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Quick-release end effectors and related systems and methods

Abstract

The various embodiments disclosed herein relate to arms or forearms of medical devices that are configured to couple with quick-release end effectors, quick-release end effectors for use with such medical devices, and arms or forearms coupled to such quick-release end effectors. Certain forearms and end effectors have magnetic couplings, while others have mechanical couplings, and further implementations have both magnetic and mechanical couplings.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION (1) This patent application claims priority as a continuation of U.S. patent application Ser. No. 16/504,793, filed on Jul. 8, 2019, now issued as U.S. Pat. No. 11,576,695 and entitled “Quick-Release End Effectors and Related Systems and Methods,” which claims priority as a continuation of U.S. patent application Ser. No. 14/853,477, filed on Sep. 14, 2015, now issued as U.S. Pat. No. 10,342,561 and entitled “Quick-Release End Effectors and Related Systems and Methods,” which claims the benefit under 35 U.S.C. § 119(e) to U.S. Provisional Application 62/049,419, filed Sep. 12, 2014 and entitled “Quick-Release End Effectors and Related Systems and Methods,” all of which are hereby incorporated herein by reference in their entireties.

FIELD OF THE INVENTION

(1) The various embodiments disclosed herein relate to various medical device systems and related components, including robotic and/or in vivo medical devices and related components. More specifically, certain embodiments include various medical device operational components, often referred to as “end effectors.” Certain end effector embodiments disclosed herein relate to quick-release end effectors that can be easily coupled to and removed from a medical device—including the forearm of a robotic medical device—with ease and efficiency. Further embodiments relate to systems and methods for operating the above components.

BACKGROUND OF THE INVENTION

(2) 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 the need to remove and insert new surgical tools into the body cavity when changing surgical instruments due to the size of the access ports. Known robotic systems such as the da Vinci® Surgical System (available from Intuitive Surgical, Inc., located in Sunnyvale, CA) are also restricted by the access ports and trocars, the necessity for medical professionals to remove and insert new surgical tools into the abdominal cavity, as well as having the additional disadvantages of being very large, very expensive, unavailable in most hospitals, and having limited sensory and mobility capabilities.

(3) Various robotic surgical tools have been developed to perform certain procedures inside a target cavity of a patient. These robotic systems are intended to replace the standard laparoscopic tools and procedures—such as, for example, the da Vinci® system—that involve the insertion of long surgical tools through trocars positioned through incisions in the patient such that the surgical tools extend into the target cavity and allow the surgeon to perform a procedure using the long tools. As these systems are developed, various new components are developed to further improve the operation and effectiveness of these systems.

(4) There is a need in the art for improved end effectors for use with medical devices, including

robotic surgical systems.

BRIEF SUMMARY OF THE INVENTION

(5) Discussed herein are various arms or forearms of medical devices that are configured to receive quick-release end effectors. Further embodiments relate to such quick-release end effectors. Additional implementations relate to arms or forearms of medical devices coupled to such quick-release end effectors.

(6) In Example 1, an arm component for a medical device comprises an arm body, a rotatable cylinder disposed within the arm body, and a rotatable linear drive component operably coupled to the rotatable cylinder. The rotatable cylinder comprises a fluidically sealed end effector lumen defined within the rotatable cylinder and at least one torque transfer channel defined in a wall of the end effector lumen. The rotatable linear drive component comprises a rotatable body, and a drive component lumen defined in a distal portion of the rotatable body, wherein the drive component lumen comprises mating features defined within the drive component lumen.

(7) Example 2 relates to the arm component according to Example 1, further comprising a ring seal disposed between the arm body and the rotatable cylinder.

(8) Example 3 relates to the arm component according to Example 1, further comprising a first motor operably coupled to a first drive gear, wherein the first drive gear is operably coupled to an external gear disposed on an outer wall of the rotatable cylinder, wherein actuation of the first motor causes rotation of the rotatable cylinder.

(9) Example 4 relates to the arm component according to Example 1, further comprising a second motor operably coupled to a second drive gear, wherein the second drive gear is operably coupled to a driven gear operably coupled to the linear drive component, wherein actuation of the second motor causes rotation of the linear drive component. Example 5 relates to the arm component according to Example 1, further comprising a first outer contact ring disposed around the rotatable cylinder, a second outer contact ring disposed around the rotatable cylinder, a first contact component disposed on an outer wall of the rotatable cylinder such that the first contact component is in continuous contact with the first inner contact ring regardless of a rotational position of the rotatable cylinder, a second contact component disposed on the outer wall of the rotatable cylinder such that the second contact component is in continuous contact with the second inner contact ring regardless of the rotational position of the rotatable cylinder, a first inner contact ring disposed on the inner wall of the end effector lumen, and a second inner contact ring disposed on the inner wall of the end effector lumen.

(10) Example 6 relates to the arm component according to Example 5, further comprising a quick-release end effector configured to be positionable within the end effector lumen, the quick-release end effector comprising first and second end effector contact components, wherein the first end effector contact component is in contact with the first inner contact ring and the second end effector contact component is in contact with the second inner contact ring when the quick-release end effector is operably coupled to the arm.

(11) Example 7 relates to the arm component according to Example 1, further comprising a quick-release end effector configured to be positionable within the end effector lumen. The quick-release end effector comprises an end effector body, at least one torque transfer protrusion defined in an exterior portion of the end effector body, a rod disposed within the end effector body, and a rod coupling component disposed at a proximal portion of the rod. The at least one torque transfer protrusion is configured to be mateable with the at least one torque transfer channel in the end effector lumen. The rod coupling component is configured to be coupleable with the mating features defined in the lumen of the rotatable linear drive component.

(12) In Example 8, a quick-release end effector for a medical device comprises an end effector body, an end effector coupling component disposed around the end effector body, at least one torque transfer protrusion defined in an exterior portion of the end effector body, a rod disposed within the end effector body, a rod coupling component disposed at a proximal portion of the rod,

and first and second contact rings disposed around the rod. The end effector coupling component comprises at least one male protrusion extending from the coupling component. The rod coupling component comprising first mating features disposed on an external portion of the rod coupling component.

(13) Example 9 relates to the quick-release end effector according to Example 8, further comprising an end effector disposed at a distal end of the end effector body, wherein the end effector is operably coupled to the rod such that actuation of the rod causes actuation of the end effector.

(14) Example 10 relates to the quick-release end effector according to Example 8, further comprising a grasper end effector comprising first and second grasper arms, wherein the first contact ring is electrically coupled to the first grasper arm and the second contact ring is electrically coupled to the second grasper arm.

(15) Example 11 relates to the quick-release end effector according to Example 8, wherein the end effector is configured to be positionable in a lumen of an arm of a medical device.

(16) Example 12 relates to the quick-release end effector according to Example 8, wherein the end effector is configured to be positionable in a lumen of an arm of a medical device, the lumen comprising at least one torque transfer channel defined in the lumen, wherein the at least one torque transfer protrusion is configured to be mateable with the at least one torque transfer channel in the end effector lumen.

(17) Example 13 relates to the quick-release end effector according to Example 8, wherein the end effector is configured to be positionable in a lumen of an arm of a medical device, wherein the arm comprises at least one female channel defined in a distal portion of the arm, wherein the end effector coupling component is configured to be coupleable to the arm such that the at least one male protrusion is mateable with the at least one female channel.

(18) Example 14 relates to the quick-release end effector according to Example 8, wherein the end effector is configured to be positionable in an arm of a medical device. The arm comprises an arm body, a rotatable cylinder disposed within the arm body, and a rotatable linear drive component operably coupled to the rotatable cylinder. The rotatable cylinder comprises an end effector lumen defined within the rotatable cylinder, and at least one torque transfer channel defined in a wall of the end effector lumen. The linear drive component comprises a rotatable body, and a lumen defined in a distal portion of the rotatable body, wherein the lumen comprises second mating features defined within the lumen. The first mating features of the rod coupling component are configured to be coupleable with the second mating features defined within the lumen of the rotatable linear drive component.

(19) In Example 15, an arm component for a medical device comprises a forearm and a quick-release end effector. The forearm comprises a forearm body, a fluidically sealed tube defining an end effector lumen within the forearm body, a magnetic ring disposed around the end effector lumen, and a linear drive component disposed at a proximal end of the end effector lumen. The linear drive component comprises a proximal section comprising external threads and a slot defined in a distal portion of the linear drive component. The quick-release end effector is configured to be positionable within the end effector lumen and comprises an end effector body, a magnetic collar disposed around the end effector body, a rod disposed within the end effector body, and at least one finger component operably coupled to the rod, wherein the at least one finger component extends proximally from the rod and is configured to be coupleable with the slot in the linear drive component.

(20) Example 16 relates to the arm component for a medical device according to Example 15, further comprising a first motor operably coupled to a first drive gear, wherein the first drive gear is operably coupled to a first driven gear, wherein the driven gear is operably coupled to the magnetic ring, wherein actuation of the first motor causes rotation of the magnetic ring.

(21) Example 17 relates to the arm component for a medical device according to Example 16,

wherein the magnetic collar is magnetically coupleable with the magnetic ring such that rotation of the magnetic ring causes rotation of the magnetic collar.

(22) Example 18 relates to the arm component for a medical device according to Example 15, further comprising a second motor operably coupled to a second drive gear, wherein the second drive gear is operably coupled to a drive cylinder, wherein the drive cylinder is operably coupled to the proximal section of the linear drive component, wherein the actuation of the second motor causes axial movement of the linear drive component.

(23) Example 19 relates to the arm component for a medical device according to Example 15, wherein the fluidically sealed tube is fixedly coupled to the linear drive component, wherein the fluidically sealed tube is configured to flex when the linear drive component moves axially.

(24) Example 20 relates to the arm component for a medical device according to Example 15, further comprising a compression spring disposed within the forearm body, wherein the compression spring is operably coupled to the forearm body and the at least one finger.

(25) In Example 21, an arm component for a medical device comprises a forearm comprising a forearm body, a fluidically sealed tube defining an end effector lumen within the forearm body, a first magnetic ring disposed around the end effector lumen at or near the distal end of the forearm body, a first motor operably coupled to a first drive gear, a second magnetic ring disposed around the end effector lumen at or near a proximal end of the forearm body, and a second motor operably coupled to a second drive gear. The lumen comprises an opening defined at a distal end of the forearm body. The first drive gear is operably coupled to a first driven gear, wherein the first driven gear is operably coupled to the first magnetic ring. The second drive gear is operably coupled to a second driven gear, wherein the second driven gear is operably coupled to the second magnetic ring.

(26) In Example 22, an arm component for a medical device comprises a forearm and a quick-release end effector. The forearm comprises a forearm body, a rotatable cylinder disposed within the forearm body, a linear drive component operably coupled to the rotatable cylinder, and a rotatable drive component defining a drive component lumen comprising internal threads. The rotatable cylinder comprises an end effector lumen defined within the rotatable cylinder. The linear drive component comprises a proximal section comprising external threads, a lumen defined in a distal portion of the linear drive component, and a cylinder coupling pin coupled to the linear drive component. The lumen comprises a hook coupling pin disposed within the lumen. Each end of the cylinder coupling pin is slideably disposed in a longitudinal slot defined in the rotatable cylinder. The drive component lumen is configured to be threadably coupled to the proximal section of the linear drive component. The quick-release end effector is configured to be positionable within the end effector lumen and comprises an end effector body, a rod disposed within the end effector body, and a coupling hook operably coupled to a proximal portion of the rod, wherein the coupling hook extends proximally from the rod and is configured to be coupleable with the hook coupling pin.

(27) 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.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. 1A is a perspective view of a robotic surgical device having arms.

- (2) FIG. 1B is a perspective view of another robotic surgical device having arms.
- (3) FIG. 1C is a perspective view of a further robotic surgical device having arms.
- (4) FIG. 1D is a perspective view of a forearm of a robotic surgical device having a quick-release end effector, according to one embodiment.
- (5) FIG. 2 is a perspective view of a quick-release end effector, according to one embodiment.
- (6) FIG. 3A is an expanded cross-sectional side view of a portion of the quick-release end effector of FIG. 2 positioned in a portion of a forearm, according to one embodiment.
- (7) FIG. 3B is a further expanded cross-sectional side view of the portion of the quick release end effector positioned in the portion of the forearm of FIG. 3A.
- (8) FIG. 4A is a perspective view of a quick-release forearm configured to receive a quick-release end effector, according to another embodiment.
- (9) FIG. 4B is a cross-sectional side view of the quick-release forearm of FIG. 4A.
- (10) FIG. 4C is a side view of the quick-release forearm of FIG. 4A.
- (11) FIG. 4D is an end view of the quick-release forearm of FIG. 4A.
- (12) FIG. 5A is a perspective view of another quick-release end effector, according to a further embodiment.
- (13) FIG. 5B is an expanded cross-sectional perspective view of a portion of the quick-release end effector of FIG. 5A positioned in a portion of a forearm, according to one embodiment.
- (14) FIG. 6 is a perspective view of another quick-release end effector, according to yet another embodiment.
- (15) FIG. 7 is a perspective view of another quick-release end effector, according to another embodiment.
- (16) FIG. 8 is a cross-sectional side view of another quick-release forearm configured to receive a quick-release end effector, according to another embodiment.
- (17) FIG. 9A is a perspective view of a rotatable cylinder that can define the end effector lumen in the quick-release forearm of FIG. 8, according to one embodiment.
- (18) FIG. 9B is a cross-sectional perspective view of the rotatable cylinder of FIG. 9A.
- (19) FIG. 10 is a perspective view of a linear drive component that can be positioned in the quick-release forearm of FIG. 8, according to one embodiment.
- (20) FIG. 11 is a perspective view of a support cylinder that can be positioned around the rotatable cylinder in the quick-release forearm of FIG. 8, according to one embodiment.
- (21) FIG. 12 is a cross-sectional side view of the quick-release forearm of FIG. 8 with a quick-release end effector positioned therein, according to one embodiment.
- (22) FIG. 13 is an expended perspective view of the quick-release forearm of FIG. 8 with certain components removed for easier viewing of certain portions of the forearm.
- (23) FIG. 14 is an expanded perspective view of the quick-release end effector of FIG. 6 with certain components removed for easier viewing of certain portions of the end effector.
- (24) FIG. 15 is an expanded perspective view of the quick-release end effector of FIG. 7 with certain components removed for easier viewing of certain portions of the end effector.

DETAILED DESCRIPTION

(25) The various systems and devices disclosed herein relate to devices for use in medical procedures and systems. More specifically, various embodiments relate to end effector components or devices that can be used in various procedural devices and systems. For example, certain embodiments relate to quick-release end effector components incorporated into or used with various medical devices, including robotic and/or in vivo medical devices. It is understood that the term “quick-release” as used herein are intended to describe any end effector, forearm, or combination thereof that can be easily and/or quickly coupled and/or uncoupled by anyone in the surgical theater, including any nurse or assistant (in contrast to a component that cannot be coupled or uncoupled quickly or easily or requires someone with technical expertise).

(26) It is understood that the various embodiments of end effector devices or components disclosed

herein can be incorporated into or used with any other known medical devices, systems and methods, including, but not limited to, robotic or in vivo devices as defined herein. For example, FIGS. 1A-1D depict certain exemplary medical devices and systems that could incorporate a quick-release end effector as disclosed or contemplated herein. More specifically, FIGS. 1A-1C show robotic surgical devices **10**, **12**, **14** having arms **16A**, **16B**, **18A**, **18B**, **20A**, **20B** to which certain end effectors **22A**, **22B**, **24A**, **24B**, **26A**, **26B** have been coupled. In one implementation, the end effectors **22A**, **22B**, **24A**, **24B**, **26A**, **26B** are quick-release end effectors as disclosed herein. Further, FIG. 1D depicts a forearm **28** that has a quick-release end effector **30**.

(27) As a further 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. application 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”), 61/030,588 (filed on Feb. 22, 2008), Ser. No. 12/171,413 (filed on Jul. 11, 2008 and entitled “Methods and Systems of Actuation in Robotic Devices”), Ser. No. 12/192,663 (filed Aug. 15, 2008 and entitled Medical Inflation, Attachment, and Delivery Devices and Related Methods”), Ser. No. 12/192,779 (filed on Aug. 15, 2008 and entitled “Modular and Cooperative Medical Devices and Related Systems and Methods”), Ser. No. 12/324,364 (filed Nov. 26, 2008 and entitled “Multifunctional Operational Component for Robotic Devices”), 61/640,879 (filed on May 1, 2012), Ser. No. 13/493,725 (filed Jun. 11, 2012 and entitled “Methods, Systems, and Devices Relating to Surgical End Effectors”), Ser. No. 13/546,831 (filed Jul. 11, 2012 and entitled “Robotic Surgical Devices, Systems, and Related Methods”), 61/680,809 (filed Aug. 8, 2012), Ser. No. 13/573,849 (filed Oct. 9, 2012 and entitled “Robotic Surgical Devices, Systems, and Related Methods”), Ser. No. 13/738,706 (filed Jan. 10, 2013 and entitled “Methods, Systems, and Devices for Surgical Access and Insertion”), Ser. No. 13/833,605 (filed Mar. 15, 2013 and entitled “Robotic Surgical Devices, Systems, and Related Methods”), Ser. No. 13/839,422 (filed Mar. 15, 2013 and entitled “Single Site Robotic Devices and Related Systems and Methods”), Ser. No. 13/834,792 (filed Mar. 15, 2013 and entitled “Local Control Robotic Surgical Devices and Related Methods”), Ser. No. 14/208,515 (filed Mar. 13, 2014 and entitled “Methods, Systems, and Devices Relating to Robotic Surgical Devices, End Effectors, and Controllers”), Ser. No. 14/210,934 (filed Mar. 14, 2014 and entitled “Methods, Systems, and Devices Relating to Force Control Surgical Systems), Ser. No. 14/212,686 (filed Mar. 14, 2014 and entitled “Robotic Surgical Devices, Systems, and Related Methods”), and Ser. No. 14/334,383 (filed Jul. 17, 2014 and entitled “Robotic Surgical Devices, Systems, and Related Methods”), and U.S. Pat. No. 7,492,116 (filed on Oct. 31, 2007 and entitled “Robot for Surgical Applications”), U.S. Pat. No. 7,772,796 (filed on Apr. 3, 2007 and entitled “Robot for Surgical Applications”), and U.S. Pat. No. 8,179,073 (issued May 15, 2011, and entitled “Robotic Devices with Agent Delivery Components and Related Methods”), all of which are hereby incorporated herein by reference in their entireties.

(28) In accordance with certain exemplary embodiments, any of the various embodiments disclosed herein can be incorporated into or used with a natural orifice transluminal endoscopic surgical device, such as a NOTES device. Those skilled in the art will appreciate and understand that various combinations of features are available including the features disclosed herein together with features known in the art.

(29) Certain device implementations disclosed in the applications listed above can be positioned within or into 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 into or 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.

(30) Further, the various end effector embodiments could be incorporated into various robotic medical device systems that are actuated externally, such as those available from Apollo Endosurgery, Inc., Hansen Medical, Inc., Intuitive Surgical, Inc., and other similar systems, such as any of the devices disclosed in the applications that are incorporated herein elsewhere in this application. Alternatively, the various end effector embodiments can be incorporated into any medical devices that use end effectors.

(31) FIGS. 2-3B depict a quick-release, magnetically-coupled end effector **50** that is releasably coupleable to forearm **52**, according to one embodiment. As best shown in FIG. 2, the end effector **50** in this implementation has a grasper **54**. As best shown in FIGS. 2 and 3A, the end effector **50** also has a mateable coupler **56**, a magnetic collar **58**, a disk **60**, a central rod **68**, a body (also referred to herein as a “forearm body”) **62** that is a slidable cylinder **62** slidably disposed over the rod **68**, a compression spring **70** disposed within the cylinder **62** and over the rod **68**, two leaf springs (one leaf spring **64** is visible in FIG. 2, while the second leaf spring is positioned on the other side of the cylinder **62** and thus not shown in the figure), and coupling fingers (also referred to as “finger components” or “coupling components”) **66**. As best shown in FIGS. 3A and 3B, the mateable coupler **56** has an opening **72** on its proximal side that is configured to receive and be mateable with the coupling projection **84** on the distal end of the forearm **52** (discussed further below). The opening **72** according to one embodiment can contain an o-ring **74** as best shown in FIGS. 3A and 3B that can maintain a sealed connection between the coupler **56** and the projection **84** of the forearm **52**. In one implementation, the magnetic collar **58** is made up of multiple magnets **58A**, **58B**, **58C** as shown that are positioned on the collar around the full circumference of the end effector **50**.

(32) The disk **60** is fixedly coupled to the central rod **68** via a connection tab **76** that is positioned in a slot **78** (as best shown in FIG. 2) in the slidable cylinder **62** such that the cylinder **62** is slidable in relation to the disk **60** as well as the central rod **68**. As such, the disk **60**, as will be described in further detail below, can serve as an axial constraint during insertion of the end effector **50** into the forearm **52** and as a bearing during rotation of the end effector **50** in relation to the forearm **52**.

(33) The first leaf spring **64** is electrically connected to one of the blades of the grasper **54** via a wire or other electrical connection (not shown), while the second leaf spring (not shown) is electrically connected to the other of the two blades of the grasper **54** in the same or a similar fashion. In this implementation, the blades of the grasper **54** are electrically isolated from each other. As such, the graspers **54** can be a cautery tool with electrical energy being transferred to the grasper **54** blades via the leaf springs **64**, not shown, as explained in further detail below.

(34) The two finger components **66** are positioned on opposite sides of the central rod **68** and are attached to the rod **68** at the distal end of the fingers **66** (or along a distal portion of the fingers **66**) such that the fingers **66** do not move axially in relation to the rod **68**. The proximal ends of the fingers **66** extend proximally farther than the rod **68** and are not coupled to the rod at their proximal ends, thereby allowing the proximal ends of the fingers **66** to be capable of extending radially away from the rod **68**. The cylinder **62** is slidable laterally along the length of the end effector **50**, and more specifically along the length of the central rod **68**, such that the cylinder **62** can operate in combination with the coupler **56** and the coupling fingers **66** as will be discussed in further detail below to couple the end effector **50** to the forearm **52**.

(35) In one implementation, the forearm **52** has an end effector lumen **80** defined by a fluidically impervious tube **82** such that the lumen **80** is fluidically sealed. As a result, the internal components of the forearm **52** are fluidically sealed off from any fluids present in the lumen **80**. As such, the lumen **80** is capable of receiving an end effector (such as end effector **50**) while maintaining a

complete fluidic or hermetic seal between the lumen **80** (and any fluids in the lumen **80**) and the interior portions of the forearm **52**. In this implementation, the fluidic seal created by the tube **82** makes it possible to quickly remove and replace any end effector (such as end effector **50**) without risking contamination of the interior components of the forearm **52**.

(36) The lumen **80**, in one embodiment, has a shoulder **80B** that separates a larger diameter portion **80A** from a smaller diameter portion **80C**. The tube **82** is positioned in the lumen **80** such that the tube **82** defines the lumen **80**. In one implementation, the tube **82** is fixedly coupled or affixed to the linear drive component **92** at a proximal end of the tube **82** as best shown in FIG. **3A**. In accordance with one embodiment, the tube **82** is made of a flexible material such that when the linear drive component **92** is moved laterally as described below, the tube **82** remains attached to the drive component **92** and simply flexes or deforms to accommodate the movement of the drive component **92**.

(37) Further, the forearm **52** has a coupling projection **84** (discussed above), a magnetic ring **86**, and two contact rings **88**, **90**. In addition, the forearm **52** has a linear drive component **92** that has a threaded proximal shaft **94** and a slot **108** defined in a distal portion of the component **92**.

Alternatively, the threaded shaft **94** is a separate component operably coupled to the linear drive component **92**. The forearm **52** also has a drive cylinder **95** having a threaded lumen (not shown) through which the threaded shaft **94** is positioned such that the threaded shaft **94** is threadably coupled to the drive cylinder **95**. In addition, two bearings **104**, **106** are disposed around the drive cylinder **95** such that the drive cylinder **95** is rotatably positioned within the bearings **104**, **106**.

(38) Each of the contact rings **88**, **90** is positioned around the wall of the tube **82** of the lumen **80** such that each ring **88**, **90** encircles the lumen **80**. One of the contact rings **88**, **90** is positioned along the length of the lumen **80** such that it is in contact with the leaf spring **64** when the end effector **50** is coupled to the forearm **52** as shown in FIG. **3B**, while the other of the two contact rings **88**, **90** is positioned such that it is in contact with the other leaf spring (not shown). In this configuration, once the end effector **50** is coupled to the forearm **52**, the leaf springs (**64**, not shown) are continuously in contact with the contact rings **88**, **90**, even when the forearm body **62** is rotating. Further, each of the contact rings **88**, **90** is operably coupled to a separate wire (not shown) that extends to an electrical energy source (such as a cautery generator, for example) such that electrical energy can be transmitted from the power sources to the rings **88**, **90** and—via the contact between the rings **88**, **90** and the leaf springs (**64**, not shown)—to the leaf springs (**64**, not shown), and thereby to the grasper **54** blades. As a result, the grasper **54** can be a bipolar cautery tool. Alternatively, the end effector **50** can also be a monopolar cautery tool if the same electrical energy is supplied to both contact rings **88**, **90**. In fact, as will be discussed specifically with certain of the additional embodiments below, every forearm implementation disclosed or contemplated herein is configured to be coupleable with a cautery end effector that can operate as either a bipolar or monopolar cautery tool.

(39) The magnetic ring **86** is made up of at least one magnet, and the ring is configured to rotate around the lumen **80**. The end effector **50** is rotated via the magnetic interaction of the magnetic collar **58** on the end effector **50** and the magnetic ring **86** on the forearm **52**. That is, the motor **102** in the forearm **52** can be actuated to drive the drive gear **98**, which drives the driven gear **96**, which is operably coupled to the magnetic ring **86** such that the magnetic ring **86** is rotated. The magnetic ring **86** is magnetically coupled to the magnetic collar **58** such that rotation of the magnetic ring **86** causes the magnetic collar **58** to rotate, thereby rotating the end effector **50**. That is, the magnetic coupling of the magnetic ring **86** in the forearm **52** and the magnetic collar **58** on the end effector **50** can cause the rotation of the end effector **50** without a physical connection between the end effector **50** and the forearm **52**.

(40) In addition, the end effector **50** is actuated such that the grasper **54** moves between an open position and a closed position via the linear drive component **92**. The end effector **50** is coupled to the linear drive component **92** via the coupling fingers **66**, which are positioned around the drive

component **92** and into a slot **108** defined in the drive component **92** as shown in FIGS. 3A and 3B. That is, the fingers **66** extend proximally beyond the proximal end of the central rod **68** and thus the proximal ends of the fingers **66** can be positioned into the slot **108** as shown. The coupling of the drive component **92** to the end effector **50** via the coupling fingers **66** results in the end effector **50** being linearly coupled to the linear drive component **92** such that the end effector **50** cannot move linearly in relation to the drive component **92**. On the other hand, the coupling fingers **66** do allow the end effector **50** to rotate in relation to the drive component **92**. That is, the fingers **66** are configured to allow for rotation of the fingers **66** in relation to the linear drive component **92** while not allowing for linear movement of the fingers **66** in relation to the linear drive component **92** when the fingers **66** are positioned in the slot **108** as shown in FIG. 3B. Alternatively, instead of coupling fingers **66**, the coupling component **66** consists of any one or more mechanisms or components that are configured to be positioned within the slot **108** as described herein to couple the drive component **92** to the end effector **50**.

(41) As a result, the actuation of the linear drive component **92** causes the end effector **50** to be actuated to move linearly. That is, as discussed above, the threaded shaft **94** is threadably coupled at its proximal end to a drive cylinder **95** that can be actuated to cause the threaded shaft **94** to move axially. More specifically, the drive cylinder **95** is operably coupled to a drive gear (not shown) that is operably coupled to a motor (not shown) that can be actuated to rotate the drive gear and thereby rotate the drive cylinder **95**. The rotation of the drive cylinder **95** causes the threaded shaft **94** to move axially via the threaded connection between the drive cylinder **95** and the threaded shaft **94**. The threaded shaft **94** is configured such that it cannot be rotated. That is, the threaded shaft **94** has a slot **97** defined longitudinally in the shaft **94** such that a projection (also referred to as a “tongue” or “key”) (not shown) coupled to the forearm **52** can be positioned in the slot **97**, thereby preventing the threaded shaft **94** from rotating while allowing the threaded shaft **94** to move axially. The linear drive component **92** is coupled to the threaded shaft **94** such that rotation of the drive cylinder **95** causes the threaded shaft **94** to move axially, thereby causing the linear drive component **92** to move axially. Thus, actuation of the drive cylinder **95** by the motor (not shown) causes linear movement of the threaded shaft **94** and the linear drive component **92**, thereby causing linear movement of the central rod **68**, which results in the moving of the grasper **54** between an open configuration and a closed configuration via known grasper components for accomplishing the movement between those two configurations.

(42) The end effector **50** is configured to be easily coupled to and uncoupled from the forearm **52** such that a user (such as a surgeon) can easily remove and replace one end effector with another during a medical procedure. As shown in FIG. 3A, the end effector **50** has been inserted into the lumen **80** but is not yet fully coupled to the forearm **52**. That is, in FIG. 3A, the end effector **50** has been inserted into the lumen **80** such that the central rod **68** is in contact with the linear drive component **92** and the coupling fingers **66** have been positioned in the slot **108** of the drive component **92**, but the coupler **56** has not yet been coupled to the projection **84**. Note that, in this position (in FIG. 3A), the slidable cylinder **62** is in its retracted position.

(43) In FIG. 3B, the coupler **56** has been coupled to the projection **84**, thereby coupling the end effector **50** to the forearm **52** for use. That is, the urging of the coupler **56** proximally toward the forearm **52** urges the entire end effector **50** proximally toward the forearm. However, the disk **60** on the end effector **50** was already in contact with the shoulder **80B** in the lumen **80** in FIG. 3A, so the disk **60** is restrained by the shoulder **80B** from moving any further into the lumen **80** when the coupler **56** is urged proximally toward the forearm. Thus, the central rod **68**, which is directly coupled to the disk **60** such that the rod **68** cannot move linearly in relation to the disk **60**, also is restrained from moving any further into the lumen **80**. However, the cylinder **62**, which can move linearly in relation to the disk **60** (because the disk **60**, as explained above, is seated in a tab **76** that is slidably positioned in the slot **78** in the cylinder **62**), moves proximally toward the forearm due to the urging of the coupler **56** proximally. This causes the proximal end of the cylinder **62** to move

proximally over the coupling fingers **66**, which are positioned in the slot **108**, as best shown in FIG. **3B**. The result is that the cylinder **62** is positioned at least partially over the slot **108**, thereby securing the fingers **66** in the slot **108**, which thereby secures the end effector **50** to the forearm **52**. This also causes the tension spring **70** disposed in the cylinder **62** to be compressed, because it is positioned between a shoulder **110** in the cylinder and tabs **112** at the distal end of the fingers **66**. That is, the proximal advancement of the cylinder **62** as described above causes the shoulder **110** to move proximally toward the tabs **112** on the fingers **66**, thereby causing the spring **70** to be compressed as shown.

(44) It is understood that the end effector **50** can also be removed just as easily. First, the coupler **56** is pulled distally away from the forearm **52**, thereby uncoupling the coupler **56** from the projection **84** as best shown in FIG. **3A**. This removes the restraint placed on the end effector **50**, thereby allowing the compressed spring **70** as shown in FIG. **3B** to urge the cylinder **62** distally toward the grasper **54**. This causes the proximal end of the cylinder **62** to move distally away from the linear drive component **92** and specifically from the slot **108**, thereby freeing the proximal end of the fingers **66** from their position in the slot **108**, as best shown in FIG. **3A**. With the fingers **66** released from the slot **108**, the end effector **50** can be removed from the lumen **80** of the forearm **52**.

(45) It is understood that the end effector **50** can be either bipolar or monopolar. Similarly, any of the other end effector embodiments disclosed or contemplated herein can also be either bipolar or monopolar, except as discussed in detail below with respect to the end effectors **260**, **262** depicted in FIGS. **6-15**.

(46) FIGS. **4A-4D** depict another embodiment of a magnetic coupling forearm **150**, to which a quick-release, magnetically-coupled end effector (not shown) can be attached, according to one embodiment. In this embodiment, the forearm body **150** has two sets of magnets (in contrast to one set of magnets in the previous embodiment shown in FIGS. **2-3B**). The first magnetic ring **152** is positioned at the distal end of the forearm **150** and drives rotation of the end effector (not shown), while the second magnetic ring **154** is positioned at the proximal end of the forearm **150** and drives linear actuation of the end effector (not shown), thereby actuating operation of the end effector. For example, in those embodiments in which the end effector (not shown) is a grasper, the second magnetic ring **154** would actuate opening and closing of the grasper. Both magnetic rings **152**, **154** are each made up of at least one magnet. More specifically, in this exemplary embodiment, the first ring **152** is made up of six magnets **156**, while the second ring **154** is also made up of six magnets **158**. Alternatively, each of the rings **152**, **154** is made up of at least one magnet. In a further alternative, the number of magnets in each ring **152**, **154** can range from 1 to as many magnets that can fit in the ring to accomplish the purposes described herein.

(47) Further, like the previous embodiment (above), the forearm body **150** has an end effector lumen **160** defined by a fluidically impervious tube **162** such that the lumen **160** is fluidically or hermetically sealed, thereby fluidically sealing the internal components of the forearm **150** from any fluids present in the lumen **160**. The tube **162** is positioned in the lumen **160** such that the tube **162** defines the lumen **160**. The lumen **162** contains two contact rings **164**, **166**.

(48) Each ring **152**, **154** is configured to rotate around the lumen **160** and thereby actuate the end effector (not shown) as described above. More specifically, the first magnetic ring **152** is caused to rotate and thereby cause a magnetic collar (not shown) or other magnetic component on the end effector (not shown) to rotate via the magnetic coupling between the ring **152** and the collar (not shown), thereby causing the end effector (not shown) to rotate. Further, the second magnetic ring **154** is caused to rotate and cause a second magnetic collar (not shown) or other magnetic component on the end effector (not shown) to rotate via the magnetic coupling between the two components, thereby actuating the end effector to operate.

(49) Each of the contact rings **164**, **166** is positioned around the wall of the tube **162** of the lumen **160** such that each ring **164**, **166** encircles the lumen **160**. In this embodiment, each of the contact

rings **164, 166** is positioned along the length of the lumen **160** such that each is in contact with one contact component on the end effector (not shown). For example, if an end effector similar to the end effector **50** discussed above and depicted in FIG. **2** were used, the rings **164, 166** would be positioned to contact the leaf springs (**64**, not shown) of that end effector **50**. Alternatively, the rings **164, 166** can be configured to contact any contact component on the end effector that is coupled to the forearm **150**. Regardless, the contact rings **164, 166** make it possible to transmit electrical energy from power sources to the rings **164, 166** and on to the end effector in a fashion similar to that described above with respect to end effector **50**. As a result, any end effector used with the forearm **150** can be a bipolar cautery tool or, alternatively, can be a monopolar cautery tool if the same electrical energy is supplied to both contact rings **164, 166**.

(50) The first magnetic ring **152** is actuated by a first motor **180**, which is operably coupled to a drive gear **182**, which is operably coupled to a driven gear **184**, which is operably coupled to the first magnetic ring **152**. Thus, actuation of the first motor **180** actuates the first magnetic ring **152** to rotate. Similarly, the second magnetic ring **154** is actuated by a second motor **190**, which is operably coupled to a drive gear **192**, which is operably coupled to a driven gear **194**, which is operably coupled to the second magnetic ring **154**. Thus, actuation of the second motor **180** actuates the second magnetic ring **154** to rotate.

(51) Thus, in this embodiment, the forearm **150** actuates an end effector (not shown) entirely by magnetic couplings, rather than mechanical couplings. The first magnetic ring **152** rotates the end effector (not shown) via the magnetic interaction between the ring **152** and the corresponding magnetic collar (not shown) or other magnetic component on the end effector (not shown), while the second magnetic ring **154** actuates the end effector (not shown) via the magnetic interaction between the ring **154** and the corresponding magnetic collar (not shown) or other magnetic component on the end effector (not shown).

(52) Hence, the forearm **150** is configured to allow for easy coupling and removal of an end effector (not shown), such that a user (such as a surgeon) can easily remove and replace one end effector with another during a medical procedure.

(53) FIGS. **5A** and **5B** depict another implementation of a quick-release end effector **200** that is releasably coupleable to a forearm **202**, according to one embodiment. More specifically, this exemplary implementation is configured to allow for coupling the end effector **200** to the forearm **202** with a single ninety degree turn of the end effector **200** once the end effector **200** is positioned within the lumen **220** of the forearm **202**. This embodiment does not utilize magnetic coupling.

(54) As best shown in FIG. **5A**, the end effector **200** in this implementation has a grasper **204**. The end effector **200** also has a tubular body **206**, a rod (also referred to as a “central rod”) **208** that is disposed within, is slidable in relation to, and extends proximally from the tubular body **206**, two protrusions (the first protrusion **210** is depicted in FIG. **5A** and a second protrusion is not shown), a release button **212**, a coupling hook **214** at a proximal end of the central rod **208**, and an o-ring **216** disposed around the tubular body **206**. In addition, the rod **208** has two contact elements (also referred to as “contact strips”) **209, 211** that are electrically coupled to the blades of the grasper **204** via separate wires or other connection components such that one strip **209** is coupled to one blade and the other strip **211** is coupled to the other blade. The central rod **208** is operably coupled to the grasper **204** such that linear actuation of the central rod **208** in relation to the tubular body **206** causes the grasper **204** to move between its open and closed configurations. The first **210** and second (not shown) protrusions are positioned on opposite sides of the tubular body **206** and are configured to be positioned within corresponding channels in the forearm **202** as described below.

(55) The forearm body **202** has an end effector lumen **220** defined by a rotatable cylinder **222** such that the cylinder **222** defines the lumen **220**. The cylinder **222** has a button channel **224** defined in the cylinder **222** to accommodate the release button **212** when the end effector **200** is positioned within the lumen **220**, and two contact rings **226, 228**. In addition, the cylinder **222** has two longitudinal channels (not shown) defined on opposite sides of the inner wall of the lumen **220** that

are configured to receive the first protrusion **210** (as shown in FIG. 5A) and the second protrusion (not shown) on the end effector **200** such that the protrusions **210** move along the channels as the end effector **200** is inserted into the lumen **220** of the forearm **202**. Further, the channels (not shown) both include a substantially ninety degree turn at the proximal end of the channels that results in two axial slots in communication with the longitudinal channels. The axial slots are configured to accommodate the rotation of the end effector **200** as it is coupled to the forearm **202** as described below.

(56) Each of the contact rings **226**, **228** is positioned on the cylinder **222** such that a portion of each ring **226**, **228** is positioned around the inner wall of the cylinder **222** such that each ring encircles the lumen **220**. In this embodiment, each of the contact rings **226**, **228** is positioned along the length of the lumen **220** such that each is in contact with one of the two contact strips **209**, **211** on the rod **208** when the end effector **200** is coupled to the forearm **202** as shown in FIG. 5B. More specifically, the contact ring **226** contacts contact strip **209** while contact ring **228** contacts contact strip **211**. In this configuration, once the end effector **200** is coupled to the forearm **202**, the contact strips **209**, **211** are continuously in contact with the contact rings **226**, **228**, even when the rod **208** is rotating or moving axially. That is, the strips **209**, **211** are configured to have some longitudinal length as shown in FIG. 5A such that when the rod **208** is actuated to move axially while coupled to the forearm **202**, the strips **209**, **211** remain in contact with the contact rings **226**, **228** despite the fact that the rings **226**, **228** do not move axially.

(57) Further, each of the contact rings **226**, **228** is in contact with a stationary contact ring **227**, **229** disposed in the forearm **202** such that they encircle the cylinder **222**. In addition to being positioned such that a portion is disposed around the inner wall of the cylinder **222**, each of the rings **226**, **228** also has a portion that is disposed around the external wall of the cylinder **222** such that each ring **226**, **228** contacts one of the two stationary contact rings **227**, **229** as well. Thus, electrical energy can be transmitted from the power sources to the stationary contact rings **227**, **229** and— via the contact between the stationary rings **227**, **229** and the contact rings **226**, **228**—to the contact strips **209**, **221** and thereby to the grasper **204** blades. As a result, the grasper **204** can be a bipolar cautery tool. Alternatively, the end effector **200** can also be a monopolar cautery tool if the same electrical energy is supplied to both stationary contact rings **227**, **229**.

(58) In addition, the forearm **202** has a linear drive component **230** disposed in a proximal end of the rotatable cylinder **222**. The drive component **230** has a lumen **232** defined in its distal end, and the lumen **232** has a coupling pin (also referred to as a “hook coupling pin”) **234** extending from one side of the lumen **232** to the other. The pin **234** is configured to be coupleable with the coupling hook **214** of the end effector **200** as will be described in further detail below. Further, the drive component **230** also has a coupling pin (also referred to as a “cylinder coupling pin”) **235** that extends beyond the outer circumference of the drive component **230** such that the ends of the pin **235** are positioned in slots **237A**, **237B** defined in the inner wall of the rotatable cylinder **222**. The pin **235** is fixedly coupled to the drive component **230**. Each of these slots **237A**, **237B** has a length that extends longitudinally along the length of the rotatable cylinder **222**. As a result, this pin **235** is slidably positioned in the slots **237A**, **237B** such that the drive component **230** can be moved linearly but cannot rotate in relation to the rotatable cylinder **222**. Thus, any rotation of the drive component **230** causes rotation of the rotatable cylinder **222**. This configuration prevents the hook **214** from becoming decoupled from the pin **234**. That is, the pin **235** prevents the drive component **230** from rotating in relation to the rotatable cylinder **222**, thereby ensuring the hook **214** remains coupled to the pin **234**.

(59) Further, the proximal end of the drive component **230** has an externally threaded proximal shaft (also referred to as a linear translation component) **236**. Alternatively, the shaft **236** is a separate component operably coupled to the drive component **230**, via a retaining ring **241**. The retaining ring **241** results in the drive component **230** being capable of rotating in relation to the linear translation component **236**. Further, the shaft **236** is prevented from rotating by a groove (not

shown) defined in the shaft **236** that mates with a tongue **243**. In addition, the shaft **236** is positioned within a lumen **238** in a rotatable linear drive component **239** and is threadably coupled to the internal threads defined in the lumen **238**. Thus, when the rotatable drive component **239** is rotated by the linear actuation motor (not shown), the threaded connection of the shaft **236** to the rotatable drive component **239** causes the shaft **236** to move linearly, thereby resulting in the drive component **230** moving linearly as well.

(60) The forearm **202** also has a motor **240** coupled to a drive gear **244** via a drive shaft **242**. The drive gear **244** is coupled to a driven gear **246** that encircles and is coupled to the rotatable cylinder **222** such that rotation of the driven gear **246** causes the rotatable cylinder **222** to rotate.

(61) The end effector **200** is rotated via the motor **240** that is operably coupled to the driven gear **246**. That is, the motor **240** in the forearm **202** can be actuated to drive the drive gear **244**, which drives the driven gear **246**, which is operably coupled to the rotatable cylinder **222** as described above such that the rotatable cylinder **222** is rotated. The rotatable cylinder **222** is coupled to the end effector **200** when the end effector **200** is fully seated in the lumen **220** of the forearm **202** such that rotation of the rotatable cylinder **222** causes the end effector **200** to rotate. That is, as best shown in FIG. 5A, the first protrusion **210** and second protrusion (not shown) are positioned in the channels (not shown) in the lumen **220** such that the tubular body **206** is coupled to the cylinder **222** such that the tubular body **206** rotates when the cylinder **222** rotates.

(62) In addition, the end effector **200** is actuated such that the grasper **204** moves between an open position and a closed position via the linear drive component **230**. The end effector **200** is coupled to the linear drive component **230** via the coupling hook **214**, which is positioned into the lumen **232** of the drive component **230** and around the pin **234** positioned in the lumen **232**. That is, during insertion of the end effector **200** into the forearm **202**, the hook **214** is positioned into the lumen **232** prior to the substantially ninety degree rotation of the end effector **200** such that the hook **214** extends proximally past the pin **234**. Thus, when the end effector **200** is rotated, the hook **214** couples to the pin **234** and thereby couples the end effector **200** to the drive component **230**. The coupling of the drive component **230** to the end effector **200** via the hook **214** and pin **234** results in the end effector **200** being linearly coupled to the linear drive component **230** such that the end effector **200** cannot move linearly in relation to the drive component **230**.

(63) As a result of the coupling of the hook **214** to the pin **234**, the actuation of the linear drive component **230** causes the end effector **200** to be actuated to move linearly. That is, the rotatable linear drive component **239** is coupled at its proximal end to a driven gear **250** that is coupled to a drive gear (not shown), which is coupled to a motor (not shown) that can be actuated to rotate the driven gear **250** and thus the rotatable drive component **239**. As discussed above, the threaded section **236** of the linear drive component **230** is positioned in and threadably connected with the lumen **238** in the rotatable drive component **239**. As a result, rotation of the drive component **239** causes the linear drive component **230** to move axially. Thus, actuation of the drive component **239** by the motor (not shown) causes linear movement of the linear drive component **230**, thereby causing linear movement of the central rod **208**, which results in the moving of the grasper **204** between an open configuration and a closed configuration via known grasper components for accomplishing the movement between those two configurations.

(64) The end effector **200** is configured to be easily coupled to and uncoupled from the forearm **202** such that a user (such as a surgeon) can easily remove and replace one end effector with another during a medical procedure. To insert the end effector **200** into the forearm **202** and couple it thereto as shown in FIG. 5B, the end effector **200** is inserted into the lumen **220** such that the first protrusion **210** and second protrusion (not shown) are positioned in the channels (not shown) in the lumen **220**. As the end effector **200** is urged proximally into the lumen **220**, the hook **214** will advance proximally until it moves into the lumen **232** and past the pin **234**. When the hook **214** can advance proximally no farther, the protrusions **212** (and not shown) are also advanced as far proximally as possible along the channels (not shown). At this point, the user rotates the end

effector **200**, thereby coupling the hook **214** to the pin **234** and advancing the protrusions **212** (and not shown) along the axial slots described above. Thus, a user can couple the end effector **200** to the forearm **202** via two mechanisms with a single twist or rotation of the end effector **200**.

(65) It is understood that the end effector **200** can also be easily removed. The release button **212** on the end effector **200** is operably coupled to the coupling hook **214** such that actuation of the button **212** causes the hook **214** to uncouple from the pin **234**. Thus, to remove the end effector **200** from the forearm **202**, a user can depress the button **212** and then rotate or twist the end effector **200** (in the opposite direction of that required to couple the end effector **200**). The rotation of the end effector **200** moves the protrusions **212** (and not shown) along the axial slots (not shown) so that the protrusions **212** (and not shown) are positioned in the channels (not shown) such that they can move distally along the channels (not shown). At this point, the end effector **200** can be removed from the lumen **220** of the forearm **202**.

(66) FIGS. **6-14** depict certain additional embodiments of quick-release end effectors **260**, **262** that are releasably coupleable to a forearm **264**, according to one embodiment. More specifically, these exemplary implementations are configured to allow for coupling of the end effector **260**, **262** to the forearm **264** with a single turn of the end effector **260**, **262** once the end effector **260**, **262** is positioned within the lumen **300** of the forearm **264**.

(67) As shown in FIGS. **6** and **14**, the end effector **260** in one implementation has a grasper **266**. The end effector **260** also has a tubular body **270**, a rod (also referred to herein as a “central rod”) **272** that is disposed within and is rotatable in relation to the tubular body **270** and has a rod coupling component **274** that extends proximally from the tubular body **270**, a handle **276**, an end effector coupling component **278**, torque transfer protrusions **280**, two contact rings **282**, **284**, an o-ring **286** adjacent to the handle **276**, and a pin hole **290** defined in the tubular body **270**. Further, as best shown in FIG. **14**, the first contact ring **282** is coupled to a first contact wire **400** that extends from the contact ring **282** to the distal end of the end effector **260**, where the wire **400** is operably coupled to a proximal portion of one arm **266A** of the grasper **266**. Similarly, the second contact ring **284** is coupled to a second contact wire **402** that extends from the ring **284** to the distal end of the end effector **260**, where the wire **402** is operably coupled to a proximal portion of the other arm **266B** of the grasper **266**. Thus, each of the two contact rings **282**, **284** is electrically coupled to one of the grasper arms **266A**, **266B** such that electrical energy can be separately transferred from each of the rings **282**, **284** to one of the arms **266A**, **266B**, thereby resulting in a bipolar grasper **266**. The central rod **272** is operably coupled to the grasper **266** such that rotational actuation of the central rod **272** (via the rod coupling component **274**) in relation to the tubular body **270** causes the grasper **266** to move between its open and closed configurations. The end effector coupling component **278** has male protrusions **288** that mate with female channels **380** on the forearm such that protrusions **288** can be positioned into the channels **380** and the end effector **260** can be coupled to the forearm **264** with a single twist or rotation of the end effector **260**. The torque transfer protrusions **280** are formed or positioned around the tubular body **270** and are configured to be positioned within corresponding torque transfer channels **304** in the forearm **264** as described below such that the end effector **260** is not rotatable in relation to the forearm **264** when the protrusions **280** are seated in the channels **304**. Note that the ends of the torque transfer protrusions **280** are tapered to make it easier to align the protrusions **280** with the channels **304**. In the embodiment of FIG. **6**, there are four protrusions **280** (with three visible in the figure).

Alternatively, there can be any other number of protrusions that can be used to couple the end effector **260** to the forearm **264**, including one to three protrusions, or five or more protrusions.

(68) In an alternative embodiment, the end effector **262** can have a pair of scissors **268** as shown in FIG. **7**. According to one implementation, the other components of this end effector **262** are substantially the same as those of the end effector **260** depicted in FIG. **6** and discussed above. As such, those components are identified with the same reference numbers such that the discussion above applies equally to these components as well. One difference, in certain embodiments, relates

to the electrical coupling of the contact rings **282**, **284** to the scissor arms **268A**, **268B**. That is, according to some embodiments, both arms **268A**, **268B** are electrically coupled to both rings **282**, **284**, thereby resulting in a monopolar pair of scissors **268** as will be described in further detail below. More specifically, as best shown in FIG. **15**, the first contact ring **282** is coupled to a first contact wire **400** that extends from the contact ring **282** to the distal end of the end effector **262**, where the wire **400** is operably coupled to a proximal portion of the pair of scissors **268** such that the contact ring **282** is electrically coupled to both arms **268A**, **268B** of the pair **268**. Similarly, the second contact ring **284** is coupled to a second contact wire **402** that extends from the ring **284** to the distal end of the end effector **262**, where the wire **402** is operably coupled to a proximal portion of the pair of scissors **268** such that the contact ring **284** is electrically coupled to both arms **268A**, **268B** of the pair **268**. Thus, each of the two contact rings **282**, **284** is electrically coupled to both scissor arms **268A**, **268B** such that electrical energy is transferred from both rings **282**, **284** to both arms **266A**, **266B**, thereby resulting in a monopolar grasper **268**.

(69) As shown in FIGS. **8-13**, the forearm body **264** has an end effector lumen **300** defined by a rotatable cylinder **302** (as best shown in FIGS. **8**, **9A**, and **9B**) such that the cylinder **302** defines the lumen **300**. As mentioned above, the cylinder **302** has torque transfer channels **304**, two electrical contact components **306**, **308**, a rotational gear **310** defined or positioned around an external wall of the cylinder **302**, an o-ring **316** disposed around the cylinder, and a seal (a “ring seal” or “lip seal” in this embodiment) **318** disposed around the distal opening of the lumen **300**. The torque transfer channels **304** are defined in the cylinder **302** to accommodate the torque transfer protrusions **280** of either end effector **260/262** when that end effector **260/262** is positioned within the lumen **300**. The channels **304** are tapered to make it easier to align the protrusions **280** with the channels **304**. In this exemplary embodiment, the two electrical contact components **306**, **308** are contact leaflets **306**, **308** that are electrically coupled to contact rings **312**, **314** (as best shown in FIG. **9B**) (such that the electrical contact component **306** is coupled to the contact ring **312** and contact component **308** is coupled to the contact ring **314**). The contact rings **312**, **314** are disposed along the inner wall of the lumen **300** and are positioned along the length of the lumen **300** such that they are configured to be in contact with the contact rings **282**, **284** on the end effector **260/262** when the end effector **260/262** is coupled to the forearm **264**. In one embodiment as shown in FIG. **9B**, the contact leaflet pair **306**, **308** extend away from the cylinder **302** in the proximal direction. Alternatively, it is understood that the contact leaflets **306**, **308** can extend away from the cylinder **302** in the distal direction. In a further alternative, the contact components **306**, **308** can each have any known configuration for a contact component.

(70) As best shown in FIGS. **9A** and **9B**, the lip seal **318** operates to serve as the primary seal to retain the fluidic seal of the forearm **264**, thereby preventing fluid from accessing the forearm **264**. The o-ring **316** (as also best shown in FIGS. **9A** and **9B**), according to one embodiment, can operate to serve as a structural support with respect to the cylinder **302**, retaining the cylinder **302** in position in relation to the forearm **264** while allowing the cylinder **302** to rotate. In addition, the o-ring **316** can also operate as a backup to the lip seal **318**, thereby providing a fluidic seal that prevents any fluid that gets past the lip seal **318** from accessing the internal components of the forearm **264**. Further, according to another implementation, the o-ring **316** can also serve to retain lubricant disposed between the lip seal **318** and the o-ring **316**.

(71) Alternatively, instead of seal **318**, which extends from the rotatable cylinder **302**, the seal (not shown) for retaining the fluidic seal of the forearm **264** can instead extend from an inner lumen of the forearm **264**—such as a portion of the forearm **264** proximal to the female channels **380**—and contact the rotatable cylinder **302**, thereby providing the desired fluidic seal for the forearm **264** as described above.

(72) In addition, the forearm **264** has a rotatable linear drive component **330** disposed in the forearm **264** proximally to the rotatable cylinder **302**, as best shown in FIGS. **8** and **10**. The drive component **330** has a lumen **332** defined in its distal end (as best shown in FIG. **10**), and the lumen

332 has teeth **334** extending from the inner wall of the lumen **332** that are configured to mate with the rod coupling component **274** on the proximal end of the end effector **260/262**. Alternatively, the lumen **332** can have any type of structure or mechanism—such as ribs, threads, channels, or the like—for mating with or coupling to the rod coupling component **274**. In addition, the drive component **330** has an external structural feature **336**, a seal **338** (such as a “ring seal”), and an o-ring **340**. The ring seal **338** and o-ring **40**, according to one embodiment, can function in substantially the same fashion as the seal **318** and o-ring **316** discussed above. The external structural feature **336** is an external hexagon **336** as best shown in FIG. **10** that is configured to mate with a driven gear **342** operably coupled with a drive gear **344** that is operably coupled with a motor **346** (as best shown in FIG. **8**) such that actuation of the motor **346** causes the rotation of the rotatable drive component **330**.

(73) Alternatively, instead of ring seal **338**, which extends from the linear drive component **330**, the seal (not shown) for retaining the fluidic seal can instead extend from the lumen **300** of the rotatable cylinder **302** and contact the rotatable linear drive component **330**, thereby providing the desired fluidic seal.

(74) When the end effector **260/262** is coupled to the forearm **264** as best shown in FIGS. **12**, the rod coupling component **274** of the end effector **260/262** is positioned within the lumen **332** of the drive component **330** and thereby coupled to the rotatable drive component **330**. As a result of this coupling, when the rotatable drive component **330** is rotated, the rod coupling component **274** is caused to rotate, thereby rotating the central rod **272** of the end effector **260/262**. The central rod **272** is disposed within housing **273** and has a slot **294** defined around the outer circumference of the rod **272** that is configured to receive the pin **292**, which is best shown in FIGS. **12**, **14**, and **16**. The pin **292** is positioned through the pin hole **290** in the tubular body **270** as best shown in FIGS. **6** and **7**. As best shown in FIG. **12**, the pin **292** is positioned in the slot **294** such that the rod **272** can rotate but cannot move axially when the pin **292** is in the slot **294**. Alternatively, instead of a pin, the housing **273** has a protrusion similar to the pin **292** that extends from an inner lumen of the housing **273** such that the protrusion can be positioned in the slot **294** in a fashion similar to the pin **292**, thereby allowing the rod **272** to rotate but not move axially. The central rod **272** has an externally threaded section **390** on its distal end which threadably couples with a linear drive component **392** such that rotation of the central rod **272** causes the linear drive component **392** to move linearly. The linear drive component **392** is operably coupled to the grasper **266** or pair of scissors **268** such that linear movement of the drive component **392** causes the grasper **266** or pair of scissors **268** to move between open and closed configurations. Thus, the rotation of the central rod **272** causes the grasper **266** or pair of scissors **268** to move between open and closed positions.

(75) Returning to FIG. **8**, in accordance with one implementation, the forearm **264** also has a motor **350** coupled to a drive gear **352**. The drive gear **352** is coupled to the rotational gear **310** on the rotatable cylinder **302** (as best shown in FIG. **9A**) such that rotation of the drive gear **352** causes the rotatable cylinder **302** to rotate. The rotatable cylinder **302** is coupled to the end effector **260/262** when the end effector **260/262** is fully seated in the lumen **300** of the forearm **264** such that rotation of the rotatable cylinder **302** causes the end effector **260/262** to rotate. That is, the protrusions **280** are positioned in the channels **304** in the lumen **300** such that the tubular body **270** is coupled to the cylinder **302** such that the tubular body **270** rotates when the cylinder **302** rotates.

(76) In one embodiment as best shown in FIGS. **8**, **11**, and **13**, the forearm **264** also has a support cylinder **360** positioned around the rotatable cylinder **302** and having a lumen **362** such that the rotatable cylinder **302** can be positioned in the lumen **362** and rotate in relation to the support cylinder **360**. As best shown in FIG. **13**, the support cylinder **360** (shown in dotted lines) has two inner contact rings **364**, **366** disposed on the inner wall of the support cylinder lumen **362**. The two rings **364**, **366** are configured to be in contact with the two contact leaflet pairs **306**, **308** on the rotatable cylinder **302**.

(77) As best shown in FIGS. **8** and **12**, both of the end effectors **260**, **262** are configured to be

easily coupled to and uncoupled from the forearm **264** such that a user (such as a surgeon) can easily remove and replace one end effector with another during a medical procedure. To insert either end effector **260/262** into the forearm **264** and couple it thereto as shown in FIG. **12**, the end effector **260/262** is inserted into the lumen **300** such that the torque transfer protrusions **280** are positioned in the channels **304** in the lumen **300**. As the end effector **260/262** is urged proximally into the lumen **300**, the rod coupling component **274** will advance proximally until it is positioned in the lumen **332** of the rotatable drive component **330** and mates with the teeth **334** therein. At the same time, the proximal advancement of the end effector **260/262** causes the male protrusions **288** on the end effector coupling component **278** to advance proximally into the female channels **380** defined in the distal end of the forearm **264**, as best shown in FIG. **8**. The female channels **380** are configured such that once the protrusions **288** have been advanced proximally into the channels **380**, the end effector **260/262** can be rotated via the handle **276** by a user to cause the protrusions **288** to rotate in the channels **288**, thereby securing the end effector **260/262** to the forearm **264**. Thus, a user can couple the end effector **260/262** to the forearm **264** with a single twist or rotation of the end effector **260/262**. Further, the user can also remove the end effector **260/262** in the same fashion by simply twisting or rotating the handle **276** in the opposite direction.

(78) In one implementation, any lumen in any forearm device described or contemplated herein is configured to be easy to sterilize. That is, each lumen is configured to have no crevices or other features that are inaccessible or difficult to access during sterilization. Further, certain embodiments have lumens that have dimensions that make for easy sterilization. That is, such lumens have a length that is sufficiently short and a diameter that is sufficiently large to be accessible by appropriate sterilization tools and techniques. In one specific example, any one or more of the lumens disclosed or contemplated herein can have an inside diameter of at least 3 mm and a length of 400 mm or shorter. Alternatively, the lumen(s) can have an inside diameter of at least 2 mm and a length of 250 mm or shorter. In a further alternative, the lumen(s) can have an inside diameter of at least 1 mm and a length of 125 mm or shorter. In yet another alternative, the lumen(s) can have any dimensions that simplify sterilization.

(79) According to certain embodiments, the various forearm and end effector embodiments disclosed or contemplated herein provide for easy, quick coupling and uncoupling of the end effector to the forearm while providing for one or even two mechanical couplings or interfaces and one or two electrical couplings or interfaces. That is, the various embodiments disclosed herein allow for simple attachment of an end effector to a forearm while also providing up to two electrical couplings and up to two mechanical couplings between the forearm and the end effector.

(80) Although the various embodiments have 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.

Claims

1. An arm component for a medical device, the arm component comprising: (a) an arm body; (b) a rotatable cylinder disposed within the arm body, the rotatable cylinder comprising: (i) a fluidically sealed end effector lumen defined within the rotatable cylinder; and (ii) at least one torque transfer channel defined in a wall of the end effector lumen; and (c) a rotatable drive component operably coupled to the rotatable cylinder, the rotatable drive component comprising: (i) a rotatable body; and (ii) a drive component lumen defined in a distal portion of the rotatable body, wherein the drive component lumen comprises mating features defined within the drive component lumen.
2. The arm component of claim 1, further comprising a ring seal disposed between the arm body and the rotatable cylinder.
3. The arm component of claim 1, further comprising a first motor operably coupled to a first drive gear, wherein the first drive gear is operably coupled to an external gear disposed on an outer wall

of the rotatable cylinder, wherein actuation of the first motor causes rotation of the rotatable cylinder.

4. The arm component of claim 1, further comprising a second motor operably coupled to a second drive gear, wherein the second drive gear is operably coupled to a driven gear operably coupled to the rotatable drive component, wherein actuation of the second motor causes rotation of the rotatable drive component.

5. The arm component of claim 1, further comprising: (a) a first outer contact ring disposed around the rotatable cylinder; (b) a second outer contact ring disposed around the rotatable cylinder; (c) a first contact component disposed on an outer wall of the rotatable cylinder such that the first contact component is in continuous contact with the first inner contact ring regardless of a rotational position of the rotatable cylinder; (d) a second contact component disposed on the outer wall of the rotatable cylinder such that the second contact component is in continuous contact with the second inner contact ring regardless of the rotational position of the rotatable cylinder; (e) a first inner contact ring disposed on the inner wall of the end effector lumen; and (f) a second inner contact ring disposed on the inner wall of the end effector lumen.

6. The arm component of claim 5, further comprising a quick-release end effector configured to be positionable within the end effector lumen, the quick-release end effector comprising first and second end effector contact components, wherein the first end effector contact component is in contact with the first inner contact ring and the second end effector contact component is in contact with the second inner contact ring when the quick-release end effector is operably coupled to the arm.

7. The arm component of claim 1, further comprising a quick-release end effector configured to be positionable within the end effector lumen, the quick-release end effector comprising: (a) an end effector body; (b) at least one second torque transfer protrusion defined on an exterior portion of the end effector body, wherein the at least one second torque transfer protrusion is configured to be coupleable with the at least one first torque transfer channel in the end effector lumen; (c) a rod disposed within the end effector body; and (d) a rod coupling component disposed at a proximal portion of the rod, wherein the rod coupling component is configured to be coupleable with the mating features associated with the lumen of the rotatable drive component.

8. The arm component of claim 1, wherein the at least one torque transfer channel extends longitudinally along the wall from a distal end of the end effector lumen.

9. The arm component of claim 1, wherein the rotatable drive component is configured to effect linear movement of an end effector attached to the arm component.

10. An end effector for a medical device, the end effector comprising: (a) an end effector body; (b) an end effector coupling component disposed around the end effector body, the end effector coupling component comprising at least one male protrusion extending from the coupling component; (c) at least one first torque transfer protrusion defined in an exterior portion of the end effector body; (d) a rod disposed within the end effector body; and (e) a rod coupling component disposed at a proximal portion of the rod, the rod coupling component comprising at least one first coupling protrusions associated with an external portion of the rod coupling component.

11. The end effector of claim 10, further comprising an end effector disposed at a distal end of the end effector body, wherein the end effector is operably coupled to the rod such that actuation of the rod causes actuation of the end effector.

12. The end effector of claim 10, wherein the end effector body is configured to be positionable in a lumen of an arm of a medical device.

13. The end effector of claim 10, wherein the end effector body is configured to be positionable in a lumen of an arm of a medical device, the lumen comprising at least one second torque transfer channel defined in the lumen, wherein the at least one second torque transfer channel is configured to be coupleable with the at least one first torque transfer protrusion in the exterior portion of the end effector body.

14. The end effector of claim 10, wherein the end effector body is configured to be positionable in a lumen of an arm of a medical device, wherein the arm comprises at least one female channel defined in a distal portion of the arm, wherein the end effector coupling component is configured to be coupleable to the arm such that the at least one male protrusion is mateable with the at least one female channel.
15. The end effector of claim 10, wherein the end effector is configured to be positionable in an arm of a medical device, wherein the arm comprises: (a) an arm body; (b) a rotatable cylinder disposed within the arm body, the rotatable cylinder comprising: (i) an end effector lumen defined within the rotatable cylinder; and (ii) at least one second torque transfer channel defined in a wall of the end effector lumen; and (c) a rotatable drive component operably coupled to the rotatable cylinder, the drive component comprising: (i) a rotatable body; and (ii) a lumen defined in a distal portion of the rotatable body, wherein the lumen comprises at least one second coupling protrusion disposed within the lumen, wherein the at least one first coupling protrusion of the rod coupling component is configured to be coupleable with the at least one second coupling protrusion disposed within the lumen of the rotatable drive component.
16. The end effector of claim 10, further comprising first and second contact rings disposed around the rod.
17. The end effector of claim 16, further comprising a grasper end effector comprising first and second grasper arms, wherein the first contact ring is electrically coupled to the first grasper arm and the second contact ring is electrically coupled to the second grasper arm.
18. An arm component for a medical device, the arm component comprising: (a) an arm; (b) a rotatable drive component rotatably disposed within the arm and operably coupled to a motor, the rotatable drive component comprising: (i) a rotatable body; and (ii) a drive component lumen defined in a distal portion of the rotatable body, wherein the drive component lumen comprises at least one protrusion; (c) a rotatable cylinder disposed within the arm body distal from and operably coupled to the rotatable drive component, the rotatable cylinder comprising: (i) a fluidically sealed end effector lumen defined within the rotatable cylinder; and (ii) at least one of a torque transfer channel and a torque transfer protrusion defined in a wall of the end effector lumen.
19. The arm component of claim 18, wherein the at least one of a torque transfer protrusion and a torque transfer channel is configured to mate with the other of a torque transfer protrusion and a torque transfer channel disposed on an end effector.
20. The arm component of claim 18, further comprising a first motor operably coupled to a first drive gear, wherein the first drive gear is operably coupled to an external gear disposed on an outer wall of the rotatable cylinder, wherein actuation of the first motor causes rotation of the rotatable cylinder.
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