according to one embodiment as best shown in FIG. **12**A, the device **160** and the tube **166** can be initially unattached. Prior to use, the body **162** and tube **166** can be coupled as best shown in FIG. **12**B. In one embodiment, the body **162** and tube **166** can be coupled prior to insertion or alternatively can be coupled after the device **160** and tube **166** have been positioned in the desired location in the patient's body.

FIG. **13** shows another embodiment of another combination device **170** similar to those depicted in FIGS. **11-12**C except that the body **172** is coupled to the tube **174** at a location along the body **172** rather than at an end of the body **172**. It is further understood that a tube as disclosed herein can be coupled to any of these combination devices at any point along the body or any of the modular components.

Another example of a combination device that is made up of a suite of modular components is set forth in FIG. **14**. The combination device **180** has an imaging modular component **182** (also referred to as a "module"), two cautery arms or modules **184**A, **184**B, and two grasper arms or modules **186**A, **186**B. It is understood that the imaging module **182** in this embodiment is the body **182** of the device **180**, but could also be an arm in another implementation. It is further understood that the various modules **184**, **186** coupled to the device **180** could be configured in any configuration.

An alternative combination device embodiment utilizing various modules from a suite of modular components is depicted in FIG. **15**. This device **190** has an imaging module **192**, a cautery module **194**, a grasper module **196**, and a lighting module **198**. Similarly, FIG. **16** depicts yet another alternative combination device **200** having an imaging module **202**, a lighting module **204**, a cautery module **206**, and two grasper modules **208**.

FIG. **17** depicts a further alternative implementation of a fully assembled combination device **210** having a body **212**, two cautery modules **214**A, **214**B, and two grasper modules **216**A, **216**B. As shown in the figure, each of the modules is coupled to the body via a hinge coupling **218**A, **218**B, **218**C, **218**D. Alternatively, the coupling can be any known coupling, including, for example, a pivotal coupling. In a further alternative, the non-arm modules can be substantially or removably fixed to the body component, such as the lighting module **204** depicted in FIG. **16**.

It is understood that any number of additional exemplary modular components could be included in the suite of modular components available for use with these devices. For example, various additional exemplary modules include, but are not limited to, an imaging module, a sensor module (including a pH, humidity, temperature, and/or pressure sensor), a stapler module, a UV light module, an X-ray module, a biopsy module, or a tissue collection module. It is understood that "module" is intended to encompass any modular component, including an arm or a body as discussed above.

Various modules including a variety of exemplary operational components will now be described. An operational component, as described herein, is generally associated with a robotic device, and may have one or more subcomponents or functionalities. An operational component may also be referred to as an "end effector." It is generally understood that any one of the exemplary operational components and modules described below can be included in a suite of modular components used to form the robotic devices as described herein according to the various embodiments. In a further embodiment, any of the operational components described herein can be used in conjunction with any non-modular versions of these devices or systems. Additionally, the exemplary operational components and modules can be used with other surgical robotic devices as are known to those of skill in the art.

FIGS. **18**A and **18**B depict a robotic device **300** according to one embodiment. As shown in FIGS. **18**A and **18**B the device **300** has two arms **312**, **314** each having a first link **312***a*, **314***a* and a second link **312***b*, **314***b*. Each arm **312**, **314** also includes operational components **316**, **318** operably coupled at distal end **320**, **322** of each arm **312**, **314**. The operational components **316**, **318** can be the same or different from one another. In one embodiment, at least one of operational components **316**, **318** is a multi-functional operational component as described herein. In another embodiment, both of the operational components **316**, **318** are multifunctional operational components as described herein. "Multi-functional operational components" are operational components capable of performing more than one function.

In some embodiments, the robotic device **300** can also include a body **324** that is a viewing module having appropriate lighting and/or a camera to assist in viewing the procedure. As shown in FIGS. **18**A and **18**B, the body **324** is disposed between and is coupled to the two arms **312**, **314**.

FIG. **19**A is a close-up schematic view of an operational component **330** according to one embodiment. As shown in FIGS. **19**A and **19**B, the operational component **330** is a grasper (also referred to herein as "forceps") operably coupled to a distal end **332** of an arm **334** of an exemplary robotic device **340**. According to one implementation, the forceps **330** are commercially-available forceps **330**, such as the forceps available from U.S. Surgical, a subsidiary of Covidien, located in North Haven, Conn.

As shown best in FIG. **19**A, the grasper **330** includes a first arm **336** and a second arm **338**. In this embodiment, the first arm **336** includes an irrigation component **342** coupled to the arm **336** including a nozzle **344** and providing for irrigation with a liquid by ejecting the liquid from the nozzle **344**. In addition, the second arm **338** includes a suction component **346**.

In one implementation, the irrigation component **342** and suction component **346** are both thin-walled conduits made of a polymer. For each component **342**, **346**, the conduit (also referred to herein as "tubing") can be commercially available extruded tubing of various sizes depending on the specific application. Methods or techniques for attaching the conduit **342**, **346** to the grasper **330** can include any appropriate fasteners or adhesives. According to one embodiment, the nozzle **344** can be a commercially available nozzle, or alternatively can be a specifically designed nozzle that directs the fluid flow as needed.

In accordance with a further alternative embodiment, each of the suction **346** and irrigation **342** components are manufactured as part of the grasper arms **336**, **338**. More specifically, the suction component **346** is an integral component of and/or is manufactured as a part of the grasper arm **338**, while the irrigation component **342** is an integral component of and/or is manufactured as a part of the grasper arm **336**. For example, according to one implementation, the conduits could be formed in the structure of the grasper arms **336**, **338** such that the conduits do not protrude from the side of the arms **336**, **338**. Alternatively, the grasper arms **336**, **338** could be molded such that the conduits are disposed within the arms **336**, **338**. For example, the arm and conduit can be manufactured using stainless steel through a metal injection molding process. In a further alternative, the conduits could be machined into the arms **336**, **338** by any traditional machining techniques. In yet another alternative, the grasper arm **336**, **338** and conduit are manufactured using a polymer-based rapid prototyping method such as stereolithography. Alternatively, the conduits could be formed in the structure of the arms **336**, **338** by any known technique.

FIG. **19**B provides a complete view of the robotic device **340** to which the operational component **300** is coupled. As shown in FIG. **19**B, the irrigation component **342** has an irrigation connection component **352** (also referred to as an "irrigation line" or "irrigation tube") that is connected at one end to the component **342** and at the other end to a liquid source **354**. According to one embodiment, the irrigation connection component **352** is a thin-walled conduit made of a polymer. In embodiments in which the irrigation component **342** is a part of the grasper arm **336**, the polymer conduit of the connection component **352** connects or couples to the irrigation component **342** at a proximal end **356** of the grasper arm **26**.

In some embodiments, as shown in FIG. **19**B, the liquid source **354** is an external liquid source **354** and is disposed at a location or position that is external to the robotic device **340**. A pump (not shown) is also provided to power the irrigation component **342**. In one embodiment, the pump can be a commercially-available surgical irrigation pump such as those available from Nellcor (a subsidiary of Covidien) or KMC Systems which is located in Merrimack, N.H. The pump, and thus the irrigation component **342**, can be controlled by a controller (not shown) or microprocessor, which can be associated with or coupled to the pump. The controller or microprocessor may be associated with or connected to the pump via a wired or wireless connection.

In other embodiments, the liquid source **354** can be associated with, incorporated into, or disposed within the robotic device **340**. In one embodiment, a pump can be operatively coupled to the liquid source **354**. The pump can be a mechanical bellow, a mechanical pump, or any known pump suitable for use with an irrigation system such as any of the irrigation embodiments disclosed herein. In still other embodiments, the liquid source **354** is a pressurized reservoir that does not require an auxiliary pump.

According to a further embodiment, the irrigation component **354** can be used to deliver a drug or combination of drugs to the procedure site or other site within a patient's body as designated by the clinician. The drugs or any other type of treatment composition can be provided in fluid or gel form or any other form that can be injected via a delivery device. In one embodiment, these drugs could include chemotherapy drugs.

As also shown in FIG. **19**B, the suction component **346** has a suction connection component **362** connected to the component **346** and further connected to a suction source **364**. According to one embodiment, the suction connection component **362** is a thin-walled conduit made of a polymer. In embodiments in which the suction component **346** is a part of the grasper arm **338**, the polymer conduit of the connection component **362** connects or couples to the suction component **346** at a proximal end **366** of the grasper arm **28**.

In one embodiment, as shown in FIG. **19**B, the suction source **364** is an external suction source **364** and is disposed at a location or position that is external to the robotic device **340**. A pump (not shown) is also provided to power the suction source **364**. According to one embodiment, the pump is a commercially-available aspiration suction unit such as the devices available from Paragon Medical, located in Pierceton, Ind. The pump, and thus the suction component **346**, can be controlled by a controller or microprocessor (not shown), which can be associated with or coupled to the pump by a wired or a wireless connection. In other embodiments, the suction source **64** can be associated with, incorporated into, or disposed within the robotic device **340**. In one embodiment, a pump is coupled to the suction source. The pump can be a mechanical bellow, a mechanical pump, or any known pump for use with a suction system such as any of the suction embodiments disclosed herein. In still other embodiments, the suction source is a vacuumed reservoir that does not require an additional pump.

FIGS. **20**A and **20**B depict another embodiment of a grasper **400** of a robotic device **410** in which the first arm **412** includes a cautery component **414** coupled with or integrated into the first arm **412**. According to one embodiment, the cautery component **414** is a wire **414** coupled to the first arm **412**. The cautery component **414** can be any wire **414** having a large electrical resistance such that it is heated by passing an electrical current through the wire **414**. In one embodiment, the cautery wire **414** is composed of a metal alloy that provides a very high electrical resistance. One example of the composition of the wire **414** is commercially-available 80/20 Nickel-Chrome alloy (80% Nickel, and 20% Chrome).

According to some embodiments, as shown in FIG. **20**A, the second arm **416** of the grasper **400** can also include a cautery component **418**. In some embodiments, only one of the two arms **412**, **416** has a cautery component.

In one implementation, the cautery wire **414** and/or **418** is secured to the grasper arm **412** and/or **416** using high-temperature adhesives or mechanical fasteners. In another embodiment, the arms **412**, **416** of the grasper **400** are metal injection molded and the cautery wire **414** and/or **416** is molded into the arm **52**. In one embodiment, the cautery component **414** and/or **416** can be attached to the inside of the arm **412** and/or **416**, or along the side or bottom of the grasper arm **412** and/or **416**, depending on the specific application. In a further embodiment, the cautery component **414** and/or **416** can be attached to a distal tip **420** and/or **422** of the arm **412** and/or **414**.

An insulation component (not shown) is provided in certain embodiments between the cautery component **414** and the first arm **412**, thereby electrically isolating the cautery component **414** from the first arm **412** and preventing the arm **412** from acting as a heat sink or otherwise reducing the effectiveness of the cautery component **414**. A similar configuration can also be provided for the cautery component **418** on the second arm **416** when such a cautery component **418** is provided.

FIG. **20**B provides a complete view of the robotic device **410** to which the operational component **400** is coupled. As shown in FIG. **20**B, the cautery component **414** is coupled to an external power source **424** via an electrical connection **426** that runs through the robotic device **410**. In this embodiment, while the cautery component **414** can be a high resistance wire **414**, the electrical connection **426** connecting the component **400** to the power source **424** is not a high resistance wire. The external power source **424** can be any power source that is positioned at a location external to the robotic device **410**. In one exemplary embodiment, the power source **424** is a battery. Alternatively, the power source **424** can be associated with, incorporated into, or disposed within the robotic device **410**.

According to some embodiments, a controller or microprocessor (not shown), is provided for control of the cautery component **414**. In one embodiment, the controller can be a switch that is positioned on the external power source **424**. In other embodiments, the controller can be a separate component that is coupled to the power source **424** via a wired or a wireless connection. In implementations in which the power source **424** is an internal power source, the controller is provided as a separate component.

In some embodiments, there is no need for actuating the cautery component **414** with a switch or other type of separate cautery controller. For example, the cautery component **414** depicted in FIG. **20**C is actuated when the grasper arms **412**, **416** are positioned within a certain proximity of each other. In this embodiment, as the grasper arms **412**, **416** are moved closer to each other and pass a predetermined threshold, the cautery component **414** is actuated. According to one embodiment, this functionality is accomplished with a sensor **430**. The sensor **430** senses the positioning of the arms **412**, **416** and actuates the power source (not shown) when the arms **412**, **416** pass a predetermined location or position. In one embodiment, the sensor **430** is positioned in the robotic arm **432** and operatively coupled to the grasper arms **412**, **416** as depicted. Alternatively, the sensor **730** can also be positioned on one of the grasper arms **412**, **416**.

In one embodiment, the sensor **430** is a commercially-available infrared sensor. For example, the sensor **430** could be a sensor such as the sensors manufactured by Fairchild Semiconductor, located in South Portland, Me. Alternatively, the sensor **430** is a commercially-available rotational or translational variable resistance potentiometer.

According to another implementation, the multifunctional operational component can be a biopsy component. For example, FIGS. **21**A, **21**B, and **21**C depict a grasper **450** including a first arm **452** and a second arm **454**. The first arm **452** includes a biopsy component **456**. In other embodiments, both grasper arms **452**, **454** include a biopsy component such that more than one tissue sample can be taken. In still another embodiment, one or both of the arms **452**, **454** can include more than one biopsy component.

In one implementation, the biopsy component includes a reservoir **458** and a cutting tool **460**. The cutting tool can be a knife blade, a rotary cutter, or other cutting instrument. In the implementation depicted in FIGS. **21**A and **21**B, the knife **460** is slidable between a closed and an open position. In the closed position, the cutting tool **460** is positioned to cover the reservoir **458** and thereby act as a lid or cover for the reservoir **458**. In the open position, the cutting tool **460** is positioned adjacent to the reservoir **458** with the cutting edge **462** adjacent to the reservoir **458**.

In use, according to one embodiment, the cutting tool **460** can be used to obtain a biopsy sample in the following manner. The cutting tool **460** is positioned or urged into the open position (position A as shown in FIG. **21**A). In this position, the reservoir **458** is exposed or open. The arms **452**, **454** can then be used to grasp or otherwise be positioned with respect to a specimen of interest such that the cutting tool **460** can then be urged or otherwise moved toward the closed position B. As the cutting tool **460** moves toward the closed position B, the cutting edge **462** contacts the specimen of interest and cuts the specimen. Then, as the cutting tool **460** reaches the closed position B (shown in FIG. **21**B), the cut portion of the specimen is positioned in the reservoir **458** and the cutting tool **460** is positioned in the closed position B, thereby closing the opening of the reservoir **458** and retaining the cut specimen in the reservoir **458**.

In another embodiment, the cutting tool **460** and the reservoir cover or lid are separate components in which the cutting tool **460** is used to cut the specimen and the cover or lid is used to cover or close the reservoir **448**.

According to the embodiments depicted in FIGS. **21**A and **21**B, the cutting tool **90** travels between position A and position B along a track (not shown) that is formed into or associated with the grasper arm **452**. In another embodiment, the cutting tool **460** can operate by rotating in a plane parallel with the grasper face as shown in FIG. **21**C.

According to some embodiments, the biopsy component **456** can include a cutting tool actuation component (not shown). The cutting tool actuation component can be a pre-loaded spring or series of pre-loaded springs that move between a coiled or tensioned position and an uncoiled or released position to actuate the cutting tool to slide shut over the reservoir. For example, in one embodiment, the pre-loaded spring is operably coupled to a switch (not shown) positioned either in the grasper **450** or the robotic arm to which the grasper **450** is coupled. The switch releases the spring from its coiled or tensioned position. Thus, actuating the switch releases the spring and urges the cutting tool **460** to slide shut over the reservoir. This switch can be an SMA (shape memory alloy) or solenoid coil. Actuation of the switch allows the pre-loaded springs to push against the cutting tool **460**, thereby urging the cutting tool **460** to move between the open and closed positions.

In another embodiment, the pre-loaded spring or springs could be mechanically triggered when the grasper arms are sufficiently closed. Alternatively, the cutting tool actuation component could be coupled to the grasper **450**. In this embodiment, when the biopsy component **450** is engaged, the cutting tool is actuated as the grasper arms **452**, **454** are closed. In still other embodiments, the cutting tool **460** could be actuated by a small onboard motor and lead screw.

FIG. **22** depicts yet another embodiment of a grasper **470** in which the first arm **472** is equipped with at least one sensor **474**. The sensor **474**A is positioned on the back side **476** (away from the other grasper arm **478**) of the grasper arm **472**. A second sensor **474**B is positioned on the front side **480** (toward the other arm) of the grasper arm **472**. The first and second sensors **474**A and **474**B can be the same or different type of sensor. In a further embodiment, a single sensor can be provided and positioned on either side of the arm **472**. In yet another embodiment, another sensor **475** can be positioned on or otherwise coupled to the robotic arm **484**.

In one embodiment, each sensor **474**A, **474**B comprises an electronics package that includes a commercially-available sensor solid state chip (pH, humidity, pressure, temperature, etc.) and supporting capacitors and resistors. This electronics package is electrically connected to the main circuit board (not shown) in the robotic device base and the sensor readings are transmitted to an external display either in a wireless or wired fashion. This package can be placed in the robot arm **484** or in the grasper **470** so that each sensor **474**A, **474**B is exposed to the environment around the robotic device.

FIG. **23** is a close-up schematic view of an operational component **490** according to yet another embodiment. The operational component **490** is a sensor **490** and is coupled to a distal end **492** of an arm **494** of a robotic device (not shown). The sensor **490** can be any sensor capable of detecting a physiological parameter within a patient's body including, but not limited to pH, humidity, pressure, or temperature. In some embodiments, the sensor **490** is capable of detecting all or some combination of those parameters.

The sensor can be configured in any known fashion using known components. The supporting electronics can include resistors, capacitors, and oscillators that are used to drive the sensors. Output from these sensors will be a data stream transmitted to the external console either wirelessly, or through the tether cable connected to the robot. In these embodiments, the power can be supplied by a battery. In another embodiment, the power and non-essential supporting electronics can be provided in a location external to the patient so that only the sensor is onboard. According to one embodiment, power requirements for the various sensors can be met with power supplied from a standard wall outlet. Such power can be down-regulated through power regulators in the console that connect with the robotic device.

In yet another embodiment, the sensor **490** can be an ultrasound transducer including a transmitter and receiver, or an infrared transducer including a transmitter and receiver. The ultrasound transducer **490** can be a commercially-available system that is routinely used at the tip of an endoscope, which is commonly referred to as Endoscopic Ultrasound ("EUS"). In the standard technologies, placing the transducer on the tip of an endoscope allows the transducer to get close to the organs inside the body. Because of the proximity of the EUS transducer to the organ(s) of interest, the images obtained are frequently more accurate and more detailed than the ones obtained by traditional ultrasounds. Attaching the ultrasound transducer **490** to the distal end **492** of the robotic arm **494** of one embodiment of the various devices disclosed herein allows even greater access to the organ of interest. In some embodiments, the supporting electronics can be positioned inside the robotic arm **494** or elsewhere in the robotic device. In other embodiments, the supporting sensor electrics may be located external to the patient, while only the ultrasonic transducer **490** is provided onboard the robotic device.

FIG. **24** depicts another embodiment of a grasper **500** including at least a first arm **502** equipped with at least one treatment module **504**. The treatment module **504** can be provided either on the front side **506** or the back side **508** of the grasper arm **502** or both, as shown. Alternatively, more than one treatment module **504** can be provided in any configuration. If more than one treatment module is provided, the treatment modules **504** can have the same or different functions as one another.

In another embodiment depicted in FIG. **25**, an operational module **510** that is a treatment module can be coupled directly to a distal end **512** of the robotic device arm **514**. According to certain embodiments, the treatment module **510** can provide, but is not limited to providing, treatment at the site of interest through the use of RF (radio frequency) ablation, microwave ablation, and ultrasonic ablation. In one embodiment, the treatment module **510** is a commercially-available microware or ultrasonic ablation transducer used commonly in catheter-based systems.

According to one implementation, any one of the robotic devices discussed herein can have a power source and/or a processing unit to operate any embodiment of a treatment module such as the treatment module described above. In one embodiment, the power source and/or processing unit are disposed within, attached to, or otherwise associated with the device. According to one embodiment, the power source is a battery. In another embodiment, the power source and data processing can be positioned in a location external to the robotic device so that only the treatment module, and any essential supporting electronics, is coupled to the robotic device.

In one embodiment, the mechanical and electrical couplings between the modular robotic sections are universal to help facilitate ease of assembly. That is, the couplings or connections are universal such that the various modules can be easily and quickly attached or removed and replaced with other modules. Connections can include friction fits, magnets, screws, locking mechanisms and sliding fitting. Alternatively, the connections can be any known connections for use in medical devices. In use, the couplings can be established by the surgeon or user according to one implementation. Alternatively, the couplings can be semi-automated such that the components are semi-self-assembling to improve timeliness.

Modular components need not be arms or other types of components having operational components or end effectors. According to various alternative embodiments, the modular components can be modular mechanical and electrical payload packages that can be used together in various combinations to provide capabilities such as obtaining multiple tissue samples, monitoring physiological parameters, and wireless command, control, and data telemetry. It is understood that the modular payload components can be incorporated into all types of medical devices, including the various medical devices discussed and incorporated herein, such as magnetically controllable devices and/or wheeled devices similar to those disclosed in the applications incorporated above.

FIG. **26**A shows one embodiment of a device **520** having a payload area **522** that can accommodate various modular components such as environmental sensors, biopsy actuator systems, and/or camera systems. More specifically, the payload area **522** is configured to receive any one of several modular components, including such components as the sensor, controller, and biopsy components discussed herein. It is understood that in addition to the specific modular components disclosed herein, the payload areas of the various embodiments could receive any known component to be added to a medical procedural device.

It is further understood that the robotic device having the payload area can be any known robotic device, including any device that is positioned substantially adjacent to or against a patient cavity wall (such as via magnetic forces), and is not limited to the robotic devices described in detail herein. Thus, while the robotic device embodiments depicted in FIGS. **26**A and **26**B (discussed below) are mobile devices having wheels, the various modular components described herein could just as readily be positioned or associated with a payload area in any other kind of robotic device or can further be used in other medical devices and applications that don't relate to robotic devices.

Returning to FIG. **26**A, in this embodiment, the device is not tethered and is powered by an onboard battery **524**. Commands can be sent to and from the device using an RF transceiver placed on a circuit board **526**. Alternatively, the device **520** can be tethered and commands and power can be transmitted via the tether.

In the embodiment of FIG. **26**A, the wheels **528**A and **528**B are powered by onboard motors **530**A and **530**B. Alternatively, the wheels **528**A, **528**B and other components can be actuated by any onboard or external actuation components. The wheels **528** in this implementation are connected to the motors **530** through a bearing **532** and a set of spur gears **534** and **536**. Alternatively, any known connection can be used. The use of independent wheels allows for forward, reverse, and turning capabilities. In this embodiment, a small retraction ball **538** is attached to the outside of each wheel for retraction using a surgical grasper. Alternatively, no retraction component is provided. In a further alternative, any known retraction component can be included.

FIG. **26**B shows yet another embodiment of a device **540** having a payload area **542**. In this embodiment, the modular component in the payload area **542** is a sensor component. It is further understood that, according to various other implementations, more than one modular component can be positioned in the payload area **542** of this device **540** or any other device having a payload area. For example, the payload area **542** could include both a biopsy component and a sensor component, or both a biopsy component and a controller component. Alternatively, the payload area **542** could include any combination of any known functional components for use in procedural devices.

In accordance with one implementation, one component that can be included in the payload area **542** is a sensor package or component. The sensor package can include any sensor that collects and/or monitors data relating to any characteristic or information of interest. In one example, the sensor package includes a temperature sensor. Alternatively, the package includes an ambient pressure sensor that senses the pressure inside the body cavity where the device is positioned. In a further alternative, the package can include any one or more of a relative humidity sensor, a pH sensor, or any other known type of sensor for use in medical procedures.

The modular components and combination devices disclosed herein also include segmented triangular or quadrangular-shaped combination devices. These devices, which are made up of modular components (also referred to herein as "segments") that are connected to create the triangular or quadrangular configuration, can provide leverage and/or stability during use while also providing for substantial payload space within the device that can be used for larger components or more operational components. As with the various combination devices disclosed and discussed above, according to one embodiment these triangular or quadrangular devices can be positioned inside the body cavity of a patient in the same fashion as those devices discussed and disclosed above.

FIGS. **27**A-**32** depict a multi-segmented medical device **550**, in accordance with one implementation. According to one embodiment, the device **550** is a robotic device **550** and further can be an in vivo device **550**. This device embodiment **550** as shown includes three segments **552**A, **552**B, **554**. Segments **552**A and **552**B are manipulator segments, while segment **554** is a command and imaging segment. Alternatively, the three segments can be any combination of segments with any combination of components and capabilities. For example, according to an alternative embodiment, the device could have one manipulator segment, one command and imaging segment, and a sensor segment. In a further alternative, the various segments can be any type of module, including any of those modules described above with respect to other modular components discussed herein.

As best shown in FIGS. **27**A and **27**B, segments **552**A, **552**B are rotatably coupled with the segment **554** via joints or hinges **556**A, **556**B. More specifically, segment **552**A is rotatable relative to segment **554** about joint **556**A around an axis as indicated by arrow B in FIG. **27**B, while segment **552**B is rotatable relative to segment **554** about joint **556**B around an axis as indicated by arrow C in FIG. **27**B.

In accordance with one embodiment, the device **550** has at least two configurations. One configuration is an extended or insertion configuration as shown in FIG. **27**A in which the three segments **552**A, **552**B, **554** are aligned along the same axis. The other configuration is a triangle configuration as shown in FIG. **27**B in which the manipulator segments **552**A, **552**B are each coupled to the segment **554** via the joints **556**A, **556**B and further are coupled to each other at a coupleable connection **558** at the ends of the segments **552**A, **552**B opposite the joints **556**A, **556**B.

As best shown in FIG. **28**A, each of the manipulator segments **552**A, **552**B in this particular embodiment has an operational arm **560**, **562** (respectively). Each arm **560**, **562** is moveably coupled to its respective segment **552**A, **552**B at a joint **564**A, **564**B (respectively) (as best shown in FIG. **30**). Further, segment **554** has a pair of imaging components (each also referred to herein as a "camera") **566**A, **566**B (as best shown in FIG. **29**).

In one embodiment, each arm **560**, **562** is configured to rotate at its joint **564**A, **564**B in relation to its segment **552**A, **552**B to move between an undeployed position in which it is disposed within its segment **552**A, **552**B as shown in FIG. **27**B and a deployed position as shown in FIG. **28**A. In one example, arm **560** is rotatable relative to segment **552**A about joint **564**A in the direction shown by G in FIG. **30**, while arm **562** is rotatable relative to segment **552**B about joint **564**B in the direction shown by H in FIG. **30**. Alternatively, the arms **560**, **562** are moveable in relation to the segments **552**A, **552**B in any known fashion and by any known mechanism.

According to one embodiment as best shown in FIG. **28**A, each arm **560**, **562** has three components: a proximal portion **560**A, **562**A, a distal portion **560**B, **562**B, and an operational component **560**C, **562**C coupled with the distal portion **560**B, **562**B, respectively. In this embodiment, the distal portion **560**B, **562**B of each arm **560**, **562** extends and retracts along the arm axis in relation to the proximal portion **560**A, **562**A while also rotating around that axis in relation to the proximal portion **560**A, **562**A. That is, distal portion **560**B of arm **560** can move back and forth laterally as shown by the letter Kin FIG. **30** and further can rotate relative to the proximal portion **560**A as indicated by the letter J, while distal portion **562**B of arm **562** can move back and forth laterally as shown by the letter L in FIG. **30** and further can rotate relative to the proximal portion **562**A as indicated by the letter I.

In accordance with one implementation, the operational components **560**C, **562**C (also referred to herein as "end effectors") depicted in FIG. **28**A are a grasper **560**C and a cautery hook **562**C. It is understood that the operational component(s) used with the device **550** or any embodiment herein can be any known operational component for use with a medical device, including any of the operational components discussed above with other medical device embodiments and further including any operational components described in the applications incorporated above. Alternatively, only one of the two arms **560**, **562** has an operational component. In a further alternative embodiment, neither arm has an operational component.

Alternatively, each arm **560**, **562** comprises one unitary component or more than two components. It is further understood that the arms **560**, **562** can be any kind of pivotal or moveable arm for use with a medical device which may or may not have operational components coupled or otherwise associated with them. For example, the arms **260**, **262** can have a structure or configuration similar to those additional arm embodiments discussed elsewhere herein or in any of the applications incorporated above. In a further alternative, the device **550** has only one arm. In a further alternative, the device **550** has no arms. In such alternative implementations, the segment(s) not having an arm can have other components associated with or coupled with the segment(s) such as sensors or other types of components that do not require an arm for operation.

As discussed above, the segment **554** of the embodiment depicted in FIG. **29** has a pair of cameras **566**A, **566**B. Alternatively, the segment **554** can have a single camera or two or more cameras. It is understood that any known imaging component for medical devices, including in vivo devices, can be used with the devices disclosed herein and further can be positioned anywhere on any of the segments or on the arms of the devices.

In a further embodiment, the segment **554** as best shown in FIG. **29** can also include a lighting component **568**. In fact, the segment **554** has four lighting components **568**. Alternatively, the segment **554** can have any number of lighting components **568** or no lighting components. In a further alternative, the device **550** can have one or more lighting components positioned elsewhere on the device, such as one or both of segments **552**A, **552**B or one or more of the arms, etc.

In accordance with a further embodiment as best shown in FIGS. **27**B and **29**, each of the segments **552**A, **552**B, **554** has two cylindrical components—an outer cylindrical component and an inner cylindrical component—that are rotatable in relation to each other. More specifically, the segment **552**A has an outer cylindrical component **570**A and an inner cylindrical component **570**B that rotates relative to the outer component **570**A around an axis indicated by arrow F in FIG. **21**. Similarly, the segment **552**B has an outer cylindrical component **572**A and an inner cylindrical component **572**B that rotates relative to the outer component **572**A around an axis indicated by arrow E in FIG. **29**. Further, the segment **554** has an outer cylindrical component **574**A and an inner cylindrical component **574**B that rotates relative to the outer component **574**A around an axis indicated by arrow D in FIG. **29**.

In use, the embodiments having rotatable cylindrical components as described in the previous paragraph can provide for enclosing any arms, cameras, or any other operational components within any of the segments. Further, any segment having such rotatable components provide for two segment configurations: an open configuration and a closed configuration. More specifically, segment **552**A has an outer cylindrical component **570**A with an opening **576** as shown in FIG. **29** through which the arm **560** can move between its deployed and undeployed positions. Similarly, segment **552**B has an outer cylindrical component **572**A with an opening **578** as shown in FIG. **29** through which the arm **562** can move between its deployed and undeployed positions. Further, segment **554** has an outer cylindrical component **574**A with an opening **580** as shown in FIG. **29** through which the imaging component(s) **566**A, **566**B can capture images of a procedural or target area adjacent to or near the device **550**.

FIG. **27**B depicts the segments **552**A, **552**B, **554** in their closed configurations. That is, each of the inner cylindrical components **570**B, **572**B, **574**B are positioned in relation to the respective outer cylindrical component **570**A, **572**A, **574**A such that each opening **576**, **578**, **580**, respectively, is at least partially closed by the inner component **570**B, **572**B, **574**B such that the interior of each segment **552**A, **552**B, **554** is at least partially inaccessible from outside the segment.

More specifically, in the closed position, inner cylindrical component **570**B of segment **552**A is positioned in relation to outer cylindrical component **570**A such that the arm **560** is at least partially enclosed within the segment **552**A. According to one embodiment, the inner cylindrical component **570**B is configured such that when it is in the closed position as shown in FIG. **27**B, it closes off the opening **576** entirely. In a further embodiment, the inner cylindrical component **570**B in the closed position fluidically seals the interior of the segment **552**A from the exterior.

Similarly, in the closed position, inner cylindrical component **572**B of segment **552**B is positioned in relation to the outer cylindrical component **572**A such that the arm **562** is at least partially enclosed within the segment **552**B. According to one embodiment, the inner cylindrical component **572**B is configured such that when it is in the closed position as shown in FIG. **27**B, it closes off the opening **578** entirely. In a further embodiment, the inner cylindrical component **572**B in the closed position fluidically seals the interior of the segment **552**B from the exterior.

Further, in the closed position, inner cylindrical component **574**B of segment **554** is positioned in relation to the outer cylindrical component **574**A such that the imaging component(s) is not positioned within the opening **580**. According to one embodiment, the inner cylindrical component **574**B is configured such that when it is in the closed position as shown in FIG. **27**B, the imaging component(s) and any lighting component(s) are completely hidden from view and not exposed to the exterior of the segment **554**. In a further embodiment, the inner cylindrical component **574**B in the closed position fluidically seals the interior of the segment **554** from the exterior.

In contrast, FIGS. **28**A and **29** depict the segments **552**A, **552**B, **554** in their open configurations. In these configurations, each of the inner cylindrical components **570**B, **572**B, **574**B are positioned such that the openings **576**, **578**, **580** are open.

In use, according to one embodiment, the inner cylindrical components **570**B, **572**B, **574**B can thus be actuated to move between their closed and their open positions and thereby convert the device **550** between a closed or non-operational configuration (in which the operational components such as the arms **560**, **562** and/or the imaging components **566** and/or the lighting components **568** are inoperably disposed within the segments **552**A, **552**B, **554**) and an open or operational configuration (in which the operational components are accessible through the openings **576**, **578**, **580** and thus capable of operating). Thus, according to one implementation, the device **550** can be in its closed or non-operational configuration during insertion into a patient's body and/or to a target area and then can be converted into the open or operational configuration by causing the inner cylindrical components **570**B, **572**B, **574**B to rotate into the open configurations.

Alternatively, one or more or all of the segments do not have inner and outer components that rotate in relation to each other.

It is understood that the various embodiments of the device **550** disclosed herein include appropriate actuation components to generate the force necessary to operate the arms and/or the rotatable cylinders in the segments. In one embodiment, the actuation components are motors. For example, segment **552**A has a motor (not shown) operably coupled with the arm **560** and configured to power the movements of the arm **560**. Similarly, segment **552**B also has a motor (not shown) operably coupled with the arm **562** and configured to power the movements of the arm **560**. In further embodiments, each of the segments **552**A, **552**B, **554** also have motors (not shown) operably coupled to one or both of the inner and outer cylinder of each segment to power the rotation of the cylinders in relation to each other. In one embodiment, each segment can have one motor to power all drivable elements (arms, cylinders, etc.) associated with that segment. Alternatively, a separate motor can be provided for each drivable element.

In one embodiment, the joints **556**A, **556**B are configured to urge the segments **552**A, **552**B from the insertion configuration of FIG. **27**A into the triangular configuration of FIG. **27**B. That is, the joints **556**A, **556**B have torsion springs or some other known mechanism for urging the segments **552**A, **552**B to rotate around their joints **556**A, **556**B. For example, FIG. **28**C depicts one embodiment in which the joint **556**A has torsion springs **582** that are configured to urge segment **552**A toward the triangular configuration.

In use, in accordance with one implementation, the device **550** in the insertion configuration as shown in FIG. **27**A can be inserted into a patient's body through an incision, a trocar port, or natural orifice in the direction indicated by arrow A. Alternatively, the device **550** can be inserted in the other direction as well. After insertion and/or as the device **550** enters the target area or procedural area in the patient's body, the joints **556**A, **556**B with the torsion springs (or other standard mechanisms) urge the segments **552**A, **552**B from their insertion position to their triangular position. As the segments **552**A, **552**B contact each other to form joint **558**, the two segments are coupled together with mating components that semi-lock the segments **552**A, **552**B together. That is, the two segments **552**A, **552**B can only be separated at the joint **558** by a force sufficient to overcome the semi-lock. Any such known mating component or coupling component, including any mechanical or magnetic mating component(s), can be incorporated into the device **550** for this purpose.

Thus, according to one embodiment, the device **550** can be in its insertion configuration during insertion into the patient. As the device **550** enters the target cavity and exits the port or incision, the torsion springs or other mechanisms at the joints **556**A, **556**B cause the two segments **552**A, **552**B to move toward each other until they couple to form the triangular configuration. The device **550** can then be attached to the abdominal wall by some method such as an external magnetic handle. Alternatively, the device **550** can be positioned anywhere in the cavity of the patient as desired by the user. The device **550** is then used to perform some sort of procedure.

Subsequently, when the procedure is complete, the device **550** can be retracted from the cavity. To do so, the surgeon uses a grasping or retrieval tool such as a Endo Babcock grasper made by Covidien in Mansfield, Mass., to attach to or otherwise grasp the ball **584** at the joint **558** and apply sufficient force to overcome the semi-lock of the joint **558**. Alternatively, any retrieval component can be positioned at the end of segment **552**A or elsewhere on the device **550** for grasping or otherwise coupling to for purposes of removing the device **550** from the patient's body. When the coupling of the semi-lock is overcome, the force urges the segments **552**A, **552**B away from each other, thereby making it possible for the surgeon to pull the ball **584** through a port or incision and out of the patient, thereby forcing the device **550** into its insertion configuration.

The multiple segments provided in the various embodiments of the device disclosed herein result in significantly more payload space than a single cylindrical body. The increased payload space results in increased capabilities for the device in the form of more, bigger, or more complex operational components, more, bigger, or more complex motors, magnets (as described below) and other similar benefits relating to the availability of more space for more, bigger, or more complex components. For example, FIG. **28**B depicts a side view of the device **550** according to one embodiment that shows the payload space available in segment **552**B. More specifically, segment **552**B and its coupled arm **562** have payload spaces **586**, **588**, **590**, **592**, **594** that can be used to accommodate motors, operational components, sensors, magnets (as described below) or any other type of component that could be useful for a procedural device. Similarly, each segment **552**A, **552**B, **554** can have such payload spaces. In addition, the segments **552**A, **552**B, **554** allow for maximization of the payload space available across the segments **552**A, **552**B, **554** by distributing the components such as motors, operational components, or magnets to maximize their effectiveness while minimizing the amount of space required by each such component. For example, it might maximize effectiveness of the device **550** while minimizing the utilized space to have one large motor in one segment that provides force for operation of components in more than one segment.

It is understood that various embodiments of the segmented devices disclosed herein are in vivo devices that can be inserted into and positioned within a patient's body to perform a procedure. In one embodiment, an external controller is also provided that transmits signals to the device **550** to control the device **550** and receives signals from the device **550**. In one embodiment, the controller communicates with the device **550** wirelessly. Alternatively, the controller and the device **550** are coupled via a flexible communication component such as a cord or wire (also referred to as a "tether") that extends between the device **550** and the controller.

It is also understood that various embodiments of the devices disclosed herein can be used in conjunction with known attachment components to attach or otherwise position the device near, against, or adjacent to an interior cavity wall inside the patient. In one embodiment, the attachment components are one or more magnets, disposed within the device, that communicate magnetically with one or more magnets positioned outside the patient's body. The device magnets can be positioned on or in the device in any suitable configuration. For example, the device magnets in one embodiment can be positioned within the segments **552**A, **552**B, **554** at positions **596**, **598**, **600** as shown in FIG. **31**. It is understood that the external magnets can be used outside the body to position and/or move the device **550** inside the body.

It is further understood that various embodiments of the devices disclosed herein can be used in conjunction with known visualization and control components, such as the console **610** depicted in FIG. **32**. The console **610** has a display **612** and magnets **614** and is positioned outside the patient such that the magnets **614** can be in magnetic communication with the device magnets (not shown) disposed within or otherwise coupled with the device **550**. The console **610** can be used to move the device **550** by moving the console **610** outside the body such that the device **550** is urged to move inside the body, because the console magnets **550** are magnetically coupled with the device magnets (not shown) within the device **550** such that the device **550** remains substantially fixed in relation to the console **610**. In addition, it is understood that the triangular (and quadrangular) devices disclosed and described in relation to FIGS. **27**A-**33** can be used in conjunction with any of the external controller or visualization components and systems disclosed and discussed above and in the applications incorporated above.

The segmented device **550**, according to one embodiment, provides greater stability and operability for the device **550** in comparison to other in vivo devices. That is, a device having more than one segment such as device **550** provides for a configuration with a larger "footprint" for the device **550**, thereby resulting in greater stability and leverage during use of the device **550**. For example, the device **550** with the triangular configuration in FIG. **32** that is urged against the interior cavity wall of the patient by the console magnets **614** has greater stability and leverage in comparison to a device that has a smaller "footprint." That is, the device **550** can have at least three magnets (not shown) disposed at the three comers of the triangular configuration such that when the device **550** is magnetically positioned against the interior cavity wall, the arms of the device **550** can apply greater force to the target tissues while maintaining the position of the device **550** than a corresponding single cylindrical device body.

It is understood that the device embodiments disclosed herein are not limited to a triangular configuration. FIG. **33** depicts a device **620** having a quadrangular configuration with four segments. Similarly, devices are contemplated herein having any number of segments ranging from two segments to any number of segments that can be used for a device that can be positioned inside a patient's body. For example, a device incorporating the components and structures disclosed herein could have six or eight segments or more.

In accordance with one embodiment, the various medical devices disclosed herein and in the applications incorporated above can be used cooperatively. That is, two or more devices can be used at the same time during the same procedure to accomplish more or perform the procedure more quickly than when only one device is used at a time. As such, multiple robots (more than one device and up to any number capable of being inserted into a patient's cavity and present in the cavity at the same time for performing one or more procedures) are inserted into the patient's cavity and each controlled by the surgical team.

FIGS. **34**-**36** depict three different embodiments of cooperative use of two or more medical devices together. In FIG. **34**, the devices that are positioned within a cavity of a patient include a device with operational arms **630**, two lighting devices **632**A, **632**B, and a cylindrical device having a winch component with an end effector **634**. These devices can be operated at the same time using one or more external controllers and/or visualization components according to the various embodiments disclosed above or in the applications incorporated above.

Similarly, FIG. **35** depicts a cooperative procedure implementation using a cylindrical device having a winch component with an end effector **640**, a lighting device **642**, and a cylindrical device **644**. The cylindrical device **644** can have an imaging component and/or additional operational components such as sensors, etc.

Another embodiment is depicted in FIG. **36**, in which a cooperative procedure is performed using a device with arms **650** and a lighting device **652**.

According to one embodiment, the devices are assembled while being introduced through a natural orifice, a port, or an incision. For instance, if insertion is through the esophagus, each robot is inserted down the overtube, which provides an "in line" ability for consistent assembly as each robot is "pushed" down the overtube. Alternatively, after insertion into the abdominal cavity, a camera and tool can be inserted to assist with the mechanical connections, or other robotic devices can be used to help with the mechanical connections.

The level of cooperation amongst two or more in vivo medical devices varies between high network communications, planning, and some autonomy, to lower level mechanical connections and surgeon control. That is, in certain embodiments, the cooperative devices can communicate with each other and perform with some level of autonomy (without input or with limited input from the user or surgeon). In an alternative implementation, the cooperative devices can simply be positioned in the same general procedural space and separately controlled by one or more users to work cooperatively to perform a procedure or procedures.

In one embodiment, two or more devices positioned in a body cavity can be coupled to each other in some fashion. It is understood that the coupling does not necessarily result in a rigid coupling of the devices to each other in all degrees. As such, the configuration(s) of two or more devices may adapt to the varying geometry of each patient, disturbances to the abdominal wall, and respiration cycle. According to one implementation, one benefit of coupling the devices is to maintain a set distance between the devices for vision, lighting, tissue manipulation, and other procedural purposes.

Although the present invention has been described with reference to preferred embodiments, persons skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

What is claimed is:

**1**. A robotic device, comprising:

(a) an elongate device body constructed and arranged to be positionable within a cavity of a patient;

(b) a connection component operably coupled with the elongate device body;

(c) a first operational arm comprising:

(i) a first inner arm segment operably coupled with the device body via a first shoulder joint at a first end of the elongate device body;

(ii) a first outer arm segment operably coupled with the first inner arm segment via a first elbow joint; and

(iii) a first procedural tool operably coupled with the first outer arm segment;

(e) a second operational arm comprising:

(i) a second inner arm segment operably coupled with the device body via a second shoulder joint at a second end of the elongate device body;

(ii) a second outer arm segment operably coupled with the second inner arm segment via a second elbow joint; and

(iii) a second procedural tool operably coupled with the second outer arm segment; and

(f) at least one actuator disposed within each arm, the at least one actuator being configured to actuate movement of the arm, wherein the at least one actuator is operably coupled to a physical linkage extending to an external component.

**2**. The robotic device of claim **1**, wherein each of the first and second operational arms has at least four degrees of freedom.

**3**. The robotic device of claim **1**, further comprising:

(a) at least one imaging component operably coupled to the device body; and

(b) an external controller operably coupled to the device body, the external controller comprising:

(i) an image display component operably coupled to the at least one imaging component, the image display component configured to display images acquired by the at least one imaging component; and

(ii) at least one joystick operably coupled to at least one of the first and second operational arms, the at least one joystick configured to control the at least one of the first and second operational arms via the physical linkage.

**4**. The robotic device of claim **1**, wherein each of the first and second operational arms has at least three degrees of freedom.

**5**. The robotic device of claim **1**, wherein the first and second procedural tools are each chosen from a group consisting of a scalpel, a biopsy tool, a cauterizer, a forceps, a dissector, clippers, a stapler, and an ultrasound probe.

**6**. The robotic device of claim **1**, wherein the connection component is a tether.

**7**. The robotic device of claim **1**, wherein the external component is an external power source operably coupled to the physical linkage.

**8**. The robotic device of claim **1**, further comprising at least one imaging component operably coupled with the device body, wherein the at least one imaging component is disposed between the first and second operational arms such that the first and second operational arms are viewable by a user via the at least one imaging component during operation of the first and second operational arms.

**9**. The robotic device of claim **8**, further comprising an external controller operably coupled to the first and second operational arms and the at least one imaging component.

**10**. The robotic device of claim **9**, wherein the external controller comprises:

(a) an image display component operably coupled to the at least one imaging component, the image display component configured to display images acquired by the at least one imaging component; and

(b) at least one joystick operably coupled to at least one of the first and second operational arms, the at least one joystick configured to control the at least one of the first and second operational arms.

**11**. A robotic device, comprising:

(a) an elongate device body constructed and arranged to be positionable within a cavity of a patient, the elongate device body comprising a first shoulder joint at a first end and a second shoulder joint at a second end opposite the first end;

(b) a connection component operably coupled with the elongate device body;

(c) a first operational arm comprising:

(i) a first inner arm segment operably coupled with the device body via the first shoulder joint;

(ii) a first outer arm segment operably coupled with the first inner arm segment via a first elbow joint; and

(iii) a first procedural tool operably coupled with the first outer arm segment;

(d) a second operational arm comprising:

(i) a second inner arm segment operably coupled with the device body via the second shoulder joint;

(ii) a second outer arm segment operably coupled with the second inner arm segment via a second elbow joint; and

(iii) a second procedural tool operably coupled with the second outer arm segment;

(f) at least one actuator disposed within each arm, the at least one actuator being configured to actuate movement of the arm, wherein the at least one actuator is operably coupled to a physical linkage extending to an external component; and

(g) at least one imaging component operably coupled with the device body.

**12**. The robotic device of claim **11**, wherein each of the first and second operational arms has at least three degrees of freedom.

**13**. The robotic device of claim **11**, wherein each of the first and second operational arms has at least four degrees of freedom.

**14**. The robotic device of claim **11**, further comprising an external controller operably coupled to the at least one imaging component and the first and second operational arms, the external controller comprising:

(a) an image display component operably coupled to the at least one imaging component, the image display component configured to display images acquired by the at least one imaging component; and

(b) at least one joystick operably coupled to at least one of the first and second operational arms, the at least one joystick configured to control at least one of the first and second operational arms.

**15**. The robotic device of claim **11**, wherein the first and second procedural tools are each chosen from a group consisting of a scalpel, a biopsy tool, a cauterizer, a forceps, a dissector, clippers, a stapler, and an ultrasound probe.

**16**. A method of surgery comprising:

making an incision in a patient, wherein the incision provides access to a target cavity in the patient;

inserting a robotic device through the incision and into the target cavity in the patient, the robotic device comprising:

(a) an elongate device body;

(b) a connection component operably coupled with the device body;

(c) a first operational arm comprising:

(i) a first inner arm segment operably coupled with the device body via a first shoulder joint at a first end of the elongate device body;

(ii) a first outer arm segment operably coupled with the first inner arm segment via a first elbow joint; and

(iii) a first operational component operably coupled with the first outer arm segment;

(e) a second operational arm comprising:

(i) a second inner arm segment operably coupled with the device body via a second shoulder joint at a second end of the elongate device body;

(ii) a second outer arm segment operably coupled with the second inner arm segment via a second elbow joint; and

(iii) a second operational component operably coupled with the second outer arm segment; and

(f) at least one actuator disposed within each arm, the at least one actuator being configured to actuate movement of the arm, wherein the at least one actuator is operably coupled to a physical linkage extending to an external component; and

performing a procedure in the target cavity of the patient using at least the robotic device.

**17**. The method of claim **16**, wherein making the incision in the patient comprises making no more than two incisions in the patient.

**18**. The method of claim **16**, wherein performing the procedure further comprises performing the procedure using the robotic device and at least one additional device.

**19**. The method of claim **16**, wherein the external component is an external controller comprising an external power source operably coupled to the at least one actuator, wherein performing the procedure further comprises operating the external controller, wherein the external power source is configured to transmit force to the at least one actuator via the physical linkage for actuating movement of the arms.

**20**. The robotic device of claim **7**, wherein the physical linkage is an actuation system.

* * * * *

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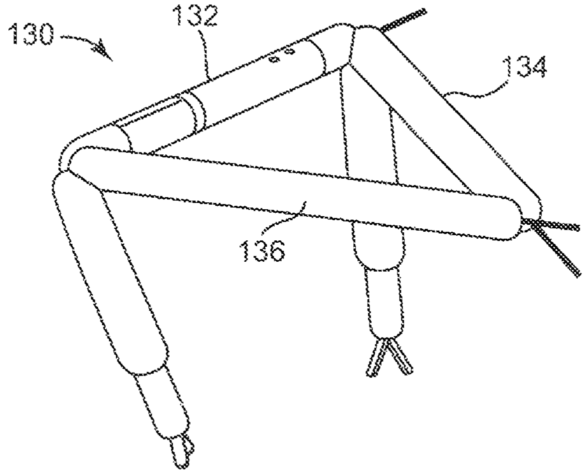
| 其他公开文献 | US20180153631A1 | | |
| 外部链接 | Espacenet | | |


**摘要(译)**

这里公开的各种实施例涉及模块化医疗设备，包括具有可拆卸模块化部件的各种设备和具有可枢转连接的模块化部件的各种设备。另外的实施例涉及协作使用各种设备的过程。医疗装置的某些实施例是机器人体内装置。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