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**Doyle et al.**

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(54) **HAND-ACTUATED ARTICULATING SURGICAL TOOL**

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**Related U.S. Application Data**

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(51) **Int. Cl.**<sup>7</sup> ..... **A61B 17/00**

(52) **U.S. Cl.** ..... **600/1; 606/205**

(58) **Field of Search** ..... 606/1, 46, 32,  
606/54; 907/2, 16, 22; 60/325, 547.1, 555,  
557

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(57) **ABSTRACT**

A double cylinder system is disclosed, comprising at least one controller being adapted to transmit hydraulic control signals; at least one slave being in fluid communication with the controller and being configured to respond to the hydraulic control signals transmitted by the controller; and at least one control line providing hydraulic communication between the controller and the slave. Also disclosed is a surgical device, comprising at least one controller located at a proximal end of the device, the controller being adapted to transmit hydraulic control signals; at least one manipulator, the manipulator being configured to be controlled by a human hand and to actuate the controller; at least one slave located at a distal end of the device, the slave being in fluid communication with the controller and being configured to respond to the hydraulic control signals transmitted by the controller; and at least one control line providing hydraulic communication between the controller and the slave.

**13 Claims, 26 Drawing Sheets**

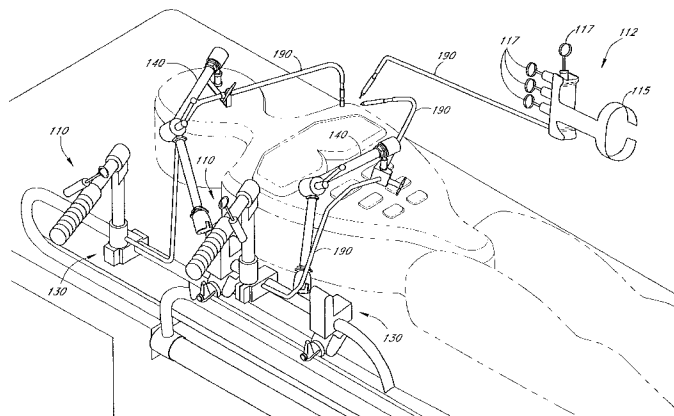
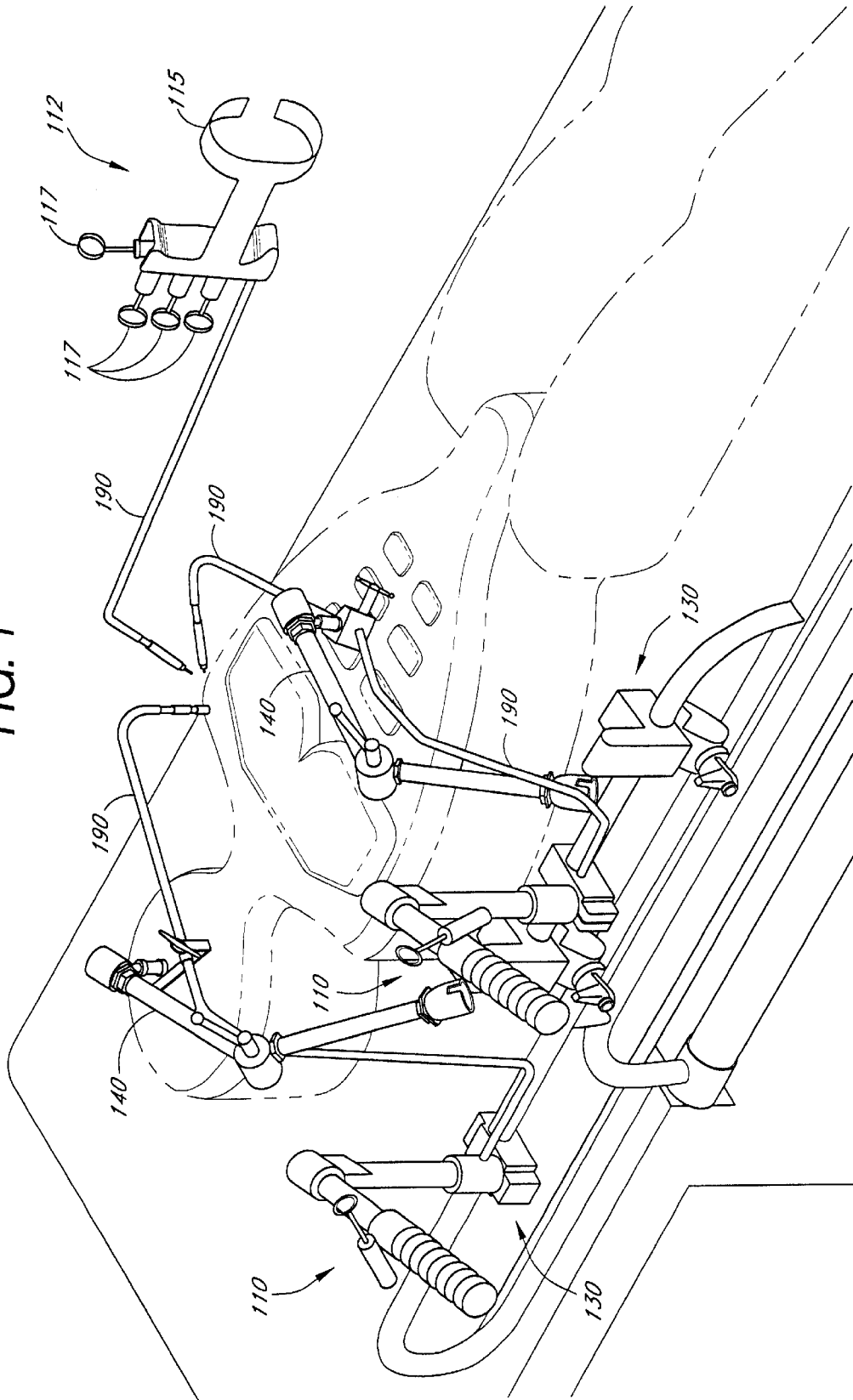


FIG. 1



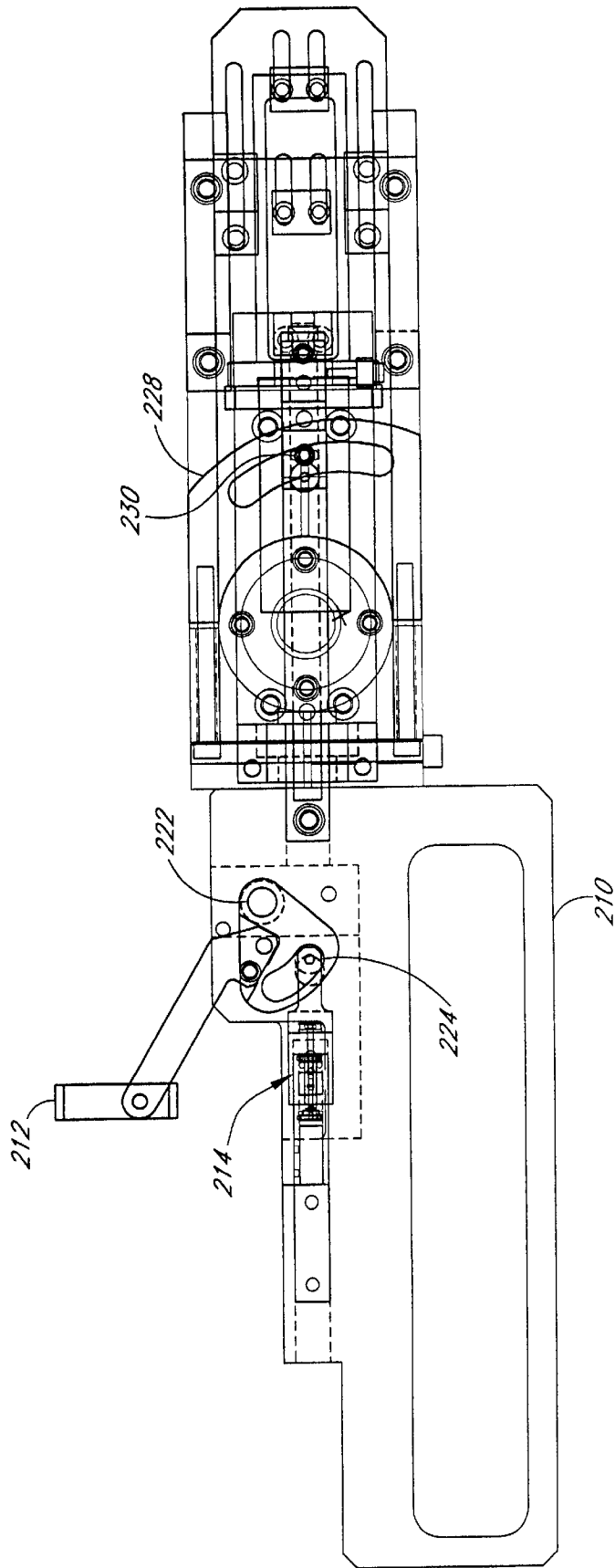


FIG. 2A

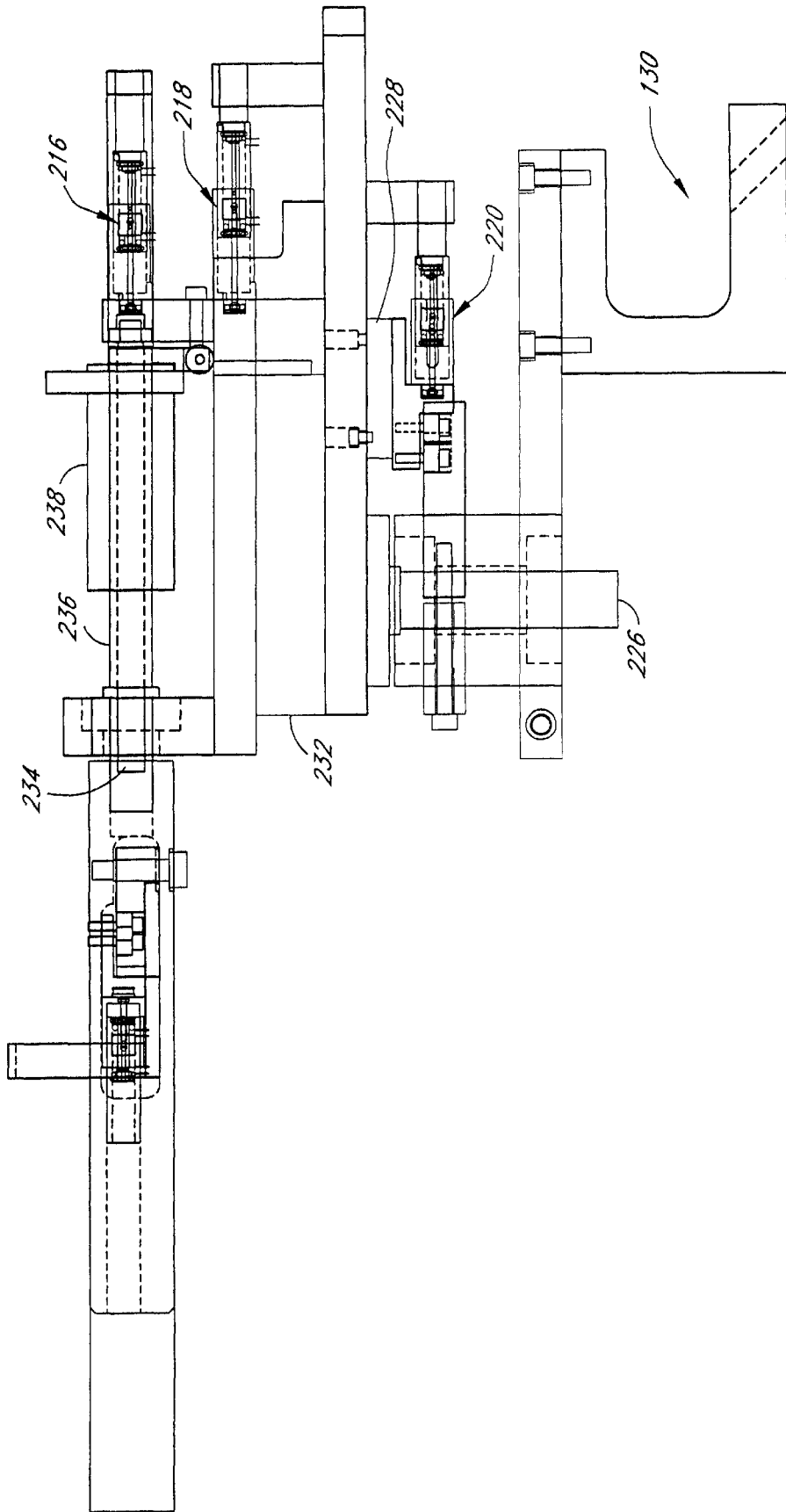


FIG. 2B

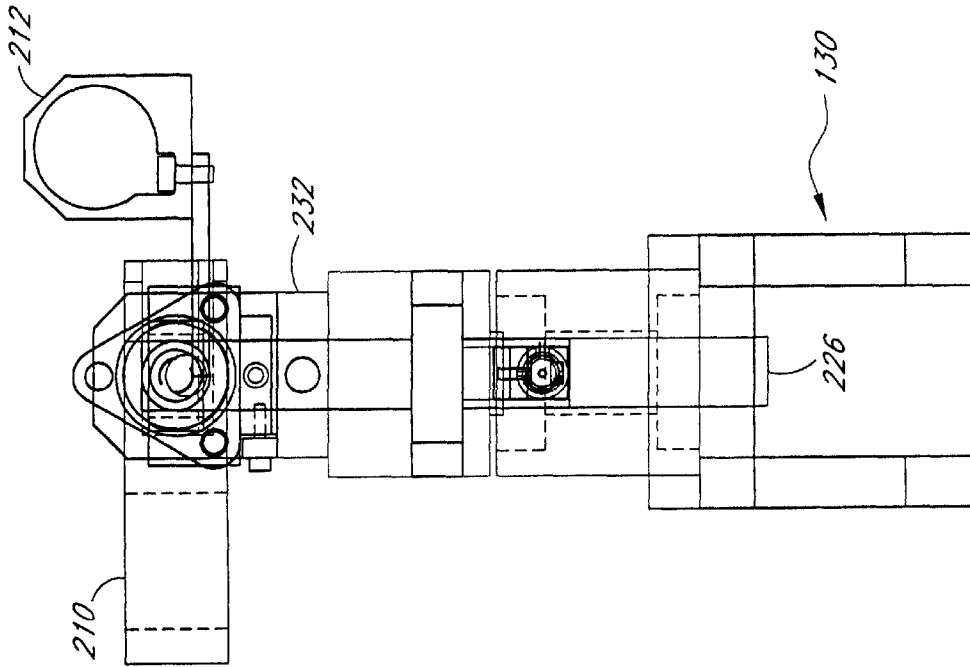


FIG. 2C

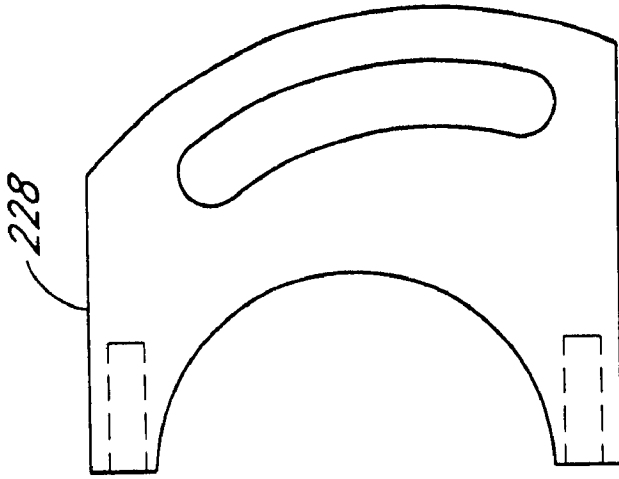


FIG. 2E

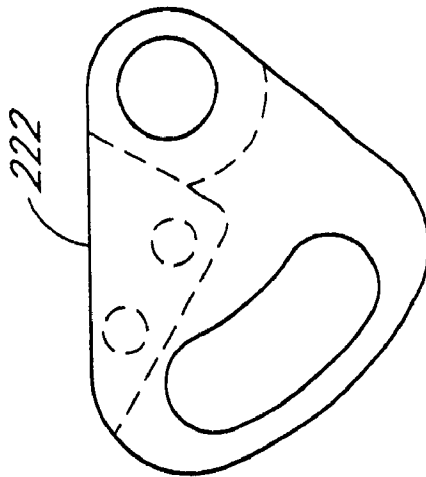


FIG. 2D

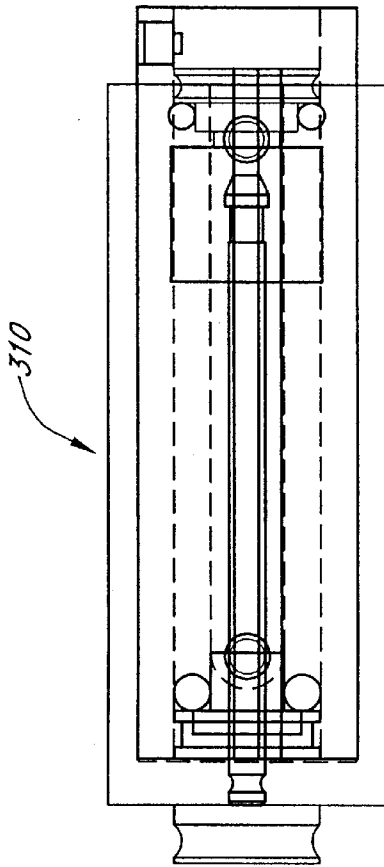


FIG. 3A

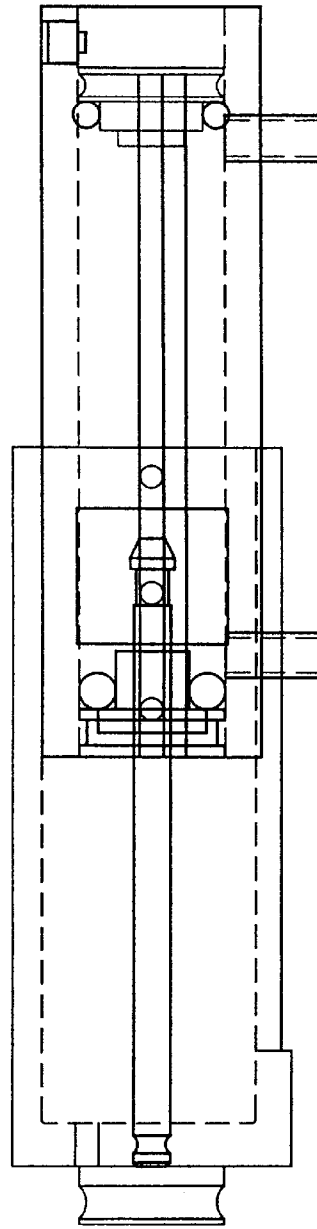


FIG. 3B

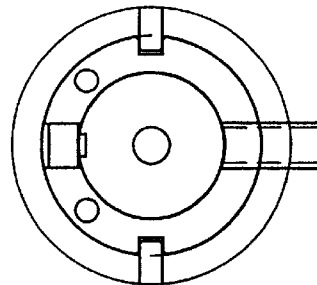


FIG. 3C

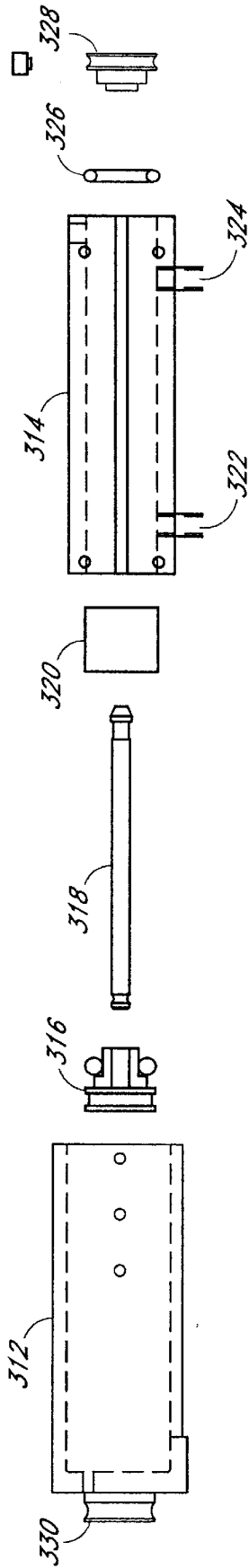


FIG. 3D



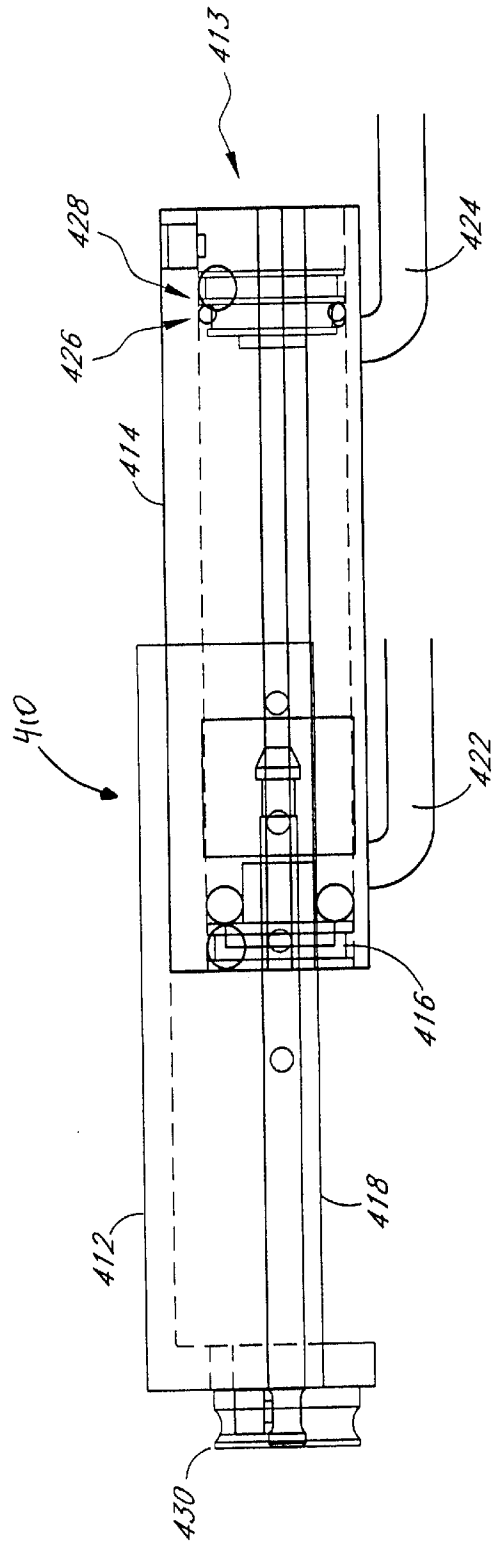
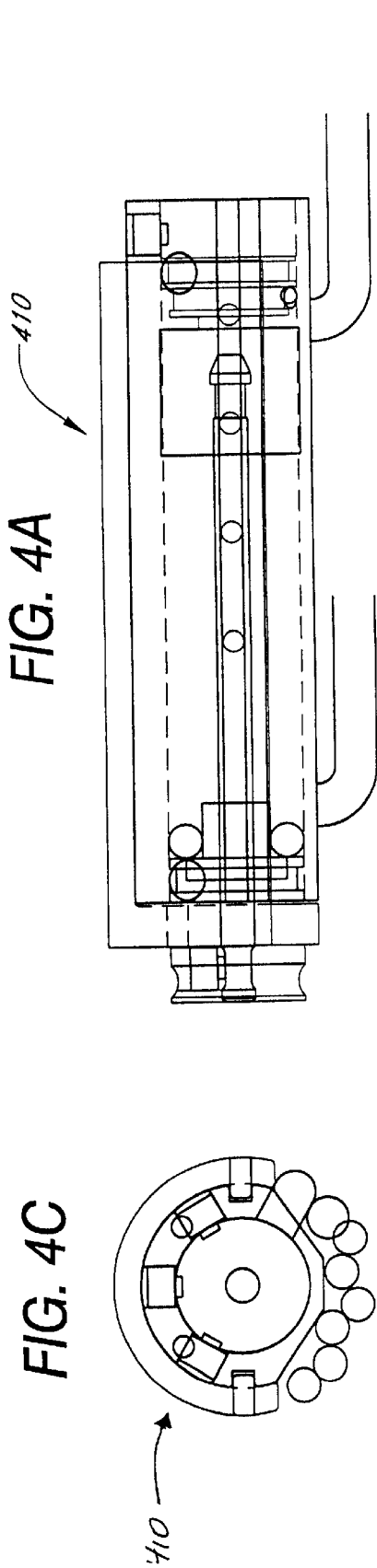


FIG. 4B

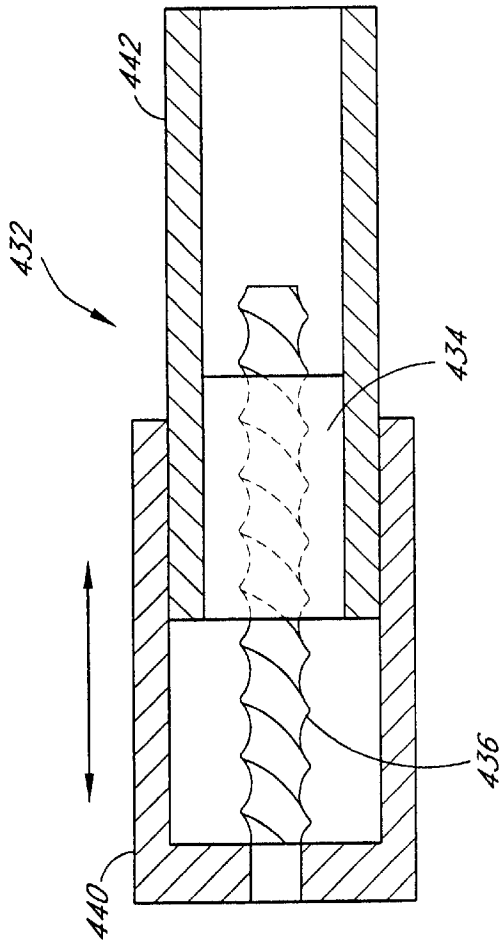


FIG. 4D

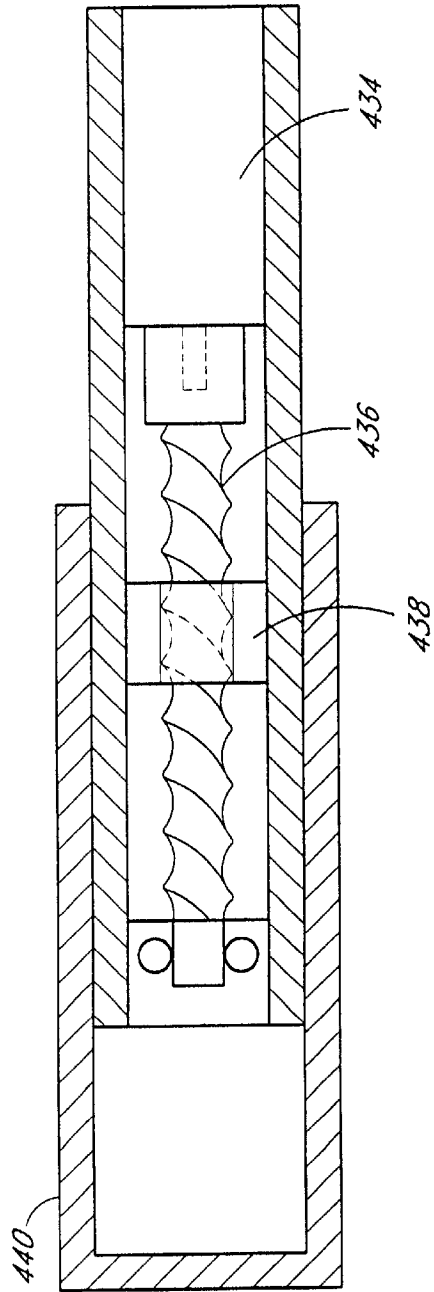


FIG. 4E

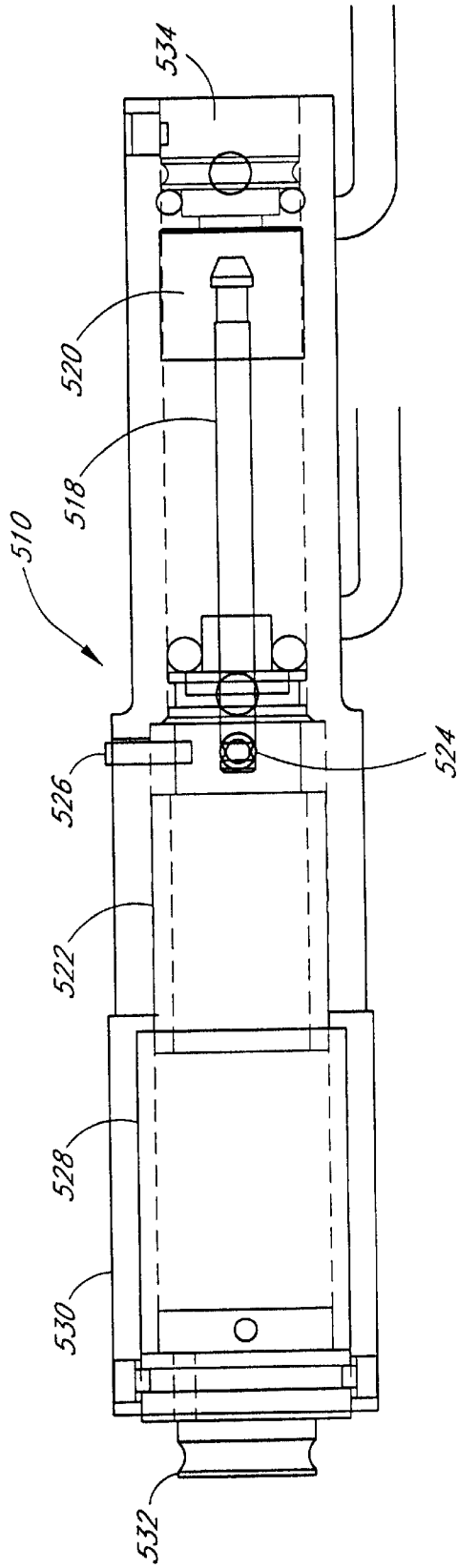


FIG. 5A

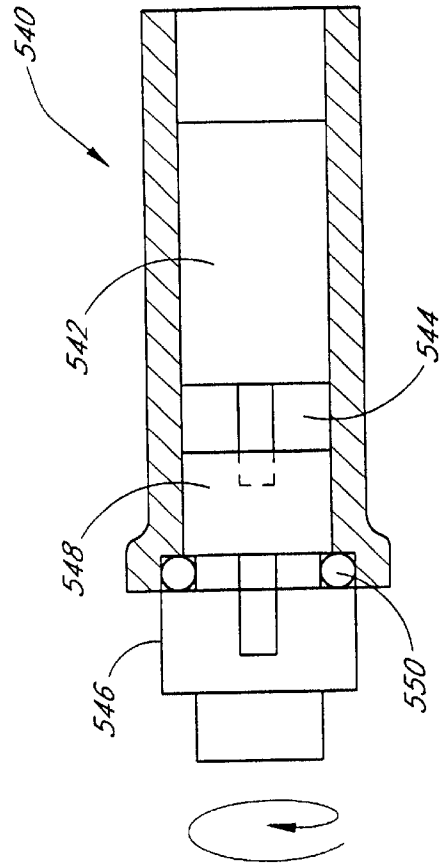


FIG. 5B

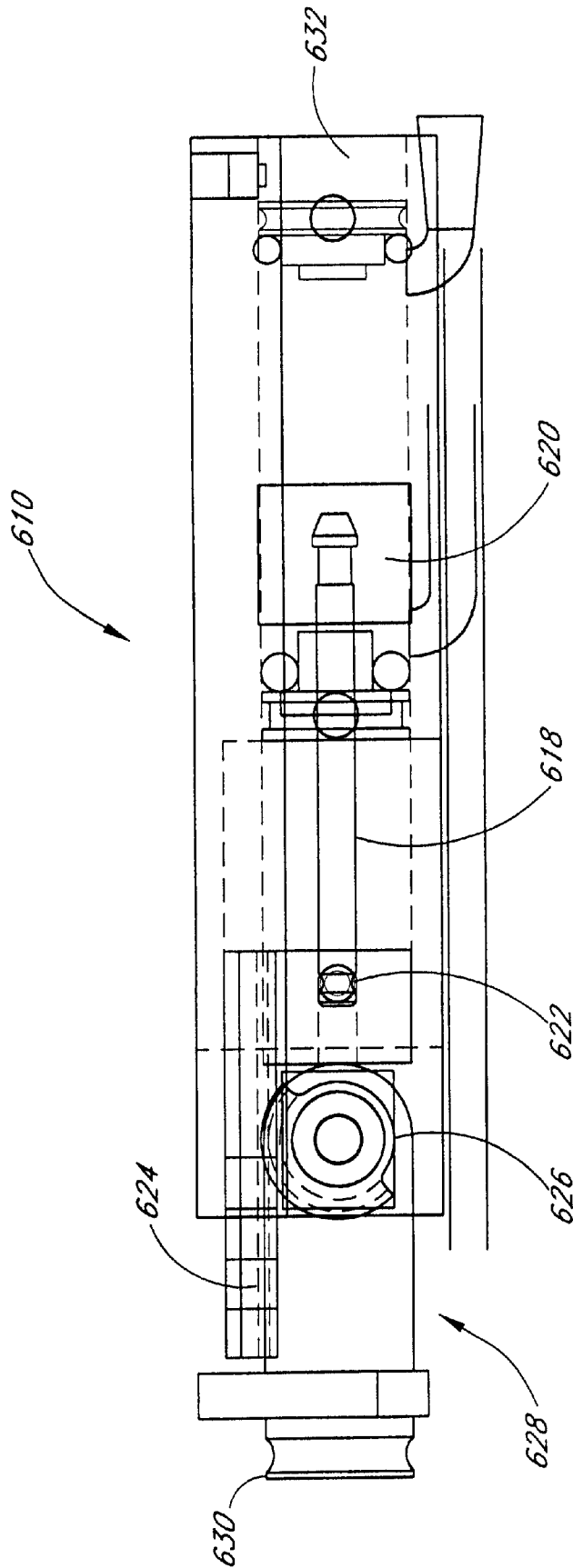


FIG. 6A

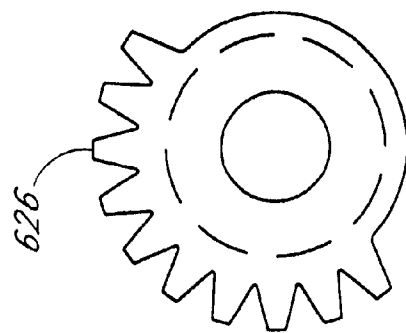


FIG. 6B

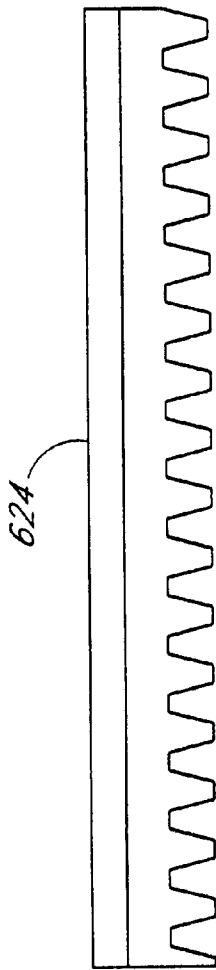


FIG. 6C

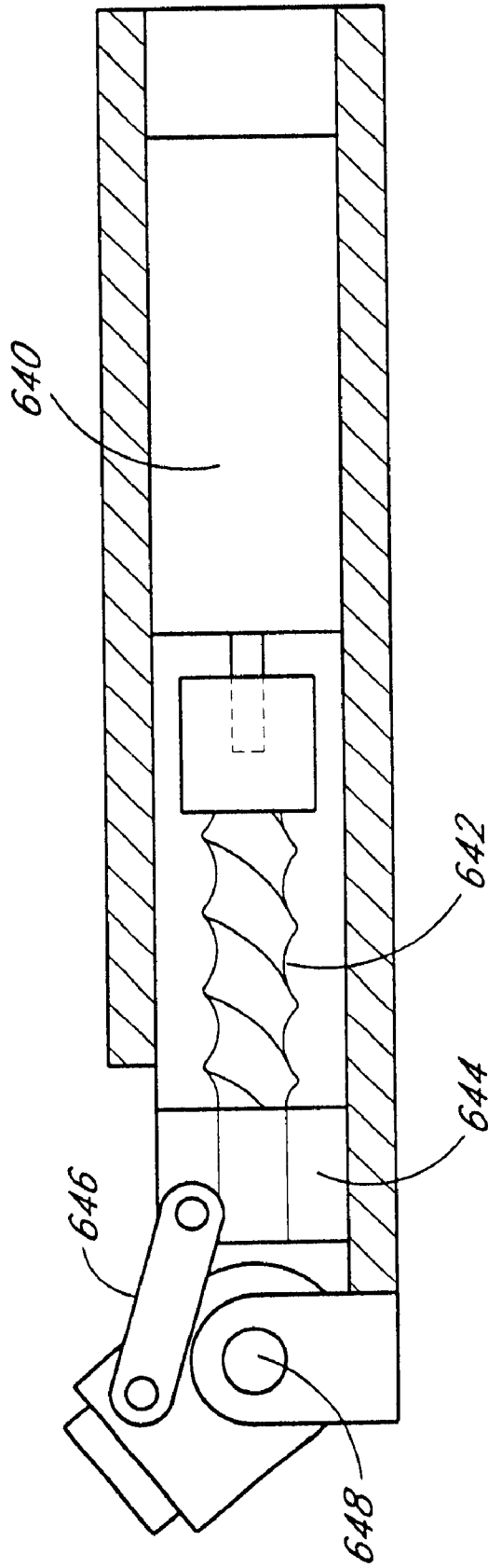


FIG. 6D

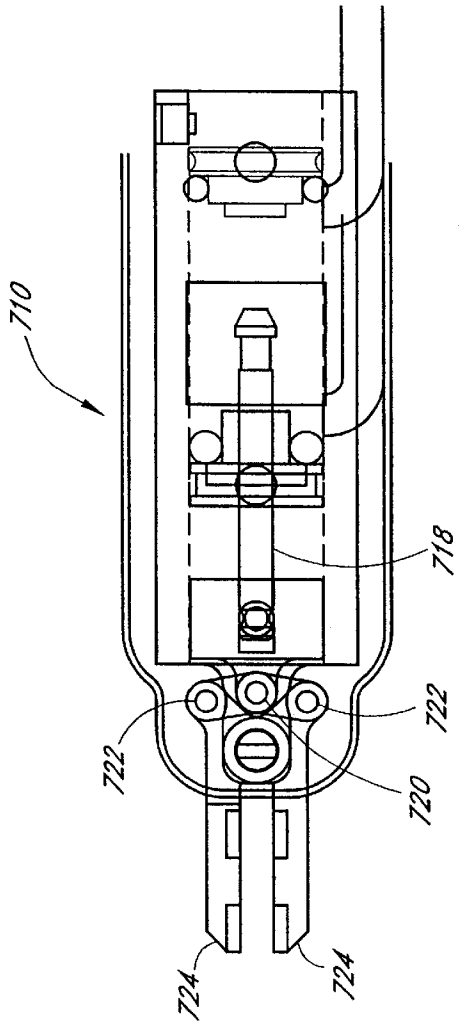


FIG. 7A

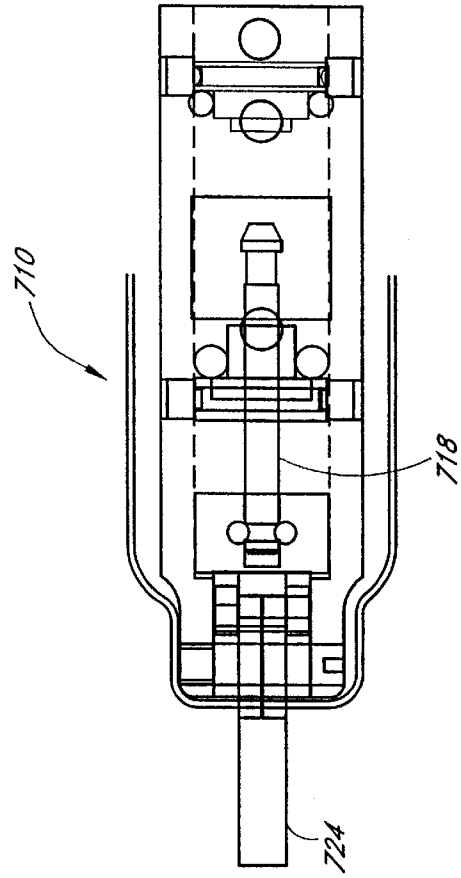


FIG. 7B

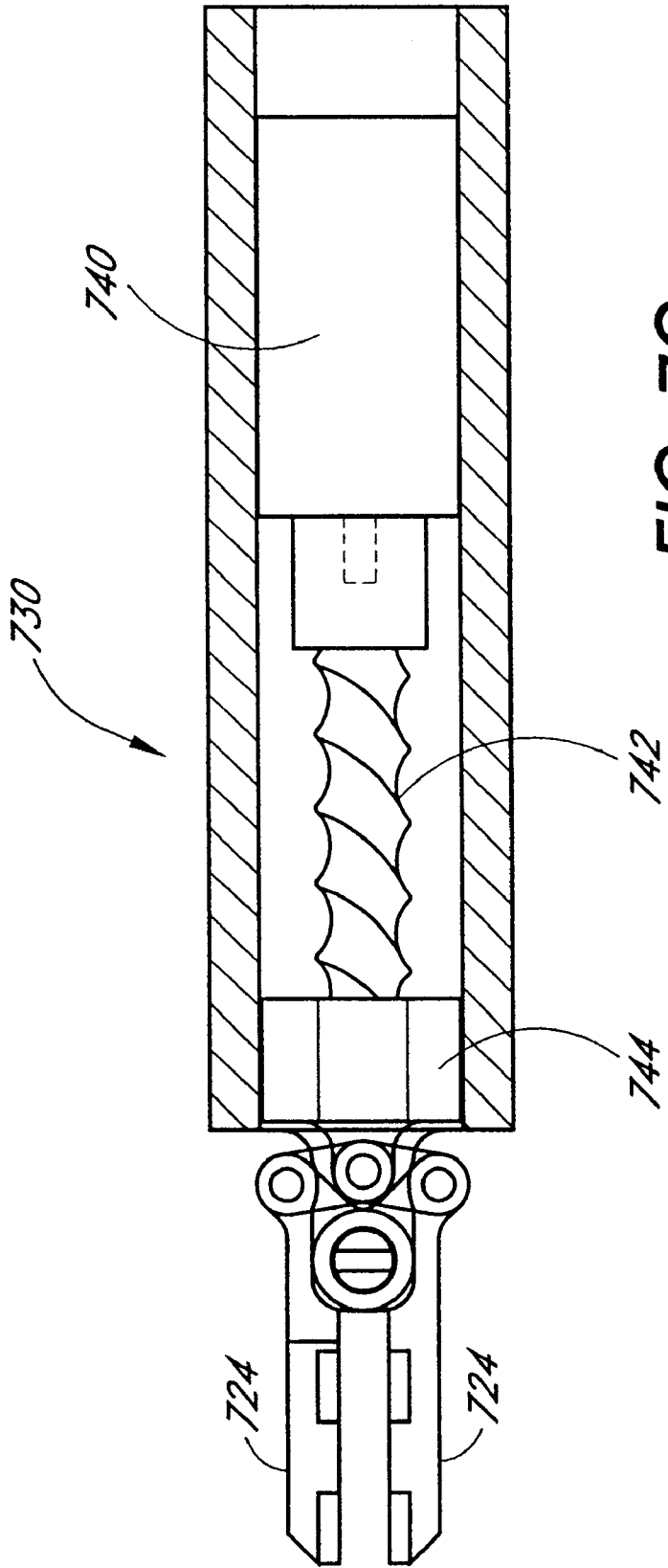


FIG. 7C



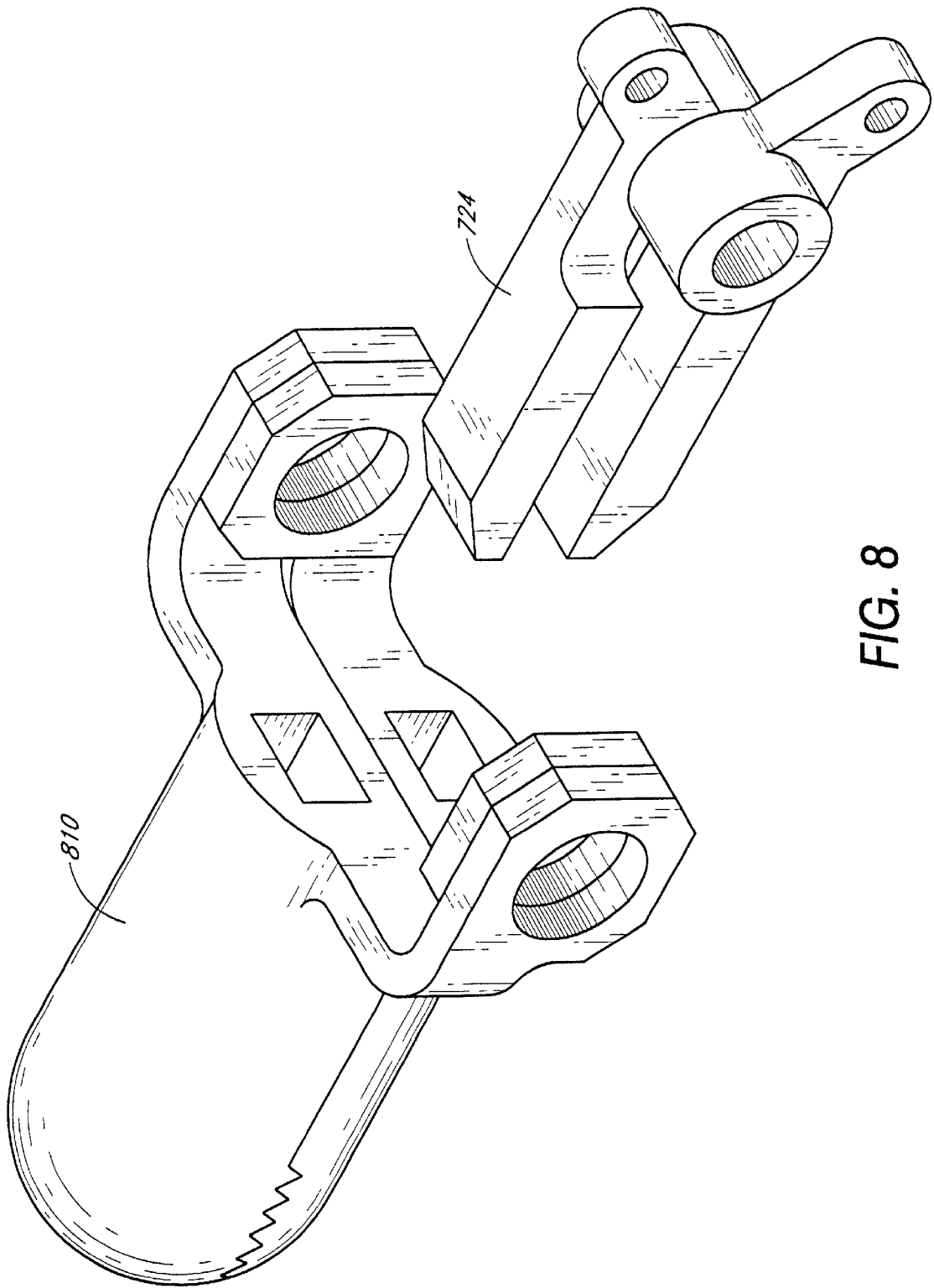


FIG. 8

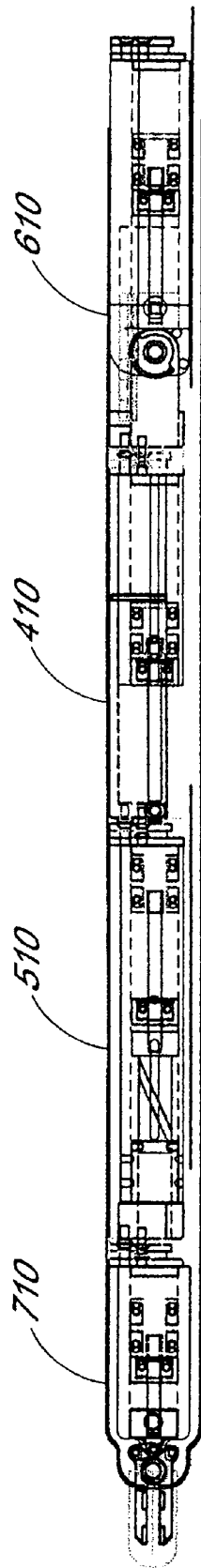


FIG. 9A

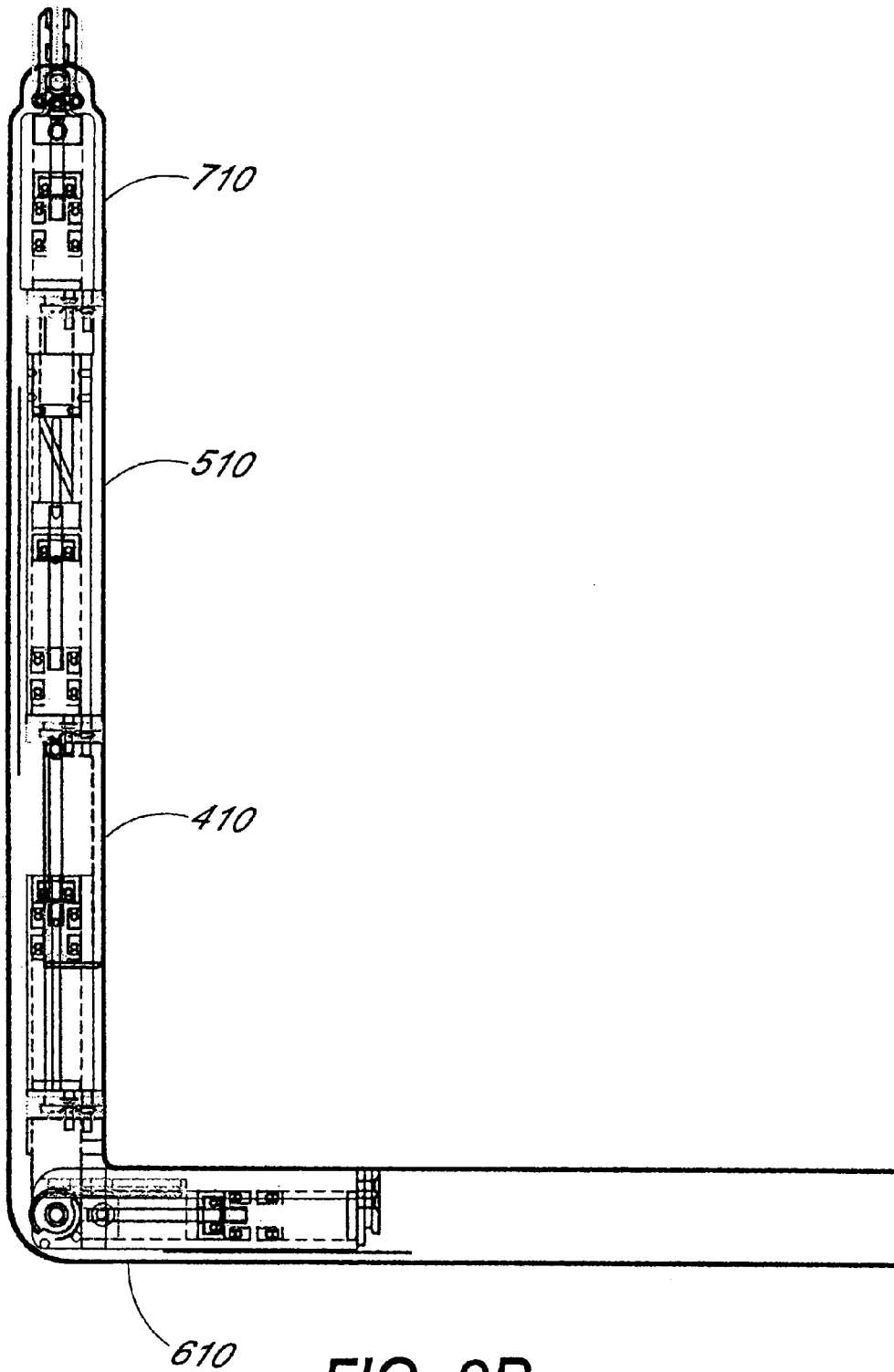


FIG. 9B

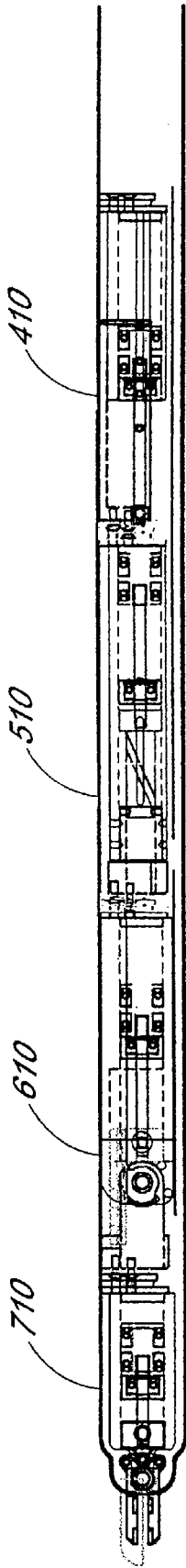


FIG. 9C

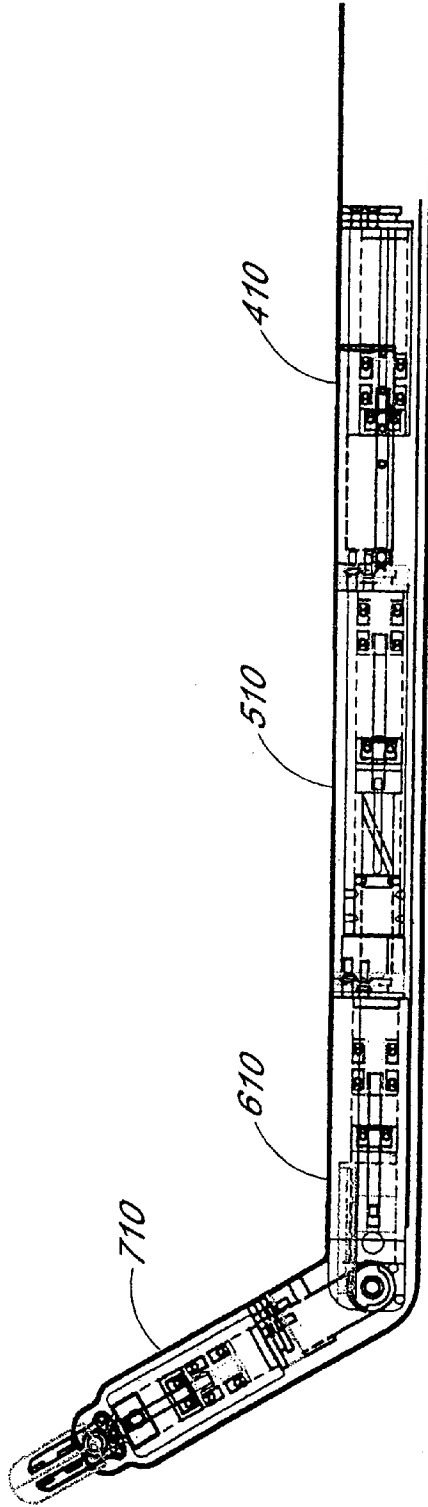


FIG. 9D

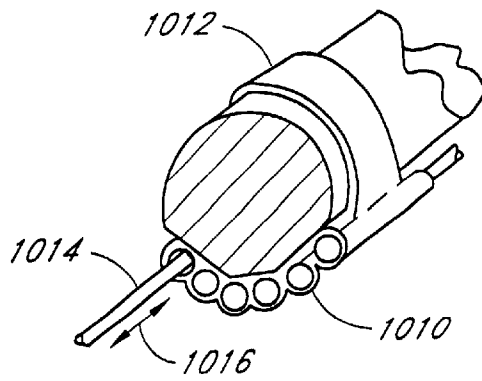


FIG. 10A

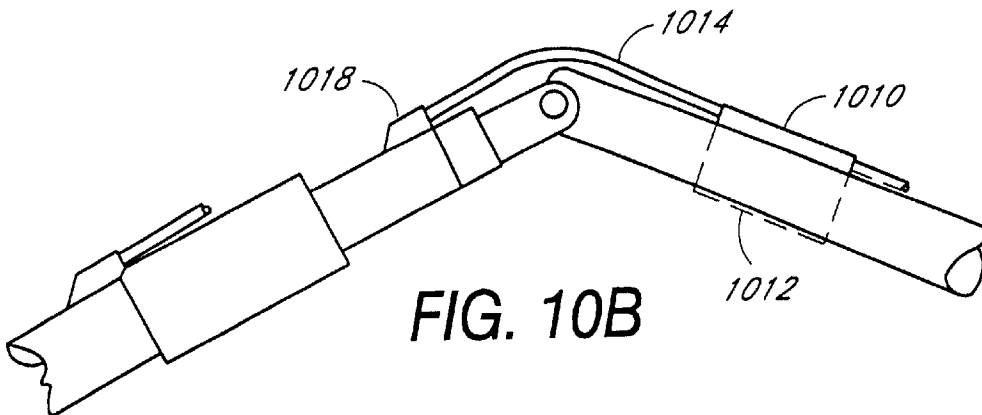


FIG. 10B

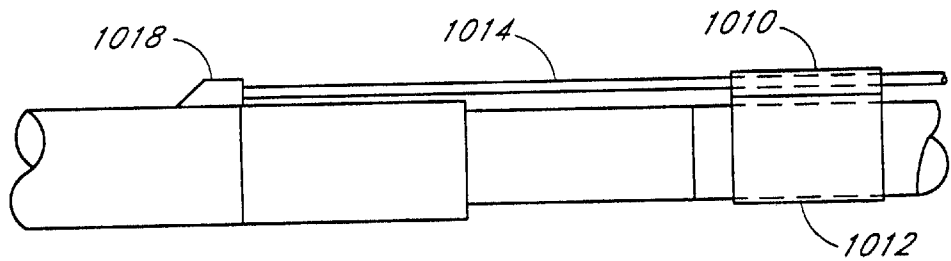


FIG. 10C

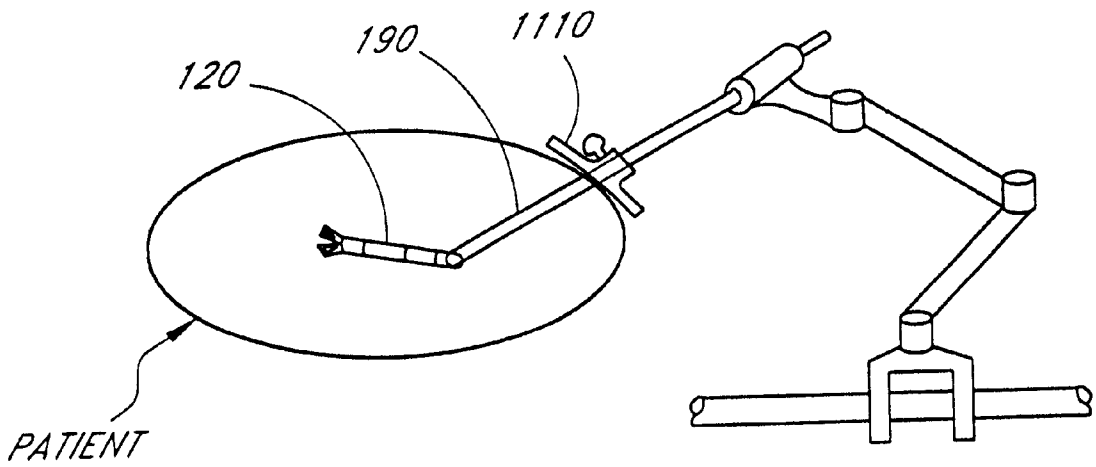


FIG. 11A

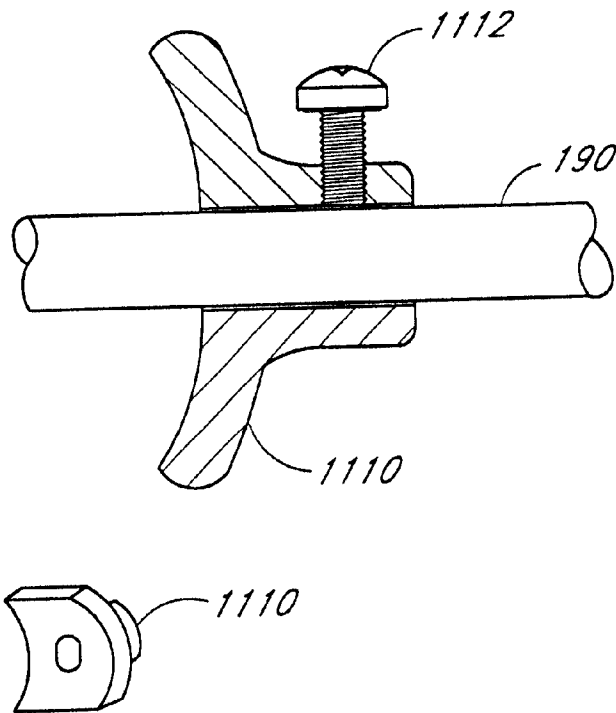


FIG. 11B

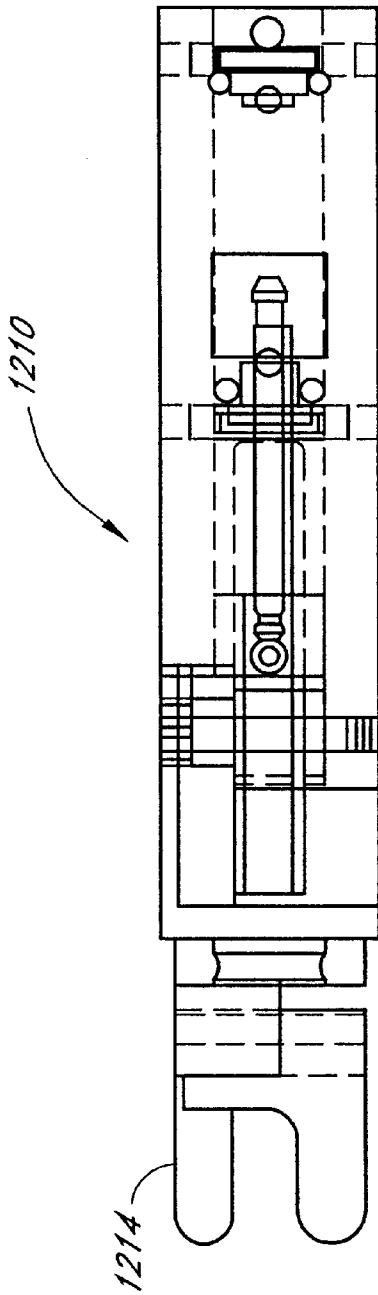


FIG. 12A

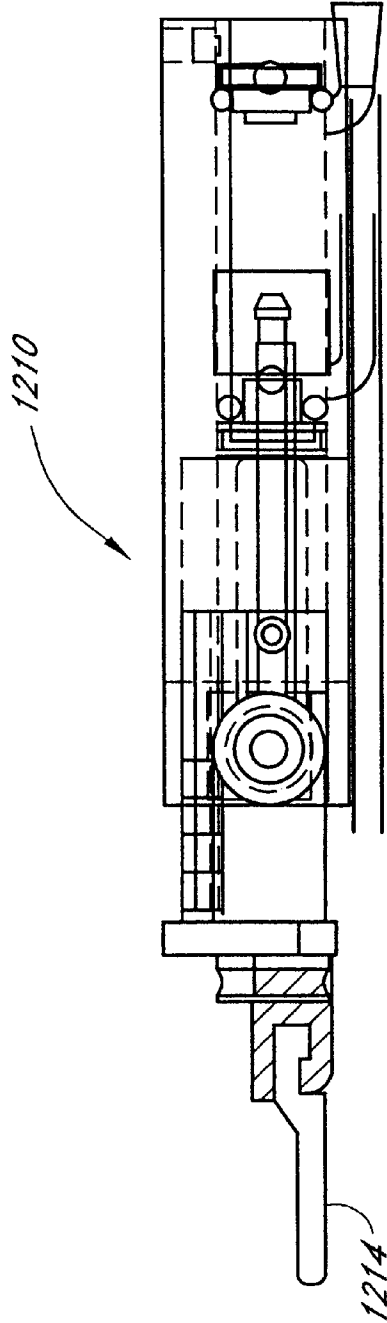
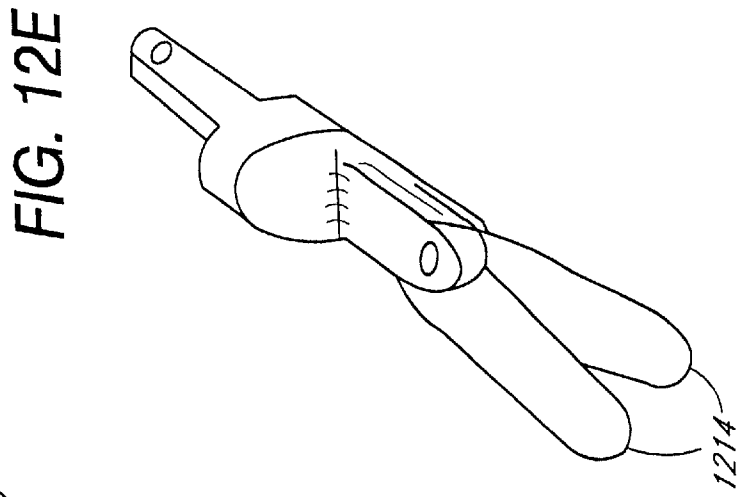
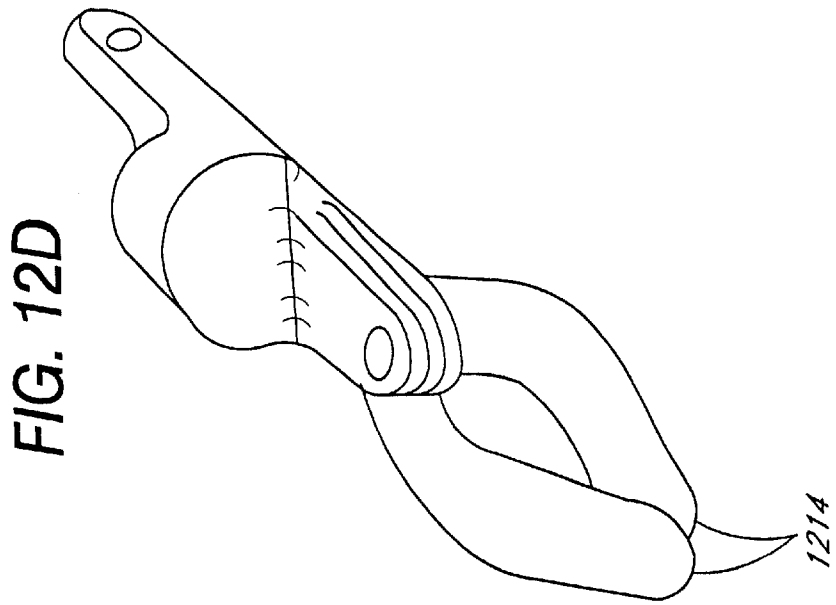
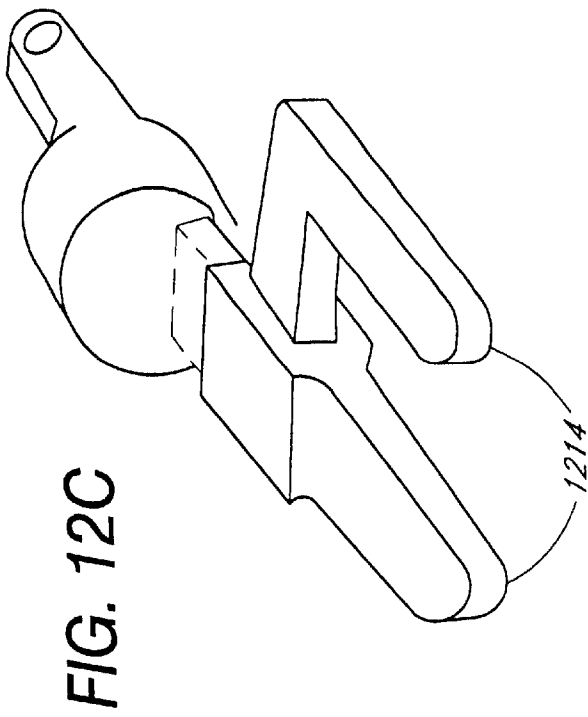


FIG. 12B





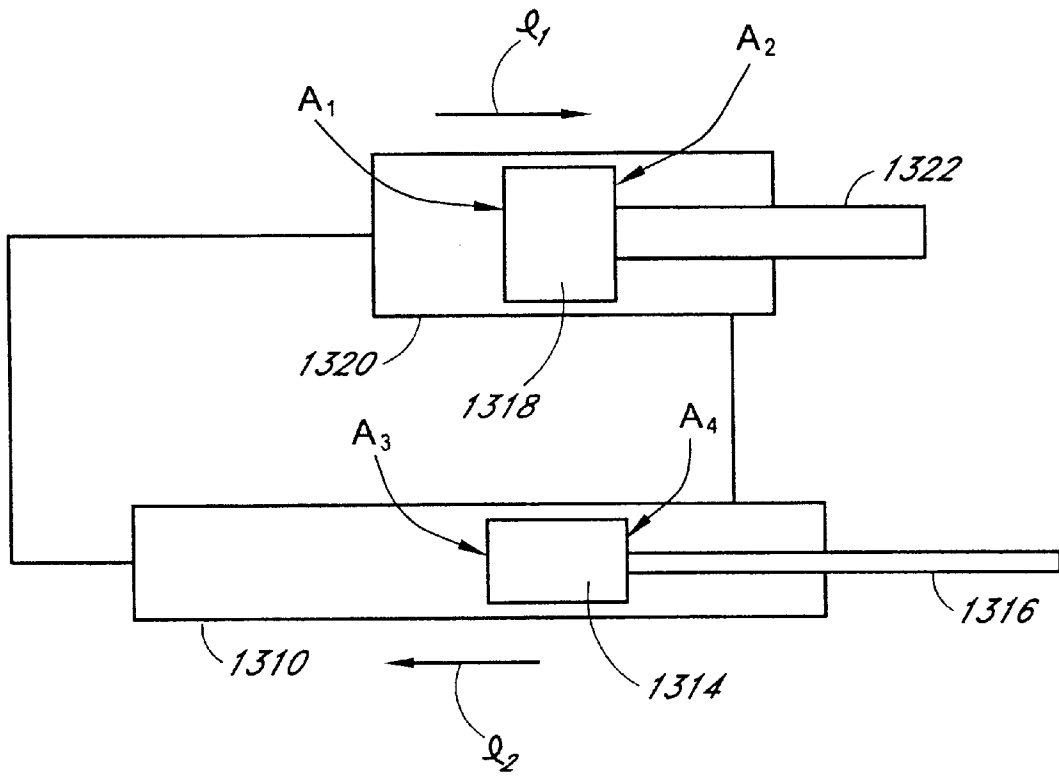


FIG. 13

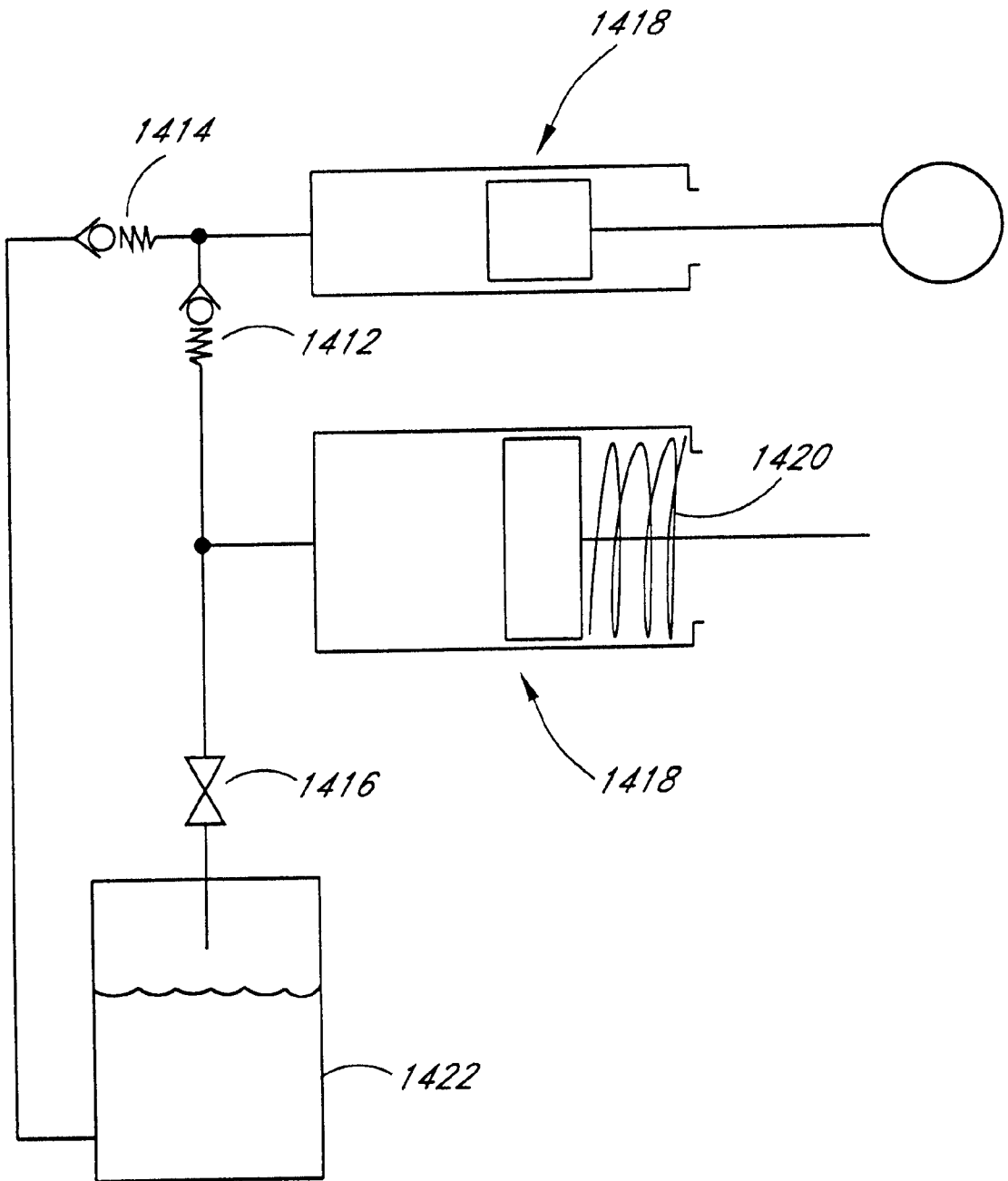
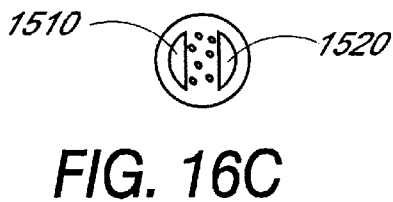
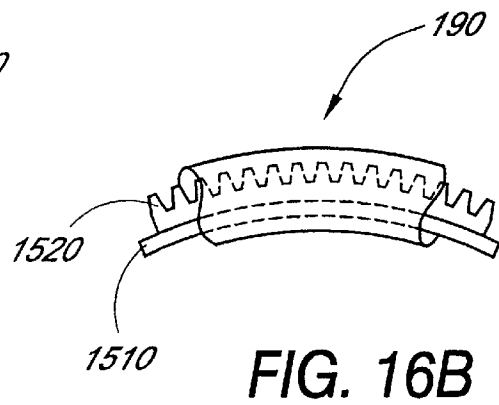
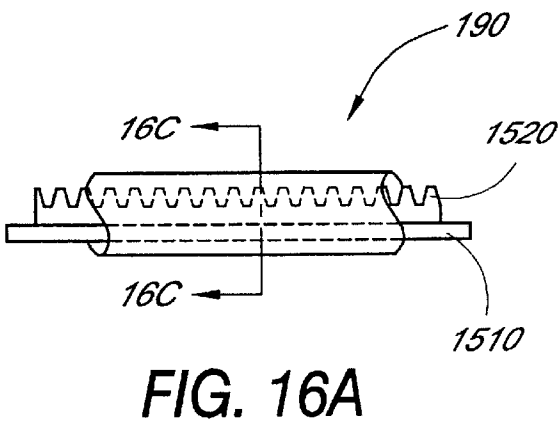
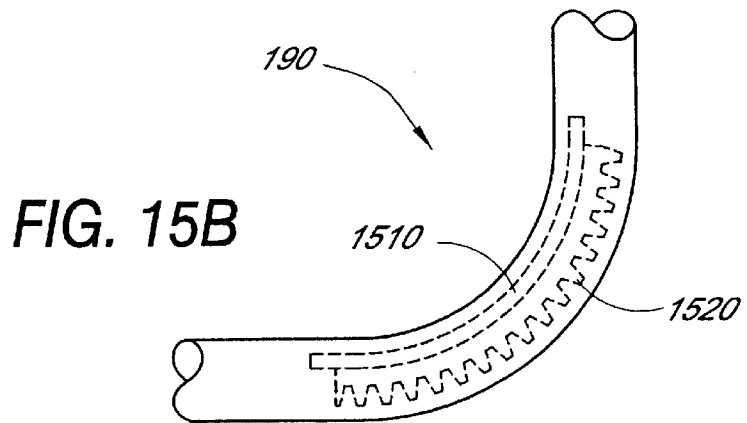
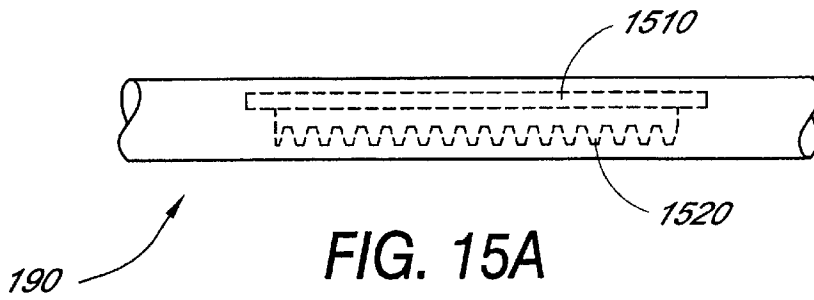


FIG. 14



## HAND-ACTUATED ARTICULATING SURGICAL TOOL

### RELATED APPLICATIONS

This application claims priority to the U.S. Provisional Application Ser. No. 60/219,593, filed Jul. 20, 2000, by Doyle et al., and entitled "HAND-ACTUATED ARTICULATING SURGICAL TOOL," which is incorporated by reference herein in its entirety, including any drawings.

### FIELD OF THE INVENTION

The invention relates generally to surgical instruments. More particularly, the invention relates to a hand-actuated articulating surgical tool for use in minimally invasive surgical procedures.

### BACKGROUND OF THE INVENTION

Current laparoscopic surgical tools are limited in accessibility of certain regions of the human body. Existing tools can perform invasive surgery without making a substantial incision, but these tools are incapable of bending within the body to reach, for example, the backside of the human heart.

Additionally, existing tools rely on use of cables to manipulate the surgical tip of the tool. These tools have the disadvantage of requiring extensive sterilization of the internal components. The cleaning of internal metal cables can be a lengthy and expensive process. This process must be repeated prior to each procedure. Alternatively, disposable components may be used with a substantial increase in recurring costs.

In order for a surgeon to perform a surgical procedure on an active organ, such as the heart, current tools require the organ to be arrested. For example, in order to operate on a small portion of the heart, the patient must be placed on an artificial support system while the heart is temporarily stopped for the surgery. This requires additional equipment such as the artificial support system, substantially increasing the cost of the procedure. Also, the recovery period for the patient is substantially increased.

### SUMMARY OF THE INVENTION

The present invention provides an apparatus for performing minimally invasive surgery while allowing articulation of the tool within the patient's body. Further, the present invention provides a surgical tool that is simple and inexpensive to sterilize and reuse. Another embodiment of the invention allows a surgeon to operate on a portion of an organ, for example, the heart, without the need for arresting the entire organ.

One embodiment of the present invention is a surgical device, comprising at least one controller located at the proximal end of the device adapted to transmit hydraulic control signals. At least one manipulator, configured to be controlled by a human finger actuates the controller. At least one slave, located at the distal end of the device, is in fluid communication with the controller and is configured to respond to the hydraulic control signals transmitted by the controller. A control line provides hydraulic communication between the controller and the slave.

In a preferred embodiment, the controller comprises a control cavity and a piston within the control cavity. The piston divides the control cavity into a first control cavity portion and a second control cavity portion and prevents communication between the two portions. The slave comprises a slave cavity and a piston within the slave cavity that

divides the slave cavity into first and second portions and prevents communication between the two portions. The control line provides hydraulic communication between the first control cavity portion and the first slave cavity portion.

A second control line provides hydraulic communication between the second control cavity portion and the second slave cavity portion.

In another embodiment, the surgical device comprises a control portion located at the proximal end having a plurality of controllers, each controller being adapted to transmit hydraulic control signals. A plurality of manipulators, configured to be controlled by a human finger, actuate a corresponding controller. A slave portion located at the distal end of the device comprises a plurality of slaves. Each slave is in communication with a corresponding controller, and responds to the hydraulic control signals transmitted by the controller. A surgical tip is manipulated by the slaves in response to the hydraulic control signals. Control lines provide communication between the controllers and the slaves. In a preferred embodiment, an outer sleeve envelops the control lines.

The device can also include an articulating portion. The articulating portion comprises a spring bar on one side and a plurality of pockets on an opposing side. The pockets are configured to receive a hydraulic fluid and expand, causing the device to bend as desired. In a preferred embodiment, the device includes a stabilizer having a rigid shaft and a stabilizing plate. The stabilizing plate has an access cutout, and is configured to pivot about the end of the shaft. The shaft can include an articulating portion, if desired.

### BRIEF DESCRIPTION OF THE DRAWINGS

The features, objects and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like references identify correspondingly throughout, and wherein:

FIG. 1 is an overview of one embodiment of the invention.

FIG. 2 is a detailed drawing of one embodiment of the control portion of the invention. FIG. 2A is top view, FIG. 2B is side view, and FIG. 2C is front view. FIG. 2D shows a top view of a grasp cam. FIG. 2E shows a top view of a bend cam.

FIG. 3 is a detailed drawing of an embodiment of a control cylinder. FIG. 3A shows the cylinder's retracted position, while FIG. 3B shows the cylinder's extended position. FIG. 3D shows the components of the control cylinder individually.

FIG. 4 is a detailed drawing of an embodiment of a hydraulic extend module. FIG. 4A shows the module's retracted position, while FIG. 4B shows the module's extended position. FIG. 4C shows the front view of the module. FIGS. 4D-E show two embodiments of an electrical extend module.

FIG. 5A is a detailed drawing of an embodiment of a hydraulic rotate module. FIG. 5B is a detailed drawing of an embodiment of an electrical rotate module.

FIG. 6A is a detailed drawing of an embodiment of a hydraulic bend module. FIG. 6B is a drawing of a gear component in the module. FIG. 6C is a drawing of a rack component in the module. FIG. 6D is a detailed drawing of an embodiment of an electrical bend module.

FIGS. 7A-B is a detailed drawing of an embodiment of a hydraulic grasp module. FIG. 7A is top view and FIG. 7B is

side view. FIG. 7C is a detailed drawing of an embodiment of an electrical grasp module.

FIG. 8 depicts a tool adapted to fit over the tynes of a grasp module.

FIG. 9 depicts various arrangements of the modules. FIG. 9A shows the modules in bend-extend-rotate-grasp configuration, with the bend module in the straight conformation. FIG. 9B shows the same arrangement with the bend module in the bent conformation. FIG. 9C shows the modules in extend-rotate-bend-grasp configuration, with the bend module in the straight conformation. FIG. 9D shows the same arrangement with the bend module in the bent conformation.

FIG. 10 shows an embodiment of the tubing management. FIG. 10A shows the guide tubes as they are attached to the cannula using an elastic strap. FIG. 10B shows the position of the guide tubes with respect to the bend module, while FIG. 10C shows the position of the guide tubes with respect to the extend module.

FIGS. 11A–B show an embodiment of the patient restraint.

FIG. 12 shows an embodiment of the tissue restraint module. FIG. 12A is top view while FIG. 12B is side view. FIGS. 12C–E show various embodiments of the separable tynes of the tissue restraint modules.

FIG. 13 shows the different cylinder diameters for changing the ratio of movement between the control cylinder and slave cylinder.

FIG. 14 shows an embodiment of the multiple stroke cylinder.

FIGS. 15A–B are side views showing the articulation mechanism of the present invention.

FIGS. 16A–C are side views showing the articulation mechanism of FIGS. 15A–B in greater detail.

#### DETAILED DESCRIPTION OF THE INVENTION

Certain embodiments of the invention will now be described in detail with reference to the figures.

FIG. 1 shows a surgical tool according to the present invention. The tool has a control portion 110, 112 at the proximal end of the device and a slave portion 120 at the distal end of the device. As used herein, “proximal” refers to the part of the device that remains outside the patient’s body, closest to the user. “Distal” refers to the end inserted into the patient, farthest away from the user. As with a specific component of the device, “proximal” refers to the part of the component closest to the proximal end of the device, whereas “distal” refers to the part of the component closest to the distal end of the device. An intermediate portion 190 lies between the control portion 110 and the slave portion 120. The “slave portion,” or the “distal end of the device,” 120 is the portion of the device comprising the slave modules, i.e., the extend module, the bend module, the rotate module, and the grasp module, as each is described in greater detail below. Each portion will now be described in greater detail. The term “cannula” is used to refer to the portion of the device comprising both the intermediate portion 190 and the slave portion 120.

The control portion 110, 112 may be any device that can translate the movements of the user’s hand and fingers into hydraulic, mechanical, or electrical signals to actuate the corresponding parts of the slave portion 120 of the device. For example, two such devices are shown in FIG. 1.

In certain embodiments, the control portion 110, 112 uses hydraulic fluid to transfer pressure from a control cylinder to

a slave cylinder. The fluid is preferably sterilized distilled water, however a saline solution, a perfluorinated hydrocarbon liquid, or any other physiologically compatible fluid could also be used. A “physiologically compatible fluid” is a fluid that once exposed to tissues and organs, does not create any intolerable reaction, such as a rash or immune response, in the patient, and does not adversely interfere with the normal physiological function of the tissues or organs to which it is exposed. In addition, a physiologically compatible fluid can remain in a patient’s body or in contact with a tissue or an organ without the need to remove the fluid.

In one embodiment, the control portion 112 clamps onto the arm of the user by way of a clamp 115. The control portion 112 features finger loops 117, into which the user inserts the user’s fingers. By squeezing each finger loop 117, the user creates hydraulic pressure or an electrical signal that results in a corresponding motion at the distal end 120 of the device. The user may then “open” the squeezed finger to create the opposite motion.

Each finger loop 117 is connected with a control cylinder 310 (shown in FIG. 3). The finger loop 117 should be large enough to allow comfortable insertion of a human finger. The finger loop 117 is connected to a longitudinal shaft. The shaft may be made of, for example, metal, ground glass, or ceramic. The shaft may be of any cross-sectional shape, but a circular cross-section is preferred. The cross-sectional size of the shaft, along with the material, are designed to provide sufficient stiffness for predictable control when the finger loop 117 is moved. The shaft slides through an opening in the end of the cylinder body. The interface between the shaft and the opening in the end of the cylinder body is formed to allow for smooth forward and backward movement of the shaft and preferably, at the same time, to provide a water-proof seal.

Another embodiment of the invention includes a control portion 110 that is clamped to the side of a surgical bed using clamps 130. In this embodiment, the user grasps the control portion 110 much in the same way that a motorcycle driver grasps the handles of a motorcycle. The user may turn the handles, push them in, pull them out, pivot them about their axes, or, with the aid of a thumb loop, squeeze them. As detailed below, each of these motions creates a corresponding motion at the distal end 120 of the device.

In another embodiment, the control portion 110 is clamped to an object other than the surgical bed, such as a table or a cart. In yet another embodiment, the control portion 110 is clamped to the user’s arms or hand. In still another embodiment, the control portion 110 is held by the user, without it being clamped to anything.

FIG. 2A shows the top view of the control portion 110. A handle 210 is provided for the user’s fingers to pass through, while the user’s thumb is inserted through a thumb loop 212. The handle 210 may exhibit ridges on the inside of the open loop in order to more comfortably accommodate a user’s fingers.

The movements of the control portion 110 are translated into hydraulic motion through the use of control cylinders 214, 216, 218, 220. When the user squeezes the thumb loop 212 towards the handle 210, a bend cam 222 is turned about a vertical axis. The bend cam 222 is shown in FIG. 2D. As the bend cam 222 turns, a roller 224 is pushed towards the back of the handle. The roller 224 is connected to an outer cylinder 312 of a control cylinder 214 via a shaft 318. The backward movement of the shaft 318 extends a piston 320 backwards, thereby creating the hydraulic pressure needed

to actuate a slave cylinder in the distal end 120 of the device. The function of a control cylinder and its connection to a slave cylinder are discussed in greater detail below. In one embodiment of the invention, the squeezing of the thumb loop actuates a grasp function at the distal end 120.

The control portion 110 may be attached to the side of a surgical bed using a clamp 130. However, the control portion is free to rotate about a vertical axis 226, shown in FIG. 2B. The rotation of the control portion 110 about the axis 226 causes a roller 230 to move within a bend cam 228. The bend cam 228 is shown in FIG. 2E. The roller 230 is connected to an outer cylinder 312 of a control cylinder 220 via a shaft 318. The forward movement of the shaft 318 extends the piston 320 forward, thereby creating the hydraulic pressure needed to actuate a slave cylinder in the distal end 120 of the device. In one embodiment of the invention, the turning of the handle results in a rotation of the distal end 120 of the device through a rotate module, described in detail below.

A user may also push the handle 210 forward, in which case, the top portion of the control portion 110 moves forward over a slide 232. The slide 232 is connected to an outer cylinder 312 of a control cylinder 218 via an attachment point 330. The outer cylinder 312 is in turn attached to the piston 320 via a shaft 318. The forward movement of the shaft 318 extends the piston 320 forward, thereby creating the hydraulic pressure needed to actuate a slave cylinder in the distal end 120 of the device. In one embodiment of the invention, the forward movement of the handle results in an extension of the distal end 120 of the device through an extension module, described in detail below.

The handle part of the control portion 110 may also rotate along a longitudinal axis coinciding with the shaft 234, as shown in FIG. 2B. In certain embodiments of the invention, the turning of the handle part causes a screw 236 to rotate within a nut 238. In some embodiments of the invention, the screw 236 is stationary and the nut 238 is mobile, whereas in other embodiments of the invention, the screw 236 is mobile and the nut 238 is stationary. The movement of the screw 236 within the nut 238 causes the mobile unit to move linearly with respect to the stationary unit. The mobile unit, whether the screw or the nut, is connected to an outer cylinder 312 of a control cylinder 216 via an attachment point 330. The outer cylinder 312 is in turn attached to the piston 320 via a shaft 318. The forward movement of the shaft 318 extends the piston 320 forward, while the backward movement of the shaft 318 pulls the piston 320 backward. The forward and backward motion of the piston 320 creates the hydraulic pressure needed to actuate a slave cylinder in the distal end 120 of the device. In some embodiments of the invention, rotation of the handle part results in the rotation of the distal end 120 of the device through a rotation module, described in detail below.

In certain embodiments of the invention, the movements of the different parts of the control portion 110 creates electrical signals that are sent through wires in the intermediate portion 190 to the slave cylinders in the distal end 120 of the device. The electrical signal is sufficient to actuate a motor in the corresponding slave cylinder, which in turn results in the slave module being actuated. Thus, for example, a forward movement of the handle 210 creates an electrical signal that actuates a motor in an extend module, which results in the extension of that module. Similarly, the rotation of the handle 210, the bending of the handle 210, and the squeezing of the thumb loop 212, result in the rotate module, the bend module, and the grasp module, respectively, being actuated. The slave modules having a motor are described in greater detail below.

Cylinders 214, 216, 218, and 220 are control cylinders. A typical control cylinder 310 is shown in its retracted position in FIG. 3A and in its extended position in FIG. 3B. The control cylinder 310 comprises an outer cylinder 312 and an inner cylinder 314. The inner cylinder 314 has a diameter that allows it to move within the outer cylinder 312. The outer cylinder 312 is connected to a shaft 318, which in turn is connected to the control portion 110 through the attachment point 330. The movements of the control portion 110, described above, causes the outer cylinder 312 to move longitudinally with respect to the stationary inner cylinder 314.

A piston 320, attached to a shaft 318, moves within the inner cylinder 314, within a distance defined by the two inlet points 322, 324 for the hydraulic fluid. The distal end of the shaft 318 is configured to be capable of attachment to the piston 320, while the proximal end of the shaft 318 is configured to be capable of attachment to the outer cylinder at a site close to the attachment point 330. The outer cylinder or the handle assembly may be provided with ratchet teeth. The ratchet teeth are adapted to engage with a locking mechanism to secure the piston 320 at a desired position relative to the cylinder body. Alternatively, a locking mechanism may employ a friction lock to secure the piston 320 at a desired position.

The piston 320 has a solid front face and is movable along the longitudinal axis of the inner cylinder 314. The front face of the piston 320 is identical in shape to the cross section of the cylindrical cavity. The outer surface of the piston 320 forms an airtight seal with the inner surface of the inner cylinder 314. Thus, the portion of the cavity on one side of the piston 320 does not communicate with the portion of the cavity on the other side of the piston 320. At the same time, the piston 320 must be allowed to move smoothly back and forth along the longitudinal axis of the inner cylinder 314.

The proximal end of the inner cylinder 314 is sealed with a seal 316, comprising an opening therethrough, through which the shaft 318 can slide. The distal end of the inner cylinder 314 is sealed with another seal 328, optionally comprising an O-ring 326.

Thus, in the extended position of the control cylinder 310, FIG. 3B, the piston 320 is at rest against the proximal seal 316. The hydraulic fluid is located in the inner cylinder 314 in front of the piston 320. When the control portion 110 is moved in a way described above, i.e., when the handle 210 is moved forward, the outer cylinder 312 moves forward, thereby moving the shaft 318 and the piston 320. Hydraulic fluid exits the inner cylinder 314 through an inlet 324, creating a hydraulic pressure at a point in the distal end 120 of the device. Additional hydraulic fluid, displaced from a slave cylinder, enters to the back of the piston 320 through another inlet 322, thereby keeping the volume of the hydraulic fluid in the system constant. When the control portion 110 is moved completely, the control cylinder 310 is in its retracted position, FIG. 3A. In this position, the piston 320 is at the distal end of the inner cylinder 314, resting against the distal seal 328. The hydraulic fluid is in the back of the piston 320. Those of skill in the art understand that although in the above discussion the piston 320 is described to move from the fully retracted position to the fully extended position, the piston 320 may move from any point along the two extremes to any other point along the two extremes, and thereby cause a corresponding movement in a slave cylinder.

The cannula 190 comprises hydraulic tubings, connecting the control cylinders of the control portion 110 with the slave cylinders at the distal end 120, and housings for the hydraulic tubings.

The distal end **120** comprises modular components. The components can be selected from, for example, an extend module, a rotate module, a bend module, and a grasp module. Other functions can be included as well and activated in the manner described in detail below. Each module is individually describe in greater detail below. The invention is adapted such that the user can pick the combination of modules and the quantity of each individual module that is best suitable for the user's needs and assemble them conveniently.

The extend module **410** is depicted in both its retracted position, FIG. **4A**, and extended position, FIG. **4B**. The extend module **410** is identical in its construction to the control module **310**; however, the function of the two are reversed. By applying hydraulic pressure using the control portion **110**, hydraulic fluid enters the inner cylinder **414** pushing the piston **420** towards the distal end of the module and the distal seal **416**. The shaft **418** moves through the distal seal **416**, but it is attached to the outer cylinder **412** at the distal end of the outer cylinder **430**. The movement of the piston **420** moves the outer cylinder **412** towards the distal end of the module, thereby extending the cannula. The hydraulic fluid present inside the inner cylinder **414** exits the inner cylinder **414** through the distal outlet **422**. The proximal seal **428** prevents the leakage of hydraulic fluid from proximal end of the inner cylinder **414**.

Additional modules can be attached to the extend module either at its distal end, through the distal attachment point **430**, or at its proximal end, through the proximal attachment point **431**.

In another embodiment, the extend module may be extended using electrical power instead of hydraulic power. In this embodiment, by pushing forward on the handle **210** of the control portion **110**, the user causes an electrical connection to be formed, whereby electrical signal is sent from the control portion **110** through wires in the intermediate portion **190** to the extend module **432**, FIGS. **4D**, **4E**. The electrical signal causes an electrical motor **434** to turn. In one embodiment, FIG. **4D**, a screw **436** is mounted within the motor **434**. The turning of the motor **434** causes the screw to move outward, thereby causing the outer cylinder **440** to move away from the inner cylinder **442**. In this embodiment, the motor is stationary, i.e., it is attached to the inner cylinder **442**, whereas the screw is mobile, i.e., it moves with respect to the motor and the inner cylinder **442**. The screw **436** is attached at its distal end to the outer cylinder **440**.

In another embodiment, FIG. **4E**, the motor **434** causes the screw **436** to turn within a nut **438**. The nut **438** is attached to the outer cylinder **440**. The turning of the screw **436** causes the nut **438** to move with respect to the screw **436**, thereby moving the outer cylinder **440** longitudinally with respect to the inner cylinder **442**, causing the module to extend. In this embodiment, the motor **434** and the screw **436** are stationary with respect to the inner cylinder **442**, whereas the nut **438** and the outer cylinder **440** are mobile.

The rotate module **510**, FIG. **5A**, comprises similar hydraulic components as those of the extend module **410**. As in the extend module **410**, hydraulic pressure, applied by rotating the control portion **110** along a longitudinal axis, causes piston **520** to move toward the distal end of the module, causing the shaft **518** to move in that direction as well. The shaft **518** is attached to a lead screw **522** at an attachment point **524**. Extension of the shaft **518** causes the lead screw **522** to move towards the distal end of the module. The lead screw is incapable of rotating, since a stabilizer **526**

prevents its rotation. The lead screw **522** instead is extended through a nut assembly **528** which is immovably attached to an outer cylinder **530**. The movement of the lead screw **522** through the nut assembly **528** causes the nut assembly **528** to rotate, thereby rotating the outer cylinder **530**.

Additional modules can be attached to the rotate module either at its distal end, through the distal attachment point **532**, or at its proximal end, through the proximal attachment point **534**.

In another embodiment, the rotate module may be rotated using electrical power instead of hydraulic power. In this embodiment, by turning the handle **210** of the control portion **110**, the user causes an electrical connection to be formed, whereby an electrical signal is sent from the control portion **110** through wires in the intermediate portion **190** to the rotate module **540**, FIG. **5B**. The electrical signal causes an electrical motor **542** to turn. The electrical motor **542** is attached to a shaft **544** which in turn is attached to the outer cylinder **546**. The turning of the shaft rotates the outer cylinder. In some embodiments, a gear reducer assembly **548** may also be present to reduce the rotation speed. In certain embodiments, the connection between the outer cylinder **546** and the cylinder housing the motor assembly **542** may feature a bearing assembly **550**.

The bend module **610** is depicted in FIG. **6A**. This module also features the same hydraulic assembly present in the extend and the rotate modules, above. Applying hydraulic pressure by rotating the control portion **110** along the vertical axis **226** in a clockwise direction causes the piston **620** and the shaft **618** to move towards the distal end of the module. The shaft **618** is attached to a rack **624** either directly or through an attachment assembly **622**. The movement of the shaft **618** moves the rack **624**. The rack **624** has teeth that correspond to the teeth on a gear **626**. The movement of the rack **624** causes the gear **626** to rotate clockwise. The gear **626** is connected to the distal end **628** of the module. The rotation of the gear **626** causes the distal end **628** of the module to bend clockwise. By rotating the control portion **110** in a counter-clockwise direction, the piston **620** is moved towards the proximal end of the module, causing the rack **624** to move backwards as well, which in turn causes the gear **626** to turn counter-clockwise, which in turn causes the distal end **628** of the module to bend counter-clockwise.

In some embodiments, the bending of the distal end **628** of the module is through an angle of at least  $110^\circ$ , i.e., when the piston **620** moves from the proximal end of the hydraulic portion completely to the distal end of the hydraulic portion, the distal end **628** of the module bends at least  $110^\circ$ . In other embodiments, the rotation is an angle of at least  $110^\circ$ , at least  $150^\circ$ , at least  $200^\circ$ , at least  $250^\circ$ , at least  $300^\circ$ , or an angle of at least  $350^\circ$ .

Additional modules can be attached to the bend module either at its distal end, through the distal attachment point **630**, or at its proximal end, through the proximal attachment point **632**.

In another embodiment, the bend module may be bent using electrical power instead of hydraulic power. In this embodiment, by turning the handle **210** of the control portion **110**, the user causes an electrical connection to be formed, whereby electrical signal is sent from the control portion **110** through wires in the intermediate portion **190** to the bend module. The electrical signal causes an electrical motor to turn. The electrical motor is attached to a shaft which in turn is attached to the rack **624**. The movement of the shaft **618** moves the rack **624**, which in turn causes the

gear 626 to rotate, which in turn causes the distal end 628 of the module to bend.

In another embodiment, FIG. 6D, the turning of the motor 640 causes a lead screw 642 to rotate within a nut 644. The lead screw 642 is stationary with respect to the motor 640 and the outer body of the module, whereas the nut 644 is mobile. The nut 644 is connected to a link 646 at the proximal end of the link 646. The distal end of the link 646 is connected to the distal end of the module. When the nut 644 is moved backwards, it causes the link 646 to move backwards, thereby causing the distal end of the module to rotate. Reversing the electrical current, by rotating the control portion 110 in the opposite direction, will cause the motor to turn in the opposite direction, thereby causing the nut to move forward and the distal end of the module to bend in a clockwise direction.

FIG. 7A depicts the top view of the grasp module 710, whereas FIG. 7B depicts its side view. The grasp module 710 also features a hydraulic portion similar to those of other modules. When the thumb loop 212 is squeezed towards the handle 210, hydraulic pressure is applied and the shaft 718 moves towards the distal end of the module. This movement causes the pin 720 to move towards the distal end of the module as well, thereby causing the two pins 722 to move away from the center. As the two pins 722 move away from the center, the angle defined by pin 722-pin 720-pin 722 tends away from 90° and towards 18°. The movement of the pins 722 causes the two tynes 724 to move towards each other and, eventually, touch. Moving the thumb loop 212 away from the handle 210 will have the opposite effect of causing the tynes 724 to move away from each other and open up.

In another embodiment, the squeezing of the thumb loop 212 causes an electrical current to turn a motor 740, FIG. 7C, in the grasp module 730. The motor 740 turns a stationary lead screw 742, which in turn causes a nut 744 to move longitudinally. The movement of the nut 744 causes the tynes to move closer to each other and, eventually, touch. Moving the thumb loop 212 away from the handle 210 will have the opposite effect of causing the tynes 724 to move away from each other and open up.

The tynes 724 of the grasp module 710 are configured to accommodate a number of different tools. For example, in FIG. 8, a grasp tool 810 is shown that can fit over the tynes 724. When the tynes 724 move towards each other, the end portion of the grasp tool 810 also move toward each other and, eventually, touch. If an object or tissue is located between the end portions of the grasp tool 810, the object is then grasped by the tool. There may be a number of tools that can be attached over the tynes 724. In addition to the grasp tool, these include a scissors, a knife for cutting the tissue, drill bits for drilling into bones, heating elements for cauterizing tissue, or any other tool necessary during a surgical procedure.

All the above tools and other tools can fit individually and interchangeably on the grasp module 710. Therefore, during a surgical procedure, the user may attach one tool to the grasp module 710, use it, remove it, and then attach another tool to the same grasp module 710. This process can be repeated any number of times with any number of tools.

As mentioned above, the modules of the present invention are designed to be placed in order that the user deems most useful. For example, FIG. 9 depicts four of the modules attached in the order of (from proximal end to distal end) bend, extend, rotate, and grasp. FIG. 9A shows the bend module in its retracted position, where the cannula is

straight. FIG. 9B shows the bend module in its extended position where the module is bent. Alternatively, the four modules could be arranged in the extend-rotate-bend-grasp configuration, as shown in FIGS. 9C, 9D. Other combinations are also possible. In addition, the user may attach more than a single module of a particular type, for example, two or three or more extend modules or two or three or more bend modules, could be put together, along with other modules to form the distal end 120 of the device. Preferably, the grasp module 710 is always the most distally located module.

As shown in FIG. 4C, the front view of the extend module, the hydraulic tubing connecting the various modules to the control cylinders are located at one side of the slave cylinders. The hydraulic tubing runs alongside the cannula and connects to the inlet openings of the hydraulic portion of each module. In some embodiments of the invention, to keep the hydraulic tubing in place, a series of low friction guide tubes 1010 are attached to the cannula by an elastic strap 1012 (FIG. 10A). Each hydraulic tubing 1014 fits through one guide tubing and is free to move longitudinally, i.e., in the direction of the arrow 1016, within the guide tubing 1010. Thus, when the bend module bends, FIG. 10B, or when the extend module extends, FIG. 10C, the hydraulic tubing can move along the cannula and maintain the connection 1018 with the hydraulic inlets of each of the modules.

In certain embodiments, the present invention features a restraint 1110 that can be attached to the cannula 190 using a thumb screw 1112 (FIG. 11). The restraint 1110 sits adjacent to the patient's skin on the outside of the patient's body at the point of entry of the cannula 190. The restraint 1110 keeps the depth of the cannula 190 with respect to the body of the patient's body. If the patient makes any moves during the surgery, for example if the anesthesia begins to wear off and the patient jolts, the cannula moves with the patient. More importantly, the depth of the cannula inside the patient's body remains unchanged. Therefore, if the patient moves, the patient will not be damaged by the cannula.

As part of their normal physiological function, certain organs in the body have continuous motion. For example, the heart beats, the lungs expand and contract as the patient breathes, and the gastrointestinal tract also undergoes contractile motion. When performing surgery, it is often necessary to stabilize the part of the organ undergoing surgery so that additional injury to the organ does not occur and the organ can be worked on. Aspects of the invention also feature a tissue restraint module 1210 (FIG. 12) that can be inserted into the patient's body at or near the site where any other cannula has been inserted. The tissue restraint module 1210 features a bend module, as described above. Once inserted into the patient's body, the separable tynes 1214 can be brought close to the tissue that is to be restrained. The bend module allows the tyne assembly to be bent with respect to the cannula, so that the tynes 1214 may be placed over the tissue. The tynes 1214 are separable so that they can provide a relatively stable tissue area for the performance of the surgery.

A number of different mechanisms for separating the tynes 1214 are shown in FIGS. 12C-E. In the embodiments shown, the tissue restraint module comprises two tynes 1214. The tynes 1214 are adapted to be separable. When inserting the module into the patient's body, the tynes 1214 are held together to reduce the width of the device. Inside the patient's body, the tynes 1214 can be separated. In the embodiment shown in FIG. 12C, one tyne 1214 is stationary, while the second tyne 1214 slides away from the first tyne



**1214.** In the embodiment shown in FIG. 12D, both tynes **1214** move away from the center. Since the two tynes **1214** are bent inward, in their fully extended position the distal end of the two tynes **1214** would be parallel to each other. The embodiment shown in FIG. 12E functions similarly, except that the two tynes are not bent. In the fully extended position the two tynes **1214** form a "V" shaped opening. Other embodiments are also contemplated. For example, the tissue restraint module may comprise only one tyne. In certain embodiments, the single-tyne module may have a shape such as "O", "f", "T".

In certain embodiments, the tissue restraint module is held against a tissue or an organ during the surgical procedure. By doing so, in the space between the two tynes **1214**, or a particular space created within a single tyne, a surface area of the tissue or organ becomes restrained, i.e., the local motion of the tissue or the organ is considerably reduced as compared with an unrestrained region of the tissue or the organ. The restraining of the tissue or the organ provides a relatively stable area on which the user can perform the surgical procedure.

In certain embodiments, the intermediate portion **190** of the cannula can be adapted to hold a number of different tools to be used during the operation. The cannula may be the cannula leading to the tissue restraint module or the cannula leading to the grasp module **710** at the distal end **120** of the device. Preferably, the cannula is the one leading to the tissue restraint module. During the operation, the user can retrieve a first tool from the cannula while within the patient's body and attach it to the grasp module **710**. After using the first tool, the user can then return the first tool to the cannula, retrieve a second tool and attach it to the grasp module **710**. Other tools may subsequently be used in a similar fashion.

The cannula **190** is held in place using a positioning arm **140** (see FIG. 1). The positioning arm **140** comprises at least one joint capable of being tightened or loosened using a release mechanism. The user can release the joint, move the positioning arm **140** to a desired location, and thereby re-position the cannula **190**. In one embodiment, the invention provides for a one-hand-release mechanism. In this embodiment, the user can grasp the positioning arm **140** with one hand, and while holding the positioning arm **140**, loosen the joint using the same hand, move the positioning arm **140** to a new location using the same hand, and then tighten the joint, again using the same hand. The one-hand-release mechanism allows the user to reposition the cannula using one hand, while manipulating the distal end **120** of the device using the control portion **110** with the other hand.

In using the devices of the present invention, it is often the case that the tools at the distal portion of the device are to move a short distance. This distance is small enough that it would become difficult for the user to move his hands or fingers for that short a distance. Therefore, a system is needed to convert a longer movement of the user's hands and fingers at the proximal end of the device to a short movement of the tools at the distal end of the device. This is accomplished by having the control cylinder and the slave cylinder be of different diameters. Of importance, is the relationship between the piston area and the shaft area when using cylinders of different diameters, as generally described below.

At least a portion of the intermediate portion **190** of the laparoscopic tool is preferably an articulation portion. FIGS. 15A-B and 16A-C illustrate one embodiment of an articulation mechanism implemented in the articulation portion of

the intermediate portion **190**. A spring bar **1510** is embedded within the body of the outer sleeve. The spring bar may be made of any material, such as plastic or metal, that allows it to resiliently bend while exerting a reacting force against the bending. The spring bar **1510** acts to prevent the articulation portion from bending unless a force is exerted to cause it to bend. An opposite wall of the sleeve is lined with small pouches **1520**. FIG. 16C illustrates the arrangement of the pouches **1520** and the spring bar **1510** in a cross-sectional view of the articulation portion. The pouches **1520** are densely placed along the length of the articulation portion. The pouches **1520** are connected to a reservoir of hydraulic liquid (not shown) by a series of orifices or valves in each pouch. When hydraulic fluid is supplied to the pouches **1520** through the orifices or valves, the pouches **1520** are filled with the hydraulic liquid. The filled pouches **1520** press against one another and force an expansion of the side of the articulation portion with the pouches **1520**. This expansion causes the spring bar **1510** to bend, causing the articulation portion to bend, as shown in FIG. 16B.

#### Double Acting/Double Cylinder System

Another aspect of the present invention includes a double acting/double cylinder system. This system is depicted in FIG. 13. The system comprises a control cylinder **1320** and a slave cylinder **1310**. The control cylinder comprises a piston **1318** and a shaft **1320** attached thereto. The piston **1318** is capable of moving within the control cylinder **1320**. The piston divides the control cylinder into two cavities: a distal cavity, a wall of which is  $A_1$ , and a proximal cavity, a wall of which is  $A_2$ . The shaft **1322** passes through the proximal cavity. The piston **1318** prevents liquid communication between the distal cavity and the proximal cavity.

The slave cylinder comprises a piston **1314** and a shaft **1316** attached thereto. The piston **1314** is capable of moving within the slave cylinder **1310**. The piston divides the slave cylinder into two cavities: a distal cavity, a wall of which is  $A_3$ , and a proximal cavity, a wall of which is  $A_4$ . The shaft **1316** passes through the proximal cavity. The piston **1314** prevents liquid communication between the distal cavity and the proximal cavity.

A control line provides hydraulic communication between the proximal cavity of the control cylinder and the proximal cavity of the slave cylinder. Another control line provides hydraulic communication between the distal cavity of the control cylinder and the proximal cavity of the slave cylinder. Thus, in the system, the two distal cavities are in hydraulic communication with each other, the two proximal cavities are in hydraulic communication with each other, but no proximal cavity is in hydraulic communication with any distal cavity.

If the control cylinder piston **1318** moves towards the distal end of the control cylinder **1320**, hydraulic fluid is moved from the distal cavity of the control cylinder, through a control line, and into the distal cavity of the slave cylinder, thereby pushing the slave cylinder piston **1314** towards the proximal end of the slave cylinder **1310**. The reverse may also happen. If the control cylinder piston **1318** moves towards the proximal end of the control cylinder **1320**, hydraulic fluid is moved from the proximal cavity of the control cylinder, through a control line, and into the proximal cavity of the slave cylinder, thereby pushing the slave cylinder piston **1314** towards the distal end of the slave cylinder **1310**. Further, while the control cylinder piston **1318** remains stationary, the slave cylinder piston **1314** also remains stationary.

In an embodiment, the double acting/double cylinder system of the invention comprises an overpressure reservoir.

If the hydraulic pressure within the cylinders or the control lines exceeds a certain amount, some hydraulic fluid is transferred to the overpressure reservoir. The opening to the overpressure reservoir may comprise a pressure gauge device, which can become activated when the hydraulic pressure within a system surpasses a certain preset value. When the pressure gauge device is activated, the opening to the overpressure reservoir opens and hydraulic fluid can then enter the reservoir.

In another embodiment, the overpressure reservoir comprises an opening, which is in constant fluid communication with the hydraulic fluid within the system. The reservoir further comprises a spring mechanism at the side opposite to the opening. When the hydraulic pressure within the system surpasses the pressure applied by the spring mechanism, hydraulic fluid enters the reservoir from the system. Conversely, when the pressure within the system falls below the pressure applied by the spring mechanism, for example due to a leak in the system, hydraulic fluid enters the system from the reservoir. Thus, the reservoir may also function as a fluid replacement reservoir.

In certain embodiments, the flow of the hydraulic fluid inside the system will move very easily so that not enough resistance is afforded. In these situations, it is difficult for a user to control the movement of the cylinders with fine precision. Therefore, certain embodiments of the invention feature a narrowing at a point in the hydraulic tubing, the purpose of which is to create resistance. In some embodiments, the user can change the amount of narrowing, and therefore, the amount of resistance in the hydraulic tubing.

FIG. 13 depicts the relationship between the control cylinder 1310 and the slave cylinder 1312. The control cylinder 1310 has a piston 1314 and a shaft 1316. The front of the piston 1314, i.e., the opposite face from where the shaft 1316 attaches to the piston 1314, has an area of  $A_3$  and the back of the piston 1314, i.e., the face where the shaft 1316 attaches, has an area is  $A_4$ . Thus,  $A_3$  is equal to  $A_4$  plus the area of the shaft 1316. When the piston 1314 moves backwards a distance of  $l_2$ , the amount of hydraulic fluid displaced in front of the piston 1314 will have a volume of  $A_3 l_2$ . However, the volume of the hydraulic fluid displaced behind the piston 1314 will be  $A_4 l_2$ .

The slave cylinder 1312 also has a piston 1318 and a shaft 1320. The volumes of displaced hydraulic fluid in front of and behind the piston 1318 must be equal to the volume of displaced hydraulic fluid in front of and behind the piston 1314. In other words,

$$A_1 l_1 = A_3 l_2$$

and

$$A_2 l_1 = A_4 l_2$$

where  $l_1$  is the distance traveled by the slave cylinder. Rearranging the equations results in

$$l_2 = \frac{A_1 l_1}{A_3} = \frac{A_2 l_1}{A_4}$$

which result in the basic relationship between the various surface areas as

$$\frac{A_1}{A_3} = \frac{A_2}{A_4}$$

It is readily understood by those of skill in the art that the above relationship will also hold true if the control cylinder and the slave cylinder are configured such that small movements by the user's hands and fingers results in longer movements at the distal end of the device. In other words, in FIG. 13, in one embodiment 1312 represents the slave cylinder and 1310 represents the control cylinder, whereas in another embodiment, 1312 represents the control cylinder and 1310 represents the slave cylinder.

In certain embodiments, when it is desirable to have a long range of movement or very fine movement at the distal end of the device, it is preferable to affect a full range of movement at a slave cylinder at the distal end of the device using multiple strokes of a control cylinder. In these embodiments, the present invention features a multiple stroke cylinder system (FIG. 14). A stroke of the control cylinder 1410 causes check valve 1414 to close and check valve 1412 to open. Hydraulic fluid is then transferred from the control cylinder 1410 to the slave cylinder 1418. Returning the piston of the control cylinder 1410 to the original position, i.e., at the proximal end of the control cylinder, causes the check valve 1412 to close and the check valve 1414 to open. Additional hydraulic fluid is then transferred from the reservoir 1422 to the control cylinder 1410. Another stroke of the control cylinder 1410 will then cause additional movement in the slave cylinder 1418.

The system is also equipped with a "dump" valve 1416. The dump valve 1416 may be activated by the user at anytime. When the dump valve 1416 is activated, hydraulic fluid is transferred from the slave cylinder 1418 back to the reservoir 1422.

In some embodiments, to aid the removal of the hydraulic fluid from the slave cylinder 1418 a spring mechanism 1420 is placed behind the piston of the slave cylinder. Those of skill in the art know of other mechanisms that can be used to return the piston of the slave cylinder to its original position.

In other embodiments, the system is so configured that the user can reverse the flow of the hydraulic fluid. Therefore by additional strokes of the control cylinder the user can remove hydraulic fluid from the slave cylinder 1418 and transfer it back to the reservoir 1422.

#### CONCLUSION

Thus, those of skill in the art will appreciate that the devices described herein provide a relatively easy and economical instrument to perform minimally invasive surgery.

One skilled in the art will appreciate that these devices are and may be adapted to carry out the objects and obtain the ends and advantages mentioned, as well as those inherent therein. The methods, procedures, and devices described herein are presently representative of preferred embodiments and are exemplary and are not intended as limitations on the scope of the invention. Changes therein and other uses will occur to those skilled in the art which are encompassed within the spirit of the invention and are defined by the scope of the disclosure.

It will be apparent to one skilled in the art that varying substitutions and modifications may be made to the invention disclosed herein without departing from the scope and spirit of the invention.

Those skilled in the art recognize that the aspects and embodiments of the invention set forth herein may be practiced separate from each other or in conjunction with each other. Therefore, combinations of separate embodiments are within the scope of the invention as disclosed herein.

All patents and publications mentioned in the specification are indicative of the levels of those skilled in the art to which the invention pertains. All patents and publications are herein incorporated by reference to the same extent as if each individual publication was specifically and individually indicated to be incorporated by reference.

The invention illustratively described herein suitably may be practiced in the absence of any element or elements, limitation or limitations which is not specifically disclosed herein. Thus, for example, in each instance herein any of the terms "comprising", "consisting essentially of" and "consisting of" may be replaced with either of the other two terms. The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention that in the use of such terms and expressions indicates the exclusion of equivalents of the features shown and described or portions thereof. It is recognized that various modifications are possible within the scope of the invention disclosed. Thus, it should be understood that although the present invention has been specifically disclosed by preferred embodiments and optional features, modification and variation of the concepts herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scope of this invention as defined by the disclosure.

What is claimed is:

1. A surgical device, comprising:
  - at least one controller located at a proximal end of the surgical device, said controller being adapted to transmit hydraulic control signals;
  - at least one manipulator, said manipulator being configured to be controlled by a human hand and to actuate said controller;
  - at least one slave located at a distal end of the surgical device, said slave being in fluid communication with said controller and being configured to respond to said hydraulic control signals transmitted by said controller; and
  - at least one control line providing hydraulic communication between said controller and said slave;
 wherein said slave directly or indirectly causes the operation of, or the change of position of, a tool necessary for performing a surgical procedure.
2. The surgical device according to claim 1, wherein said controller further comprises:
  - a control cavity; and
  - a piston within said control cavity, said piston dividing said control cavity into a first control cavity portion and a second control cavity portion and preventing communication between said first control cavity portion and said second control cavity portion;
 wherein said slave further comprises:
  - a slave cavity; and
  - a piston within said slave cavity, said piston dividing said slave cavity into a first slave cavity portion and a second slave cavity portion and preventing communication between said first slave cavity portion and said second slave cavity portion; and

wherein said control line provides hydraulic communication between said first control cavity portion and said first slave cavity portion.

3. The surgical device according to claim 2, further comprising a second control line providing hydraulic communication between said second control cavity portion and said second slave cavity portion.

4. A surgical device, comprising:

a control portion located at a proximal end of the surgical device, comprising:

- a plurality of controllers, each of said plurality of controllers being adapted to transmit hydraulic control signals; and

- a plurality of manipulators, each of said plurality of manipulators being configured to actuate a corresponding one of said plurality of controllers;

a slave portion located at a distal end of the surgical device, comprising:

- a plurality of slaves, each of said plurality of slaves being in communication with a corresponding one of said plurality of controllers and being configured to respond to said hydraulic control signals transmitted by said corresponding one of said plurality of controllers; and

- an intermediate portion, comprising a plurality of control lines, each of said plurality of control lines providing communication with one of said plurality of controllers and a corresponding one of said plurality of slaves;

wherein each of said plurality of slaves directly or indirectly causes the operation of, or the change of position of, a tool necessary for performing a surgical procedure.

5. The surgical device according to claim 4, wherein said intermediate portion further comprises an outer sleeve enveloping said plurality of control lines.

6. The surgical device according to claim 4, wherein said intermediate portion further comprises an articulating portion, said articulating portion further comprising:

- a spring bar on a first side of said articulating portion; and
- a plurality of pockets on a second side of said articulating portion, said second side opposing said first side,

wherein said pockets are configured to receive a hydraulic fluid, and

wherein, said pockets are configured to expand when said hydraulic fluid is received.

7. The surgical device of claim 4, further comprising a tip adapted to be manipulated by at least one of said plurality of slaves in response to said hydraulic control signals.

8. The surgical device of claim 4, wherein said hydraulic communication is through a hydraulic fluid.

9. The surgical device of claim 8, wherein said hydraulic fluid is physiologically acceptable.

10. The surgical device of claim 4, wherein each of said plurality of slaves has a predefined function.

11. The surgical device of claim 10, wherein said predefined function is selected from extension, rotation, bending, and grasping.

12. The surgical device of claim 10, wherein said predefined function of at least one of said plurality of slaves is different than said predefined function of at least another one of said plurality of slaves.

13. The surgical device of claim 4, further comprising a patient restraint.