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Inventor(s)	Denzinger; Christopher

Shaft deflection detection system for a surgical instrument

Abstract

A surgical instrument includes a shaft deflection detection system including one or more sensors positioned at a first mechanical junction between a shaft and an actuator coupled with the shaft and/or a second mechanical junction between the shaft and an end effector coupled with the shaft. The shaft is movable relative to the actuator at the first mechanical junction and/or relative to the end effector at the second mechanical junction. The one or more sensors are configured to generate signals indicative of movement of the shaft relative to the actuator and/or the end effector. The movement of the shaft is caused by an external force experienced by the shaft as the shaft of the surgical instrument is maneuvered inside a body of a patient.

Inventors:	**Denzinger; Christopher (Loveland, OH)**
Applicant:	**Cilag GmbH International** (Zug, CH)
Family ID:	**1000007874398**
Assignee:	**Cilag GmbH International (Zug, CH)**
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Primary Examiner: Weeks; Gloria R

Attorney, Agent or Firm: Lempia Summerfield Katz LLC

Background/Summary

BACKGROUND

(1) Surgical instruments, such as surgical staplers, may be used in various manual and/or robotic surgical procedures. For example, a circular surgical stapler may be used to provide an end-to-end, side-to-side, or end-to-side anastomosis between two sections of an anatomical lumen such as a portion of a patient's digestive tract. In some settings, laparoscopic or endoscopic surgical instruments may be preferred over traditional open surgical instruments to minimize the size of the surgical incision as well as post-operative recovery time and complications. Endoscopic surgical instruments may be suitable for placement of the end effector at a desired surgical site through the cannula of a trocar. With various surgical instruments, distal end effectors may engage tissue in a number of ways to achieve a diagnostic or therapeutic effect (e.g., endocutter, grasper, cutter, stapler, clip applier, access device, drug/gene therapy delivery device, and energy delivery device using ultrasound, RF, laser, etc.). Some such surgical instruments are operable to clamp down on layers of tissue, cut through the clamped layers of tissue, and drive staples through the layers of tissue to substantially seal the severed layers of tissue together near the severed ends of the tissue layers. Such endoscopic surgical staplers may also be used in open procedures and/or other non-endoscopic procedures. By way of example only, a surgical stapler may be inserted through a thoracotomy and thereby between a patient's ribs to reach one or more organs in a thoracic surgical procedure that does not use a trocar as a conduit for the stapler. Such procedures may include the use of the stapler to sever and close a vessel leading to an organ, such as a lung. For instance, the vessels leading to an organ may be severed and closed by a stapler before removal of the organ from the thoracic cavity. Of course, surgical staplers may be used in various other settings and procedures.

(2) Surgical instruments suitable for use in open or endoscopic procedures may include a shaft that extends proximally from the end effector to an actuator, such as a manually operated handle portion which is manipulated by the clinician, or a robotic arm operated by a robot. Such a shaft may enable insertion to a desired depth and rotation about the longitudinal axis of the shaft, thereby facilitating positioning of the end effector within the patient. Positioning of an end effector may be further facilitated through inclusion of one or more articulation joints or features, enabling the end effector to be selectively articulated or otherwise deflected relative to the longitudinal axis of the shaft.

(3) During such open or endoscopic surgical procedures, it is important to ensure that the shaft of the surgical instrument is not being too forcefully maneuvered inside a body of a patient during the procedure, for example during insertion of the surgical instrument into a body of a patient and/or removal of the surgical instrument from the body of the patient, in order to ensure that surrounding anatomy (e.g., lumens, veins, arteries, nerves, etc.) is not harmed during the surgical procedure.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention, and, together with the general description of the invention given above, and the detailed description of the embodiments given below, serve to explain the principles of the present invention.

(2) FIG. **1** depicts a perspective view of an example surgical instrument in the form of a circular surgical stapler that includes a handle assembly, a shaft assembly, and an end effector having a stapling head and an anvil;

(3) FIG. **2** depicts a perspective view of the surgical instrument of FIG. **1**, with a battery pack removed from the handle portion and the anvil separated from the stapling head assembly;

(4) FIG. **3** depicts a perspective view of the anvil of the surgical instrument of FIG. **1**;

(5) FIG. **4** depicts a perspective view of the stapling head of the surgical instrument of FIG. **1**;
(6) FIG. **5** depicts an exploded perspective view of the stapling head of FIG. **4**;
(7) FIG. **6** depicts an exploded perspective view of the surgical instrument of FIG. **1**, with portions of the shaft shown separated from each other;
(8) FIG. **7**A depicts a cross-sectional side view of the anvil of FIG. **3** positioned within a first section of a digestive tract and the stapling head of FIG. **4** positioned within a separate second section of the digestive tract, with the anvil separated from the stapling head assembly;
(9) FIG. **7**B depicts a cross-sectional side view of the anvil of FIG. **3** positioned within the first section of the digestive tract and the stapling head of FIG. **4** positioned within the separate second section of the digestive tract, with the anvil secured to the stapling head assembly;
(10) FIG. **7**C depicts a cross-sectional side view of the anvil of FIG. **3** positioned within the first section of the digestive tract and the stapling head of FIG. **4** positioned within the separate second section of the digestive tract, with the anvil retracted toward the stapling head to thereby clamp tissue between the anvil and the stapling head assembly;
(11) FIG. **7**D depicts a cross-sectional side view of the anvil of FIG. **3** positioned within the first section of the digestive tract and the stapling head of FIG. **4** positioned within the second section of the digestive tract, with the stapling head actuated to sever and staple the clamped tissue and thereby joining the first and second sections of the digestive tract;
(12) FIG. **7**E depicts a cross-sectional side view of the first and second sections of the digestive tract of FIG. **7**A joined together at an end-to-end anastomosis formed with the circular stapler of FIG. **1**;
(13) FIG. **8** depicts another example of a surgical instrument configured as a surgical stapler;
(14) FIG. **9** depicts an end effector of the surgical instrument of FIG. **8** having been actuated through a single firing stroke through tissue;
(15) FIG. **10** depicts an example of a surgical instrument configured such that the surgical instrument is attachable to a robotic device, such as a robotic arm;
(16) FIG. **11** depicts an example surgical instrument equipped with a shaft deflection detection system;
(17) FIG. **12** depicts a cross-section view of the shaft deflection detection system of the surgical instrument of FIG. **11** in a neutral or rest state;
(18) FIG. **13** depicts a cross-section view of the shaft deflection detection system of the surgical instrument of FIG. **11** in a state in which an external force is experienced by the shaft of the surgical instrument;
(19) FIGS. **14**A-B depict example graphics that may be used to display a corrective action to guide a user of a surgical instrument to mitigate a force experienced by a shaft of the surgical instrument; and—
(20) FIG. **15** is a flowchart of an example method for monitoring force experienced by a shaft of a surgical instrument as the shaft is maneuvered inside a body of a patient.
(21) The drawings are not intended to be limiting in any way, and it is contemplated that various embodiments of the invention may be carried out in a variety of other ways, including those not necessarily depicted in the drawings. The accompanying drawings incorporated in and forming a part of the specification illustrate several aspects of the present invention, and together with the description serve to explain the principles of the invention; it being understood, however, that this invention is not limited to the precise arrangements shown.

DETAILED DESCRIPTION

(22) The following description of certain examples of the technology should not be used to limit its scope. Other examples, features, aspects, embodiments, and advantages of the technology will become apparent to those having ordinary skill in the art from the following description, which is by way of illustration, one of the best modes contemplated for carrying out the technology. As will be realized, the technology described herein is capable of other different and obvious aspects, all

without departing from the technology. Accordingly, the drawings and descriptions should be regarded as illustrative in nature and not restrictive.

(23) For clarity of disclosure, the terms “proximal” and “distal” are defined herein relative to a human or robotic operator of the surgical instrument. The term “proximal” refers to the position of an element closer to the human or robotic operator of the surgical instrument and further away from the surgical end effector of the surgical instrument. The term “distal” refers to the position of an element closer to the surgical end effector of the surgical instrument and further away from the human or robotic operator of the surgical instrument. In addition, the terms “upper,” “lower,” “lateral,” “transverse,” “bottom,” “top,” are relative terms to provide additional clarity to the figure descriptions provided below. The terms “upper,” “lower,” “lateral,” “transverse,” “bottom,” “top,” are thus not intended to unnecessarily limit the invention described herein.

(24) Furthermore, the terms “about,” “approximately,” “substantially,” and the like as used herein in connection with any numerical values, ranges of values, and/or geometric/positional quantifications are intended to encompass the exact value(s) or quantification(s) referenced as well as a suitable tolerance that enables the referenced feature or combination of features to function for the intended purpose described herein. For example, “substantially parallel” encompasses nominally parallel structures.

(25) As used herein in connection with various examples of end effector jaw tips, a tip described as “angled,” “bent,” or “curved” encompasses tip configurations in which a longitudinal path (e.g., linear or arcuate) along which the tip extends is non-coaxial and non-parallel with a longitudinal axis of the jaw body; particularly, configurations in which the longitudinal tip path extends distally toward the opposing jaw. Conversely, a tip described as “straight” encompasses tip configurations in which a longitudinal axis of the tip is substantially parallel or coaxial with the longitudinal axis of the jaw body.

I. Illustrative Surgical Instrument

(26) FIGS. **1-2** depict an example surgical instrument **10** that may be used to provide an end-to-end, side-to-side, or end-to-side anastomosis between two sections of an anatomical lumen such as a portion of a patient's digestive tract. Surgical instrument **10** of this example is a circular surgical stapler and includes a body assembly in the form of an actuator such as a manually operated handle portion **100**, a shaft **200** extending distally from handle portion **100**, an end effector in the form of a stapling head **300** at a distal end of shaft **200** and an anvil **400** configured to releasably couple and cooperate with stapling head **300** to clamp, staple, and cut tissue. Instrument **10** further includes a removable battery pack **120** operable to provide electrical power to a motor **160** housed within handle **100**, as described in greater detail below.

(27) As shown in FIGS. **1-2**, and as described in greater detail below, anvil **400** is configured to removably couple with shaft **200**, adjacent to stapling head **300**. As also described in greater detail below, anvil **400** and stapling head **300** are configured to cooperate to manipulate tissue in three ways, including clamping the tissue, cutting the tissue, and stapling the tissue. A rotatable knob **130** at the proximal end of handle **100** is rotatable to provide precise clamping of the tissue between anvil **400** and stapling head **300**. When a safety trigger **140** of handle **100** is pivoted away from a firing trigger **150** of handle **100**, firing trigger **150** may be actuated to thereby provide cutting and stapling of the clamped tissue.

(28) As best seen in FIG. **3**, anvil **400** of the present example comprises a head **410** and a shank **420**. Head **410** includes a proximal stapling surface **412** that defines a plurality of staple forming pockets **414**. Staple forming pockets **414** are arranged in two concentric annular arrays in the present example. Staple forming pockets **414** are configured to deform staples as the staples are driven into staple forming pockets **414**. Proximal stapling surface **412** terminates at an inner edge **416**, which defines an outer boundary of an annular recess **418** surrounding shank **420**. A breakable washer **417** is positioned within annular recess **418** and is configured to provide the operator with a tactile and audible indication that a distal firing stroke has been completed, in addition to serving as

a cutting board, as described in greater detail below.
(29) Shank **420** defines a bore **422** and includes a pair of pivoting latch members **430**. Latch members **430** are positioned within bore **422** such that distal ends **434** are positioned at the proximal ends of lateral openings **424**, which are formed through the sidewall of shank **420**. Latch members **430** thus act as retaining clips. This allows anvil **400** to be removably secured to an actuatable closure member in the form of a trocar **330** of stapling head **300**, as will be described in greater detail below. Shank **420** of anvil **400** and trocar **330** of stapling head **300** thus cooperate with one another as coupling members.
(30) As best seen in FIGS. **4** and **5**, stapling head **300** of the present example is coupled to a distal end of shaft **200** and comprises a tubular body member **310** and a staple driver member **350** slidably housed therein. Body member **310** includes a distally extending cylindraceous inner core member **312** positioned coaxially therein. Body member **310** is fixedly secured to an outer sheath **210** of shaft **200**, and body member **310** and outer sheath **210** thus serve together as a mechanical ground for stapling head **300**.
(31) Trocar **330** is positioned coaxially within inner core member **312** of body member **310**. As described in greater detail below, trocar **330** is operable to translate distally and proximally relative to body member **310** in response to rotation of knob **130** relative to casing **110** of handle portion **100**. Trocar **330** comprises a shaft **332** and a head **334**. Head **334** includes a pointed tip **336** and a radially inwardly extending proximal surface **338**. Head **334** and the distal portion of shaft **332** are configured for insertion into bore **422** of anvil **400**. Proximal surface **338** and latch shelves **436** have complementary positions and configurations such that latch shelves **436** engage proximal surface **338** when shank **420** of anvil **400** is fully seated on trocar **330**. Anvil **400** is thus secured to trocar **330** through a snap fit provided by latch members **430**.
(32) Staple driver member **350** is operable to actuate longitudinally within body member **310** in response to activation of motor **160** as described in greater detail below. As shown best in FIG. **5**, staple driver member **350** of the present example includes two distally presented concentric annular arrays of staple drivers **352**. Staple drivers **352** are arranged to correspond with the arrangement of staple forming pockets **414** of anvil **400**. Thus, each staple driver **352** is configured to drive a corresponding staple distally into a corresponding staple forming pocket **414** when stapling head **300** is actuated (or “fired”). Staple driver member **350** also defines a bore **354** that is configured to coaxially and slidably receive core member **312** of body member **310**. An annular array of studs **356** project distally from a distally presented surface surrounding bore **354**.
(33) A cylindraceous knife member **340** is coaxially positioned within a distally-opening central recess of staple driver member **350** that communicates with bore **354**. Knife member **340** includes a distally presented, sharp circular cutting edge **342**. Knife member **340** is sized such that knife member **340** defines an outer diameter that is just smaller than the diameter defined by the radially inner-most surfaces of the inner annular array of staple drivers **352**. Knife member **340** also defines a central opening that is configured to coaxially receive core member **312** of body member **310**. An annular array of openings **346** formed in knife member **340** is configured to mate with the annular array of studs **356** of staple driver member **350**, such that knife member **340** is fixedly secured to staple driver member **350** via studs **356** and openings **346**.
(34) An annular deck member **320** is fixedly secured to a distal end of body member **310**. Deck member **320** includes a distally presented stapling surface in the form of a deck surface **322** having two concentric annular arrays of staple openings **324**. Staple openings **324** are arranged to align with the arrangement of staple drivers **352** of staple driver member **350** and staple forming pockets **414** of anvil **400** described above. Each staple opening **324** is configured to slidably receive and provide a pathway for a corresponding staple driver **352** to drive a corresponding staple distally through deck member **320** and into a corresponding staple forming pocket **414** when stapling head **300** is actuated. As best seen in FIG. **5**, deck member **320** has a central opening that defines an inner diameter that is just slightly larger than the outer diameter defined by knife member **340**.

Deck member **320** is thus configured to permit knife member **340** to translate longitudinally through the central opening concurrently with longitudinal translation of staple driver member **350**. In particular, knife member **340** is configured to actuate relative to deck member **340** between a proximal retracted position and a distal extended position, where cutting edge **342** is proximal to deck surface **322** in the proximal retracted position and distal to deck surface **322** in the distal extended position.

(35) FIG. **6** shows various components of shaft **200**, which operatively couple components of stapling head **300** with components of handle **100**. In particular, and as noted above, shaft **200** includes an outer sheath **210** that extends between handle **100** and body member **310** and includes a medial portion that extends along a curved path.

(36) Shaft **200** further includes a trocar actuation rod **220** having a proximal end operatively coupled with rotatable knob **130** and a distal end coupled with a flexible trocar actuation band assembly **230**, the assembly of which is slidably housed within outer sheath **210**. The distal end of trocar actuation band assembly **230** is fixedly secured to the proximal end of trocar shaft **332**, such that trocar **330** will translate longitudinally relative to outer sheath **210** in response to translation of trocar actuation band assembly **230** and trocar actuation rod **220** relative to outer sheath **210**, which occurs in response to rotation of rotatable knob **130**. A clip **222** is fixedly secured to trocar actuation rod **220** and is configured to cooperate with complementary features within handle portion **100** to prevent trocar actuation rod **220** from rotating within handle portion **100** while still permitting trocar actuation rod **220** to translate longitudinally within handle portion **100**. Trocar actuation rod **220** further includes a section of coarse helical threading **224** and a section of fine helical threading **226** proximal to coarse helical threading **224**, which are configured to control a rate of longitudinal advancement of trocar actuation rod **220**, as described in greater detail below.

(37) Shaft **200** further includes a stapling head driver **240** that is slidably housed within outer sheath **210** and about the combination of trocar actuation rod **220** and trocar actuation band assembly **230**. Stapling head driver **240** includes a distal end that is fixedly secured to the proximal end of staple driver member **350**, a proximal end secured to a drive bracket **250** via a pin **242**, and a flexible section disposed therebetween. It should therefore be understood that staple driver member **350** will translate longitudinally relative to outer sheath **210** in response to translation of stapling head driver **240** and drive bracket **250** relative to outer sheath **210**.

(38) As shown in FIG. **1**, handle portion **100** includes a casing **110** having a lower portion that defines an obliquely oriented pistol grip **112** and an upper portion that supports a user interface feature **114** and releasably receives a battery pack **120**, as described in greater detail below. Handle portion **100** further includes several features that are operable to actuate anvil **400** and stapling head **300**. In particular, handle portion **100** includes a rotatable knob **130**, a safety trigger **140**, a firing trigger **150**, a motor **160**, and a motor activation module **180**. Knob **130** is coupled with trocar actuation rod **220** via a nut (not shown), such that coarse helical threading **224** will selectively engage a thread engagement feature within the interior of the nut; and such that fine helical threading **226** will selectively engage a thread engagement feature within the interior of knob **130**. These complementary structures are configured such that trocar actuation rod **220** will first translate proximally at a relatively slow rate, and then translate proximally at a relatively fast rate, in response to rotation of knob **130**.

(39) It should be understood that when anvil **400** is coupled with trocar **330**, rotation of knob **130** will provide corresponding translation of anvil **400** relative to stapling head **300**. It should also be understood that knob **130** may be rotated in a first angular direction (e.g., clockwise) to retract anvil **400** proximally toward stapling head **300**; and in a second angular direction (e.g., counterclockwise) to extend anvil **400** distally away from stapling head **300**. Knob **130** may thus be used to adjust a gap distance (d) between opposing stapling surfaces **412**, **322** of anvil **400** and stapling head **300** until a suitable gap distance has been achieved, for example as shown in FIG. **7**C described below.

(40) Firing trigger **150** is operable to activate motor **160** to thereby actuate stapling head **300** to staple and cut tissue clamped between anvil **400** and stapling head **300**. Safety trigger **140** is operable to selectively block actuation of firing trigger **150** based on the longitudinal position of anvil **400** in relation to stapling head **300**. Handle portion **100** also includes components that are operable to selectively lock out both triggers **140**, **150** based on the position of anvil **400** relative to stapling head **300**. For instance, safety trigger **140** may be blocked from rotating from an engaged position to a disengaged position until the position of anvil **400** relative to stapling head **300** is within a predefined range. Accordingly, until the anvil position is within the predefined range, actuation of firing trigger **150** is blocked by safety trigger **140**, thereby inhibiting firing of stapling head **300**.
(41) Firing trigger **150** is operable to actuate a switch of motor activation module **180** (FIG. **1**) when firing trigger **150** is pivoted proximally to a fired position. Motor activation module **180** is in communication with battery pack **120** and motor **160**, such that motor activation module **180** is configured to provide activation of motor **160** with electrical power from battery pack **120** in response to firing trigger **150** actuating the switch of motor activation module **180**. Thus, motor **160** will be activated when firing trigger **150** is pivoted. This activation of motor **160** will actuate stapling head **300** via drive bracket **250**, as described in greater detail below.
(42) FIGS. **7**A-**7**E show instrument **10** being used to form an anastomosis **70** between two tubular anatomical structures **20**, **40**. By way of example only, the tubular anatomical structures **20**, **40** may comprise sections of a patient's esophagus, colon, or other portions of the patient's digestive tract, or any other tubular anatomical structures.
(43) As shown in FIG. **7**A, anvil **400** is positioned in one tubular anatomical structure **20** and stapling head **300** is positioned in another tubular anatomical structure **40**. As shown in FIG. **7**A, anvil **400** is positioned in tubular anatomical structure **20** such that shank **420** protrudes from the open severed end **22** of tubular anatomical structure **20**. In the present example, a purse-string suture **30** is provided about a mid-region of shank **420** to generally secure the position of anvil **400** in tubular anatomical structure **20**. Stapling head **300** is positioned in tubular anatomical structure **40** such that trocar **330** protrudes from the open severed end **42** of tubular anatomical structure **20**. A purse-string suture **50** is provided about a mid-region of trocar shaft **332** to generally secure the position of stapling head **300** in tubular anatomical structure **40**. Stapling head **300** is then urged distally to ensure that stapling head **300** is fully seated at the distal end of tubular anatomical structure **40**.
(44) Next, anvil **400** is secured to trocar **330** by inserting trocar **330** into bore **422** as shown in FIG. **7**B. Latch members **430** of anvil **400** engage head **334** of trocar **330**, thereby providing a secure fit between anvil **400** and trocar **330**. The operator then rotates knob **130** while holding casing **110** stationary via pistol grip **112**. This rotation of knob **130** causes trocar **330** and anvil **400** to retract proximally. As shown in FIG. **7**C, this proximal retraction of trocar **330** and anvil **400** compresses the tissue of tubular anatomical structures **20**, **40** between surfaces **412**, **322** of anvil **400** and stapling head **300**. As this occurs, the operator may observe the tactile resistance or feedback via knob **130** while turning knob **130**, with such tactile resistance or feedback indicating that the tissue is being compressed. As the tissue is being compressed, the operator may visually observe the position of an indicator needle (not shown) within user interface feature **114** of handle portion **100** to determine whether the gap distance (d) between opposing surfaces **412**, **322** of anvil **400** and stapling head **300** is appropriate; and make any necessary adjustments via knob **130**.
(45) Once the operator has appropriately set the gap distance (d) via knob **130**, the operator pivots safety trigger **140** toward pistol grip **112** to enable actuation of firing trigger **150**. The operator then pivots firing trigger **150** toward pistol grip **112**, thus causing firing trigger **150** to actuate the switch of motor activation module **180** and thereby activate motor **160** to rotate. This rotation of motor **160** causes actuation (or “firing”) of stapling head **300** by actuating drive bracket **250** distally to thereby drive knife member **340** and staple driver member **350** distally together, as shown in FIG.

7D.
(46) As knife member **340** translates distally, cutting edge **342** of knife member **340** cuts excess tissue that is positioned within annular recess **418** of anvil **400** and the interior of knife member **340**. Additionally, washer **417** positioned within annular recess **418** of anvil **400** is broken by knife member **340** when the knife member **340** completes a full distal range of motion from the position shown in FIG. **7**C to the position shown in FIG. **7**D. It should be understood that washer **417** may also serve as a cutting board for knife member **340** to assist in cutting of tissue.
(47) As staple driver member **350** translates distally from the position shown in FIG. **7**C to the position shown in FIG. **7**D, staple driver member **350** drives staples **90** through the tissue of tubular anatomical structures **20**, **40** and into staple forming pockets **414** of anvil **400**. Staple forming pockets **414** deform the driven staples **90** into a "B" shape or a three-dimensional shape, for example, such that the formed staples **90** secure the ends of tissue together, thereby coupling tubular anatomical structure **20** with tubular anatomical structure **40**.
(48) After the operator has actuated (or "fired") stapling head **300** as shown in FIG. **7**D, the operator rotates knob **130** to drive anvil **400** distally away from stapling head **300**, thereby increasing the gap distance (d) to facilitate release of the tissue between surfaces **412**, **322**. The operator then removes instrument **10** from the patient, with anvil **400** still secured to trocar.
(49) With instrument **10** removed, the tubular anatomical structures **20**, **40** are left secured together by two annular arrays of staples **90** at an anastomosis **70** as shown in FIG. **7**E. The inner diameter of the anastomosis **70** is defined by the severed edge **60** left by knife member **340**.
(50) Instrument **10** may be further constructed and operable in accordance with any of the teachings of the following references, the disclosures of which are incorporated by reference herein: in U.S. Pat. No. 5,292,053, entitled "Surgical Anastomosis Stapling Instrument," issued Mar. 8, 1994; U.S. Pat. No. 5,333,773, entitled "Surgical Anastomosis Stapling Instrument," issued Aug. 2, 1994; U.S. Pat. No. 5,350,104, entitled "Surgical Anastomosis Stapling Instrument," issued Sep. 27, 1994; and U.S. Pat. No. 5,533,661, entitled "Surgical Anastomosis Stapling Instrument," issued Jul. 9, 1996; U.S. Pat. No. 8,910,847, entitled "Low Cost Anvil Assembly for a Circular Stapler," issued Dec. 16, 2014; U.S. Pub. No. 2015/0083772, entitled "Surgical Stapler with Rotary Cam Drive and Return," published Mar. 26, 2015, now abandoned; U.S. Pat. No. 9,936,949, entitled "Surgical Sta-pling Instrument with Drive Assembly Having Toggle Features," issued Apr. 10, 2018; U.S. Pat. No. 9,907,552, entitled "Control Features for Motorized Surgical Stapling Instrument," issued Mar. 6, 2018; U.S. Pat. No. 9,713,469, entitled "Surgical Stapler with Rotary Cam Drive," issued Jul. 25, 2017; U.S. Pub. No. 2018/0132849, entitled "Staple Forming Pocket Configurations for Circular Surgical Stapler Anvil," published May 17, 2018; and/or U.S. Pat. No. 10,709,452, entitled "Methods and Systems for Performing Circular Stapling," issued Jul. 14, 2020.
(51) FIG. **8** depicts an example of a surgical stapling and severing instrument **800** that is sized for insertion through a trocar cannula or an incision (e.g., thoracotomy, etc.) to a surgical site in a patient for performing a surgical procedure. Instrument **810** of the present example includes an actuator in the form of manually operated handle portion **820**, connected to a shaft **822**. The shaft **822** distally terminates in an articulation joint **811**, which is further coupled with an end effector **812**. Once articulation joint **811** and end effector **812** are inserted through the cannula passageway of a trocar, articulation joint **811** may be remotely articulated by an articulation control **813**, such that end effector **812** may be deflected from the longitudinal axis (LA) of shaft **822** at a desired angle (a). End effector **812** of the present example includes a lower jaw **816** (also referred to herein as a cartridge jaw) that includes a staple cartridge **837**, and an upper jaw **818** in the form of a pivotable anvil jaw.
(52) Unless otherwise described, the term "pivot" (and variations thereof) as used herein encompasses but is not necessarily limited to pivotal movement about a fixed axis. For instance, in some versions, upper jaw **818** may pivot about an axis that is defined by a pin (or similar feature) that slidably translates along an elongate slot or channel as upper jaw **818** moves toward lower jaw

816. Such translation may occur before, during, or after the pivotal motion. It should therefore be understood that such combinations of pivotal and translational movement are encompassed by the term "pivot" and variations thereof as used herein.

(53) Handle portion **820** includes a pistol grip **824** and a closure trigger **826**. Closure trigger **826** is pivotable toward pistol grip **824** to cause clamping, or closing, of upper jaw **818** toward lower jaw **816** of end effector **812**. Such closing of upper jaw **818** is provided through a closure tube **832** and a closure ring **833**, which both longitudinally translate relative to handle portion **820** in response to pivoting of closure trigger **826** relative to pistol grip **824**. Closure tube **832** extends along the length of shaft **822**; and closure ring **833** is positioned distal to articulation joint **811**. Articulation joint **811** is operable to communicate/transmit longitudinal movement from closure tube **832** to closure ring **833**.

(54) Handle portion **820** also includes a firing trigger (obstructed in FIG. **8**). An elongate member (not shown) longitudinally extends through shaft **822** and communicates a longitudinal firing motion from handle portion **820** to a firing beam in response to actuation of firing trigger. This distal translation of firing beam causes the stapling and severing of clamped tissue in end effector **812**. End effector **812** includes a cutting edge to cut through tissue and a staple cartage that may be removably inserted into a channel of the end effector **812** containing staples and staple strivers for driving staples into tissue.

(55) A more detailed description of operation of instruments such as the surgical instrument **800**, according to various embodiments, may be found in the following references, the disclosures of which are incorporated by reference herein: U.S. Pat. No. 8,210,411, entitled "Motor-Driven Surgical Instrument," issued Jul. 3, 2012; U.S. Pat. No. 9,186,142, entitled "Surgical Instrument End Effector Articulation Drive with Pinion and Opposing Racks," issued on Nov. 17, 2015; U.S. Pat. No. 9,517,065, entitled "Integrated Tissue Positioning and Jaw Alignment Features for Surgical Stapler," issued Dec. 13, 2016; U.S. Pat. No. 9,622,746, entitled "Distal Tip Features for End Effector of Surgical Instrument," issued Apr. 18, 2017; U.S. Pat. No. 9,717,497, entitled "Lockout Feature for Movable Cutting Member of Surgical Instrument," issued Aug. 1, 2017; U.S. Pat. No. 9,795,379, entitled "Surgical Instrument with Multi-Diameter Shaft," issued Oct. 24, 2017; U.S. Pat. No. 9,808,248, entitled "Installation Features for Surgical Instrument End Effector Cartridge," issued Nov. 7, 2017; U.S. Pat. No. 9,839,421, entitled "Jaw Closure Feature for End Effector of Surgical Instrument," issued Dec. 12, 2017; and/or U.S. Pat. No. 10,092,292, entitled "Staple Forming Features for Surgical Stapling Instrument," issued Oct. 9, 2018.

(56) FIG. **9** shows end effector **812** having been actuated through a single firing stroke through tissue **990**. Cutting edge of the end effector **812** has cut through tissue **990**, while staple drivers have driven three alternating rows of staples **847** through tissue **990** on each side of the cut line produced by the cutting edge of the end effector **812**. After the first firing stroke is complete, end effector **812** may be withdrawn from the patient, spent staple cartridge **837** may be replaced with a new staple cartridge **837**, and end effector **812** may then again inserted into the patient to reach the stapling site for further cutting and stapling. This process may be repeated until the desired quantity and pattern of firing strokes across the tissue **990** has been completed.

(57) FIG. **10** shows an example of a surgical instrument **1010** configured such that the surgical instrument is attachable to a robotic system, such as a robotic arm. Instrument **1010** includes an actuator such as a manually operated handle portion **1020** and a shaft **1022**. Instrument **1010** has a modular configuration such that shaft **1022** is selectively removable from, and attachable to, handle portion **1020**.

(58) Instrument **1010** is configured similarly to instrument **10** or instrument **810** such that the operability and use of instrument **1010** is the same as described above for instrument **10** or instrument **810** with the added feature of instrument **1010** being a modular configuration. With its modular configuration, instrument **1010** provides a way to change the end effector. Such a change in the end effector may be made to replace an otherwise worn end effector, or to provide for a

different end effector configuration based on the procedure or user preference. In addition to or in lieu of the foregoing, features operable for providing the modular configuration of instrument **1010** may be configured in accordance with at least some of the teachings of U.S. Pat. No. 10,182,813, entitled "Surgical Stapling Instrument with Shaft Release, Powered Firing, and Powered Articulation," issued Jan. 22, 2019, the disclosure of which is incorporated by reference herein. Other suitable components, features, and configurations for providing instrument **1010** with a modular configuration will be apparent to those of ordinary skill in the art in view of the teachings herein. Moreover, it will be understood by those of ordinary skill in the art in view of the teachings herein, that instruments **10**, **810** may be modified to incorporate a modular configuration as shown and described with respect to instrument **1010** or other instruments incorporated by reference herein.

(59) In the illustrated example of FIG. **10**, instrument **1010** includes a linear end effector **1012** having an upper jaw **1018** that has an angled distal tip **1019**. It will be appreciated that end effector **1012** may be used in place of end effector with the stapling head **300** shown in FIG. **1** or end effector **812** shown in FIG. **8**, or the end effector with the stapling head **300** shown in FIG. **1** or the end effector **812** shown in FIG. **8** may be used in place of the end effector **1012**. In some versions, the end effector **1012** may be integrally formed with shaft **1022** or alternatively may be separately formed and then combined. In some versions, end effector **1012** may be provided for use in robotic systems. In such robotic systems, modular shaft **1022** having end effector **1012** may be attachable to an actuator other than a manually operated handle portion. For example, the modular shaft **1022** having end effector **1012** may be attachable to a portion of the robotic system, such as a robotic arm, for use such that handle portion **1020** is replaced by components of the robotic system. Still in other examples, end effector **1012** may be adapted for use with a robotic system in a manner where end effector **1012** connects with the robotic system without necessarily connecting the entire modular shaft **1022**. In view of the teachings herein, other ways to incorporate an end effector having an angled elastically deformable anvil tip into a user operated or robotic operated instrument will be apparent to those of ordinary skill in the art.

II. Shaft Displacement Detection In A Surgical Instrument

(60) Augmented sensing, feedback, and connectivity are desired for both robotic and handheld instruments used in both laparoscopic and open surgeries. The surgical stapling features of the present disclosure seek to enhance preoperative planning, surgical performance, therapeutic support, and training to improve patient outcomes and reduce harm. In particular, the surgical stapling features of the present disclosure augment and enhance a user's, e.g., a surgeon or a robotic system, perception of external force being applied to portions of a surgical instrument by providing feedback to help inform intraoperative decisions based on data sensed and obtained by a shaft deflection detection system.

(61) In some cases, when a surgical instrument is being maneuvered inside a body of a patent, such as during insertion of the surgical instrument into the body of the patient or removal of the surgical instrument from the body of the patient, components of the surgical instrument (e.g., the shaft, the end effector, etc.) may push against tissue or other surrounding anatomy within the body of the patient with sufficient force to potentially cause damage to the patient. For example, in an anastomosis procedure in which a circular stapler is being inserted into or removed from a tubular structure in the body of the patient, such as an intestine, if a component of the circular stapler forcefully pushes against a side of the tubular structure, the circular stapler may rip or puncture the tubular structure. As another example, in a thoracic procedure in which an endoscopic stapler is being inserted to reach a distant surgical site in the body of the patient, the endoscopic stapler may push against a rib, or other anatomical structures (e.g., veins, arteries, nerves, etc. between the ribs) that the surgical instrument needs to maneuver around to reach the distant surgical site, with sufficient force to damage the rib or the other anatomical structures inside the body of the patient.

(62) In some cases, a user operating the surgical instrument may be able to avoid causing damage

to the patient by ensuring that the surgical instrument is properly handled inside the body of the patient. For example, an experienced surgeon may feel the resistance that results from a forceful contact of the surgical instrument with the tissue or other anatomy inside the body of the patient, and may ease up on pushing the surgical instrument, and/or reposition the surgical instrument, to avoid causing damage to the patient. In other cases, however, a user may not feel or notice the resistance (or not appreciate the consequences of such resistance) and may thus continue to apply excessive force to the tissue or other anatomy inside the body of the patient, thereby potentially causing harm to the patient. Such situations may occur, for example, when the user is not an experienced surgeon, but is an assistant or a medical student working with the surgeon, for example. Also, in situations in which robotic surgery is performed, the surgical understanding of tissues, forces, and trajectories, such as tactile feedback or feeling, that a surgeon may have had if the surgeon were performing the surgery manually may be missing, and the patient may be harmed if the robotic system is not prevented from applying excessive force to tissue or other anatomy inside the body of the patient.
(63) In embodiments described below, a surgical instrument is equipped with a shaft deflection detection system that may detect movement or displacement of the shaft relative to another component that may be coupled with the shaft of the surgical instrument. The other component may include, for example, an actuator coupled with the shaft of the surgical instrument (e.g., a handle portion coupled with the shaft of the surgical instrument or a robotic arm attached to the shaft of the surgical instrument). Additionally or alternatively, the other component may include an end effector coupled with the shaft of the surgical instrument. The shaft deflection detection system may thus detect shaft displacement caused by external forces experienced by the shaft as the shaft is maneuvered inside the body of the patient. Such external forces may be due to the end effector coupled with the shaft of the surgical instrument meeting a resistance of surrounding tissue or other anatomy as the shaft is maneuvered inside the body of the patient, for example.
(64) The shaft deflection detection system may include one or more springs (e.g., linear or non-linear coil springs) that couple the shaft to the other component at a mechanical junction between the shaft and the other component. The one or more springs may allow controlled movement or deflection of the shaft with respect to the other component that is proportional to external forces experienced by the shaft as the surgical instrument is being maneuvered inside the body of the patient. The shaft deflection detection system may also include one or more sensors that are positioned at the mechanical junction between the shaft and the other component. For example, the one or more sensors may include a plurality of sensors distributed among a plurality of points around the circumference of the shaft at the mechanical junction. The one or more sensors may be configured to sense the movement of the shaft and to generate signals indicative of displacement of the shaft while the shaft is being maneuvered inside the body of the patient.
(65) The signals generated by the one or more sensors may be provided to a controller that may be communicatively coupled with the shaft deflection detection system. The controller may be configured to determine, based on the signals generated by the one or more sensors, magnitudes and directions of external forces experienced by the shaft as the shaft is maneuvered inside the body of the patient. For example, the controller may convert the displacement of the shaft to a force based on the spring force function of the one or more springs that couple the shaft to the other component. In an embodiment in which the one or more sensors comprise a plurality of sensors distributed among a plurality of points around the circumference of the shaft, the controller may determine a vector including magnitudes and directions of the external forces experienced by the shaft at the plurality of points around the circumference of the shaft.
(66) The controller may detect, based on the signals received from the one or more sensors, when excessive force is experienced by the shaft. For example, the controller may determine that excessive force is experienced by the shaft if the external force experienced by the shaft exceeds a predetermined threshold. When excessive force is detected, the controller may generate an alert and

may cause the alert to be provided to a user (e.g., a clinician or a robot) operating or otherwise using the surgical instrument. The alert may comprise a haptic feedback signal that may be provided via the handle portion of the surgical instrument, for example. Additionally or alternatively, a visual and/or auditory alert may be provided. The alert may alert the user that the user should ease up on pushing the surgical instrument, and/or reposition the surgical instrument, in order to mitigate the force and avoid harming the patient. In some embodiments, additional information regarding the force may be provided to the user. For example, the controller may determine a magnitude and/or a direction of the force experienced by the shaft and provide a display of the magnitude and/or direction of the force to the user. Such display of the magnitude and/or direction of the force may be provided, for example, on a screen located in an operating room in which the surgical instrument is being used. In an embodiment, the display of the magnitude and/or direction of the force may be overlayed with a visual representation of the shaft being maneuvered inside the anatomical structure in the body of the patient. Such additional information may inform the user of the degree to which the user should ease up and/or a direction in which the user should move the surgical instrument to mitigate the excessive force experienced by the shaft.

(67) In some embodiments, the controller may be further configured to determine a corrective action that may be performed by the user in order to mitigate the excessive force and avoid impediments or snags during insertion and/or removal. In such embodiments, an indication of the corrective action may be provided to the user, for example via a screen or other display either on the handle of the surgical instrument or in the operating room in which the surgical instrument is being used. The indication may inform the user that moving or rotating the surgical instrument in a certain direction is recommended to mitigate the force. The indication may also inform the user of a degree of movement that is recommended to mitigate the force. These and other techniques described herein may reduce chances of causing harm to the patient as the surgical instrument is being maneuvered inside the body of the patient, such as during insertion the surgical instrument into or removal of the surgical instrument from the body of the patient. For example, sensing and communicating the force experienced by the shaft can alert the user of excessive force and help navigate “hang-ups” during insertion and removal. Displaying or otherwise relaying this information to the user helps keep the user informed during the surgical procedure so that the user can ensure that the surgical instrument is properly and appropriately maneuvered to avoid harming the patient during the surgical procedure.

(68) FIG. **11** depicts an example surgical instrument **1100** equipped with a shaft deflection detection system **1102**, according to an embodiment. The surgical instrument **1100** corresponds to the surgical instrument **10**, in an embodiment. Although the shaft deflection detection system **1102** is generally described below with reference to the surgical instrument **1100** and the surgical instrument **10**, the shaft deflection detection system **1102** may be used with surgical instruments differed from the surgical instrument **1100** or the surgical instrument **10**, in some embodiments. For example, the surgical instrument **810** of FIG. **8** may be equipped with a shaft deflection detection system same as or similar to the shaft deflection detection system **1102**, in an embodiment. As another example, the surgical instrument **1010** of FIG. **10** may be equipped with a shaft deflection detection system same as or similar to the shaft deflection detection system **1102**, in an embodiment.

(69) The surgical instrument **1100** includes a shaft **1108** (e.g., corresponding to the shaft **200** of the instrument **10** of FIG. **1**) coupled with an actuator in the form of a manually operated handle portion **1110** (e.g., corresponding to the handle portion **100** of the instrument **10** of FIG. **1**) at a proximal end of the shaft **1108**. The shaft **1108** may also be coupled with an end effector **1109** (e.g., corresponding to the stapling head **300** of FIG. **1**) at a distal end of the shaft **1108**. The shaft deflection detection system **1102** includes one or more sensors **1104** positioned at a mechanical junction **1106** between the shaft **1108** and the handle portion **1110** of the surgical instrument **1100**.

In another example, the shaft **1108** may be coupled with an actuator other than the handle portion **1110** at the mechanical junction **1106**. For example, the shaft **1108** may be attached to a component of a robotic system (e.g., an end of a robotic arm) at the mechanical junction **1106**.

(70) The one or more sensors **1104** may comprise a plurality (e.g., an array) of sensors distributed among a plurality of points around a circumference of the shaft **1108** at the mechanical junction **1106**, for example. The shaft deflection detection system **1102** may additionally include one or more springs **1114** that couple the shaft **1108** to the handle portion **1110** at the mechanical junction **1106**. The one or more springs **1114** may be used to bias the shaft **1108** to a nominally centered or neutral position when no load or force is applied to the shaft **1108**. The one or more springs **1114** may comprise linear coil springs, for example. The mechanical junction **1106** may be designed such that the shaft **1108** has a degree of flexibility or compliance that allows movement of the shaft **1108** with respect to the handle portion **1110**. For example, the mechanical junction **1106** may be made of a suitable material that is sufficiently flexible or compliant to allow movement of the shaft **1108** with respect to the handle portion **1110**. Thus, as the shaft **1108** experiences external forces when the shaft or another component (e.g., the end effector **1109**) pushes against tissue or other anatomy inside a body of a patient, the shaft **1108** may move relative to the handle portion **1110**. The one or more sensors **1104** are configured to measure movement of the shaft **1108** relative to the handle portion **1110** and to generate signals indicative of a force experienced by the shaft **1108** as shaft **1108** is maneuvered inside a body of the patient.

(71) In an example, the sensors **1104** may include four sensors **1104** distributed at 90 degree angles relative to one another around the circumference of the shaft **1108**. In this example, the sensors **1104** may be configured to measure movement of the shaft **1108** in the north, south, east, and west directions, for example. In another example, the sensors **1104** may include a suitable numbers of sensors other than four. For example, the sensors **1104** may include a greater number of sensors to provide greater force direction measurement granularity. As just an example, the sensors **1104** may include eight sensors **1104** distributed at 45 degree angles relative to one another around the circumference of the shaft **1108**. In another example, the sensors **1104** may include fewer than four sensors, for example to reduce the complexity and cost of the surgical instrument **1100** while still providing useful shaft deflection measurements. As just an example, the sensors **1104** may include two sensors **1104** distributed at a 180 degree angle relative to one another around the circumference of the shaft **1108**. In this example, each of the two sensors **1104** may be configured to sense movement of the shaft **1108** in two directions. For example, a first sensor **1104** may be configured to sense movement of the shaft **1108** in the north and south directions and a second sensor **1104** may be configured to sense movement of the shaft **1108** in east and west directions. In other examples, the shaft deflection detection system **1102** may include other suitable numbers and/or other suitable configurations of sensors **1104**.

(72) The sensors **1104** may comprise Hall effect sensors or other magnetic sensors positioned on an inner surface of the handle portion **1110** at the mechanical junction **1106**, for example. The shaft deflection detection system **1102** may additionally include one or more magnets **1112** positioned on an outer surface of the shaft **1108** at the mechanical junction **1106** at least substantially directly across from the sensors **1104**. In another example, the one or more sensors **1104** may be positioned on an outer surface of the shaft **1108** at the mechanical junction **1106** and the one or more magnets **1112** may be positioned on an inner surface of the handle portion **1110** at the mechanical junction **1106** at least substantially directly across from the sensors **1104**. The one or more springs **1114** may be positioned between the shaft **1108** and the handle portion **1110** at the mechanical junction **1106** such that movement of the shaft **1108** relative to the handle portion **1110** compresses or decompresses the springs **1114**. The springs **1114** may be positioned around the circumference of the shaft **1108** in spaces between sensors **1104**, for example. The one or more springs **1114** may comprise linear coil springs characterized by a predetermined spring force function (e.g., a spring constant). In other examples, springs other than linear coil springs and/or non-linear springs may be

used. The non-linear springs may be characterized by a known spring function, for example.

(73) In an embodiment, the Hall effect sensors **1104** may comprise a plurality (e.g., an array) of sensors distributed among a plurality of points around the circumference of the handle portion **1110** at the mechanical junction **1106**. The magnets **1112** may similarly comprise a plurality (e.g., an array) of magnets distributed among a plurality of points around the circumference of the shaft **1108** at the mechanical junction **1106**. In another example, the magnets **1112** may include a single magnet that covers the circumference of the shaft **1108** at the mechanical junction **1106**. The Hall effect sensors **1104** may sense magnetic fields generated by the magnets **1112** and generate signals that are proportional to the magnetic field sensed by the sensors **1104**. As the shaft **1108** is deflected with respect to the handle **1110** at the mechanical junction **1106** due to external forces experienced along the shaft **1108**, the magnetic field sensed by the Hall effect sensors **1104** changes due to a change in distance between the Hall effect sensors **1104** and the magnets **1112**. The sensed change in magnetic field may thus be indicative of magnitudes of external forces experienced by the shaft **1108** at the plurality of points around the circumference of the shaft **1108** as the shaft **1108** is maneuvered inside the body of the patient.

(74) The shaft deflection detection system **1102** may include or be communicatively coupled with a controller **1130**. The controller **1130** may be located in the handle portion **1110** of the surgical instrument **1100**. In another example, the controller **1130** may be implemented at least partially externally to the surgical instrument **1100**. For example, the controller **1130** may be implemented at least partially on a processor of a computer that may be located in an operating room in which the surgical instrument **1100** may be used. The controller **1130** may be configured to receive signals generated by the sensors **1104** and detect external forces experienced by the shaft **1108** based on the signals received from the sensors **1104**. For example, the controller **1130** may be configured to convert the detected deflection of the shaft **1108** to a magnitude of force experienced by the shaft **1108** based on the predetermined spring force function (e.g., spring constant) of the springs **1114**. In an embodiment in which the sensors **1104** comprise a plurality (e.g., an array) of sensors distributed among a plurality of points around the circumference of the shaft **1108**, the controller **1130** may be configured to determine a vector of forces experienced along the shaft **1108** at the plurality of points around the circumference of the shaft **1108**. The vector may indicate direction and magnitude of the force experienced along the shaft **1108**. In this way, the vector may indicate movement of the shaft **1108**.

(75) The controller **1130** may detect, based on the determined forces experienced by the shaft **1108** at one or more points around the circumference of the shaft **1108**, when the external force experienced by the shaft **1108** is excessive. For example, the controller **1130** may determine that excessive force is experienced by the shaft **1108** if magnitudes of one or more of the determined forces exceed a predetermined threshold. In some embodiments, a plurality of predetermined thresholds may be provided. For example, different thresholds may be defined for different types of tissue and/or other anatomy in the body of the patient. The plurality of thresholds may be stored in a memory included in or coupled to the controller **1130**. The controller **1130** may then select an appropriate threshold based on the type of tissue or other anatomy according to a setting provided by a user depending on the surgical procedure, for example.

(76) When excessive force is detected, the controller **1130** may generate an alert and may cause the alert to be provided to the user. The alert may alert the user that the user should ease up on pushing the surgical instrument **1100**, and/or should reposition the surgical instrument **1100**, in order to mitigate the external force. The alert may comprise a haptic feedback signal that may be provided via the handle portion **1110**, for example. Additionally or alternatively, the controller **1130** may be configured to generate and provide a visual and/or auditory alert to the user.

(77) In some embodiments, additional information regarding the external force experienced by the shaft **1108** may be provided to the user. For example, the controller **1130** may determine a magnitude and/or a direction of the external force experienced by the shaft **1108**. The magnitude

and/or direction of the force may be displayed to the user. The controller **1130** may cause such display to be provided to the user via a screen located on the handle portion **1110** of the surgical instrument **1100** or via a screen or display in an operating room in which the surgical instrument **1100** is being used, for example. In an embodiment, the display of the magnitude and/or direction of the external force may be overlayed with a visual representation of the shaft **1108** being maneuvered inside the anatomical structure in the body of the patient. Such additional information, such as a vector display, may inform the user of the degree to which the user should ease up and/or a direction in which the user should move the surgical instrument **1100** to mitigate the excessive force on the tissue or other anatomical structure (e.g., bone, etc.). In some embodiments, the controller **1130** may be further configured to determine a corrective action that may be performed by the user in order to mitigate the excessive force. The controller **1130** may cause an indication of the corrective action to be provided to the user, for example via the screen or other display on the handle portion **1110** of the surgical instrument **1100** or in the operating room in which the surgical instrument **1100** is being used.

(78) The controller **1130** may include any suitable analog and/or digital circuitry configured to detect external forces experienced by the shaft **1108** and to provide indications to the user of the surgical instrument **1100** when it is determined that excessive force is experienced by the shaft **1108**. For example, the controller **1130** may be a fully analogue controller that may include analogue circuitry, such as one or more comparators, that may compare magnitudes of signals received from the sensors **1104** with a threshold, and generate indications of excessive force when the magnitudes of the signals exceed the threshold. The controller **1130** may further include analog indicators that may provide indications of shaft force and/or provide excessive force alerts to the user. In an example, the controller **1130** may include or be coupled to one or several light emitting devices, such as light emitting diodes (LEDs), that may visually indicate points at which excessive force is experienced by the shaft **1108**. In an embodiment, respective LEDs may be provided on an outside surface of the handle portion **1110**, for example around the circumference of the handle portion **1110**, to correspond with the respective ones of the sensors **1104**. The controller **1130** may be configured to cause the respective LEDs to light up (e.g., green or red) to indicate whether normal or excessive force is detected based on signals received from the corresponding sensors **1104**. In another example, a single light emitting device may be provided, and the controller **1130** may be configured to cause the single light emitting device to, for example, light up (e.g., red) in response to detecting excessive force at any point around the circumference of the shaft **1108**. In another embodiment, one or more audio indications may be provided to the user in addition to or instead of the one or more visual indications.

(79) In some implementations, the controller **1130** may be at least partially digital. In some examples, the controller **1130** may be implemented utilizing dedicated hardware, such as one or more of discrete components, an integrated circuit, an application-specific integrated circuit (ASIC), a programmable logic device (PLD), a processor executing firmware instructions, a processor executing software instructions, or any combination thereof. When implemented utilizing a processor executing software or firmware instructions, the software or firmware instructions may be stored in any suitable computer readable memory such as on a magnetic disk, an optical disk, or other storage medium, etc. The software or firmware instructions may include machine readable instructions that, when executed by one or more processors, cause the one or more processors to perform various acts related to determining force experienced by the shaft **1108**, determining whether the force or strain is excessive at one or more points around the circumference of the shaft **1108**, determining a corrective action that may be taken to mitigate the excessive force, providing indications to a user of the surgical instrument **1100**, etc. In some implementations, the controller **1130** may include one or more digital to analog converters (DACs) and one or more analog to digital converters (ADCs) configured to convert signals between analog signals received from the sensors **1104** to digital signals suitable for processing by the digital circuitry of the controller **1130**.

(80) In various examples, the alerts and/or corrective action indications may be provided to the user via one or more of i) visual indicators, such as LEDs, that may be provided, for example, on the handle portion **1110** of the surgical instrument **1110**, ii) audio indicators and/or iii) a digital screen or other display that may be integrated with the surgical instrument **1100** or communicatively coupled with the surgical instrument **1100**. For example, a transmitter may be coupled to the controller **1130** to wirelessly transmit force signals generated based on the signals received from the sensors **1104** to a processor of a computer that may be located, for example, in an operating room in which the surgical instrument **1100** is being used. The processor of the computer may be configured to further process the force signals, for example to identify one or more points around the circumference of the shaft **1108** at which excessive force is experienced by the shaft **1108**, determine corrective action that may be performed to mitigate excessive force experienced by the shaft **1108**, cause alerts and/or corrective action indications to be displayed on a display coupled to the computer, etc.
(81) It is noted that although the shaft deflection detection system **1102** is generally described herein as including Hall effect sensors **1104** configured to measure movement of the shaft **1108** and generate signals indicative of forces experienced by the shaft **1108**, the shaft deflection detection system **1102** may include sensors other than Hall effect sensors and/or may be configured to measure shaft movement quantities other than movement due to external forces experienced by the shaft **1108**. For example, the shaft deflection detection system **1102** may be configured to measure strain, pressure, etc. experienced by the shaft **1108**, in addition to or instead of measuring forces experienced by the shaft. In some examples, the one or more sensors **1104** may comprise i) one or more encoded strips (e.g., magnet scales) positioned or distributed around the circumference of the shaft **1108** or the handle portion **1110** and configured to move with movement of the shaft **1108** relative to the handle portion **1110** and ii) one or more electromagnetic encoders or read-heads configured to read movement of the encoders or read-heads and provide signals indicative of deflection of the shaft **1108** relative to the handle portion **1110** based on detecting positions of the one or more magnet scales positioned around the circumference of the shaft **1108** or the handle portion **1110**. As another example, the one or more sensors **1104** may comprise strain gauge sensors configured to measure strain on the shaft **1108**. As yet another example, the one or more sensors **1104** may comprise piezo (e.g., piezoelectric) sensors configured to measure pressure experienced by the shaft **1108**. In other examples, other suitable sensors (e.g., resistive sensors, capacitive sensors, etc.) may be used. In some examples, a sensor **1104** and a corresponding spring **1114** may be combined into a single sensor element in the shaft deflection detection system **1102**. For example the deflection of the spring may alter a measurable electrical property or other measurable property indicative of movement of the shaft **1108**, and such property may be measured by the sensor element to generate a signal indicative of the movement of the shaft **1108**.
(82) In some examples, the shaft deflection detection system **1102** may omit the one or more magnets **1112** and/or the one or more springs **1114**. For example, mechanisms other than the one or more springs **1114** may be used to bias the shaft **1108** to a nominally centered or neutral position when no load or force is applied to the shaft **1108**. In some embodiments, for example, rubber or polymer material may be used instead of the one or more springs **1114**. In an example, a rubber or polymer gasket may encircle the shaft **1108** at the mechanical junction **1106** between the shaft **1108** and the handle portion **1110**. The rubber or polymer gasket may act as a seal between the shaft **1108** and the handle portion **1110** and may also stretch in any direction when load or force is experienced by the shaft **1108**. In other embodiments, other suitable biasing materials and/or mechanisms may be used to bias the shaft **1108** to a nominally centered or neutral position while having the ability to stretch (e.g., compress or decompress) when load or force is experienced by the shaft **1108**.
(83) It is also noted that although the deflection detection system **1102** is generally described herein as being positioned at the mechanical junction **1106** (sometimes referred to herein as “first mechanical junction”) between the shaft **1108** and the handle portion **1110**, in some embodiments,

the deflection detection system **1102** may additionally or alternatively include sensors **1104** (and, if needed, other corresponding components such as magnets **1112** and springs **1114** as described herein) at a mechanical junction other than the mechanical junction **1106** between the shaft **1108** and the handle portion **1110**. For example, in some embodiments, the shaft deflection detection system **1102** may additionally or alternatively include sensors **1104** (and, if needed, other corresponding components such as magnets **1112** and springs **1114** as described herein) positioned at a mechanical junction **1107** (sometimes referred to herein as "second mechanical junction") between the shaft **1108** and the end effector **1109**. The sensors **1104** positioned at the mechanical junction **1107** may detect movement of the shaft **1108** relative to the end effector **1109**.
(84) FIG. **12** depicts a cross-section view of the shaft deflection detection system **1102** in which Hall effect sensors are used, according to an embodiment. The shaft deflection detection system **1102** is illustrated in FIG. **12** in a neutral or rest state. The neutral or rest state corresponds to a state in which no external force, or very small external force, is experienced by the shaft **1108** of the surgical instrument **1100**. As illustrated in FIG. **12**, in the neutral or rest state, the distances between the Hall effect sensors **1104** and the corresponding magnets **1112** of the shaft deflection detection system **1102** may be at least approximately equal. Accordingly, magnitudes of signals generated by different ones of the Hall effect sensors **1104** may be approximately equal to each other. In some embodiments, the controller **1130** may be calibrated to the neutral state of the shaft deflection detection system **1102**. For example, the controller **1130** may be configured to measure, and store in a memory, magnitudes of signals received from the sensors **1104** when the shaft deflection detection system **1102** is in the neutral state.
(85) FIG. **13** depicts a cross-section view of the shaft deflection detection system **1102** in a state in which an external force **1302** is experienced by the shaft **1108** of the surgical instrument **1100**, according to an embodiment. The external force **1302** may be due, for example, to the shaft **1108** pushing against tissue or other substance (e.g., bone, rib, etc.) inside of a body a patient, such as during insertion or removal of the surgical instrument **1100** into or from the body of the patient (e.g., into or form a tubular structure, such as an intestine, in the body of the patient). The force **1302** causes deflection of the shaft **1108** relative to the handle portion **1110** of the surgical instrument **1100**. Accordingly, distances between Hall effect sensors **1104** and corresponding magnets **1112** change with the movement of the shaft **1108**. For example, as illustrated at a point **1304** in FIG. **13**, distances between Hall effect sensors **1104** and corresponding magnets **1112** at or near the point(s) around the circumference of the shaft **1108** at which the external force **1302** is exerted along the shaft **1108** decrease as the magnets **1112** positioned on the shaft **11108** are pushed towards the corresponding sensors **1104** positioned on the handle portion **1110**. Further, distances between one or more sensors **1104** that are farther away from (e.g., across from) the point(s) around the circumference of the shaft **1108** at which the external force **1302** is exerted along the shaft **1108** increase as the magnets **1112** positioned on the shaft **11108** are pushed farther away from the corresponding sensors **1104** positioned on the handle portion **1110**. The changing distances between the sensors **1104** and the magnets **1112** result in corresponding changes of magnetic fields sensed by the sensors **1104**, thereby changing the magnitudes of the signals generated by the sensors **1104**.
(86) The controller **1130** may thus detect the changes in distance between the Hall effect sensors **1104** and the corresponding magnets **1112**, for example by comparing the distances to the corresponding distances measured in the neutral state of the shaft deflection detection system **1102**. In an example, the controller **1130** may convert the deflection distances indicated by the signals received from the sensors **1104** to respective forces based on the predetermined spring force functions (e.g., spring constants) of the springs **1114**. For example, the force experienced by the shaft **1108** at a particular point around the circumference may be determined by dividing the change in distance between the sensor **1104** at or closest to the particular point on the circumference of the handle portion **1110** and the corresponding sensor **1104** on the shaft **1108**. The controller **1130** may further be configured to determine whether the force experienced by the shaft

1108 is excessive. For example, the controller **1130** may be configured to determine whether the force is excessive based on a comparison of the determined force and a predetermined threshold.
(87) In an embodiment, if the controller **1130** determines that the force at one or more points around the circumference of the shaft **1108** exceeds a predetermined threshold, the controller **1130** may generate an alert and/or determine a corrective action, and may provide the alert and/or the determined corrective action to the user of the surgical instrument **1100**. The user may thus ease up on pushing the surgical instrument **1100** to avoid causing damage to the patient. The user may also perform the corrective action, for example by shifting the surgical instrument **1100** in a direction determined by the controller **1130**, rotating the instrument **1100** as determined by the controller **1130**, etc. The user may thus ensure safe maneuvering of the surgical instrument **1100** during a surgical procedure, such as during insertion or removal of the instrument **1100** into or from a tubular structure (e.g., intestine) inside the body of the patient. Accordingly, the user may ensure that components of the surgical instrument **1100** do not, for example, rupture the tubular structure inside the body of the patient during the surgical procedure.
(88) FIGS. **14**A-B depict example of graphics **1400**, **1450** that may be displayed to a user to inform the user of a corrective action that may be performed to mitigate an excessive force experienced by a shaft of a surgical instrument (e.g., the surgical instrument **1100**). The graphics **1400**, **1450** may be displayed on a display (e.g., a screen) of the handle portion **1110** of the surgical instrument **1100** or a computer that may be located in a room in which the surgical instrument **1100** is being used, for example. The graphics **1400**, **1450** may provide a visual illustration of the handle portion **1110** and an indication of how to handle (e.g., rotate or otherwise move) the handle portion **1110** in order to reduce excessive forces experienced by the shaft **1108** of the surgical instrument **1100**. Referring to FIG. **14**A, the graphics **1400** include an illustration of a user's hand **1402** holding the handle portion **1110** and an arrow **1404** pointing in the clockwise direction. Accordingly, the user may be guided to rotate the handle portion **1110** in a direction indicated by the clockwise direction of the arrow **1404** in order to mitigate the force experienced by the shaft **1108**. In this case, the user would be guided to tilt the distal end of the handle portion **1110** downward and/or the proximal end of the handle portion **1110** upward. Referring now to FIG. **14**B, the graphics **1450** include an illustration **1452** of the user's hand holding the handle portion **1110** in a current position and an arrow **1454** guiding the user to an illustration **1456** illustrating the handle portion **1110** tilted down with respect to the current position. Accordingly, in this case, the user may be guided to tilt the handle portion **1110** down in order to mitigate the force experienced by the shaft **1108**.
(89) In some examples, various graphics may be provided in which the determined forces experienced by the shaft **1108** are continuously displayed. For example, a display of the determined forces experienced by the shaft **1108** may be provided as an overlay of the force on an illustration of the handle portion **1110** and/or the shaft **1108** to show the force being mitigated as the user is moving (e.g., rotating, tilting, etc.) the handle portion **1110**. In other examples, other suitable graphics may be generated and displayed to alert the user of excessive force experienced by the shaft **1108**, guide the user in order to mitigate the force, provide a real-time display of force as the user is moving the handle portion **1110**, etc. Such graphics may help the user avoid “hang-ups” or causing any damage to a patient as the user maneuvers components of the surgical instrument **1100** inside the body of the patient.
(90) FIG. **15** is a flowchart of an example method **1500** for monitoring force experienced by a shaft of a surgical instrument as the shaft is maneuvered inside a body of a patient, according to an embodiment. In an embodiment, the method **1500** is implemented by the controller **1130** to monitor a force experienced by the shaft **1108** of the surgical instrument **1100** of FIG. **11**. It is noted, however, that the method **1500** may be implemented by a controller different from the controller **1130** and/or with a surgical instrument different from the surgical instrument **1100** of FIG. **11**, in other embodiments.
(91) At a block **1502**, the controller **1130** may receive a plurality of signals from a plurality of

sensors positioned at one or both of i) a first mechanical junction between the shaft and an actuator coupled with the shaft or ii) a second mechanical junction between the shaft and an end effector coupled with the shaft. The actuator may include a handle portion of the surgical instrument, for example. In another example, the actuator may include a robotic arm attached to the shaft of the surgical instrument. The plurality of sensors may be configured to sense movement of the shaft relative to the actuator and/or the end effector as the shaft is being maneuvered inside the body of the patent. The signals generated by the sensors may thus be indicative of a force experienced by the shaft as the shaft is being maneuvered inside the body of the patent. In an example, the plurality of sensors may include sensors distributed among a plurality of points around the circumference of the shaft at the first mechanical junction and/or the second mechanical junction. The signals generated by the sensors may thus be indicative of forces experienced along the shaft at the plurality of points around the circumference of the shaft as the shaft is being maneuvered inside the body of the patent.

(92) At a block **1504**, the controller **1130** may detect, based on the plurality of signals, when force experienced by the shaft meets a predetermined excessive force criterion as the shaft is maneuvered inside the body of the patient. For example, the controller **1130** may determine, based on respective signals received from respective sensors among the plurality of sensors, respective forces experienced by the shaft at a plurality of points around the circumference of the shaft. The controller **1130** may compare the respective forces experienced by the shaft at the plurality of points around the circumference of the shaft with a predetermined threshold, and may determine that the force experienced by the shaft meets the predetermined excessive force criteria in response to determining that one or more forces, among the respective forces, exceeds the predetermined threshold. In an embodiment, the controller **1130** may also be configured to further process the signals received from the plurality of sensors, for example to determine a magnitude and/or direction of the force experienced by the shaft.

(93) At a block **1506**, the controller **1130** may generate an alert and may provide the alert to the user to inform the user that the shaft is experiencing excessive force. The controller **1130** may generate the alert at block **1506** in response to detecting at block **1504** that the force experienced by the shaft meets the predetermined excessive force criterion. The alert may comprise a haptic feedback signal that may be provided via the handle portion of the surgical instrument, for example. Additionally or alternatively, a visual and/or auditory alert may be provided. The alert may alert the user that the user should ease up on pushing the surgical instrument, and/or reposition the surgical instrument, in order to mitigate the force and avoid harming the patient. In some embodiments, additional information regarding the force may be provided to the user. For example, a display of the magnitude and/or direction of the force may be provided to the user, for example, on a screen located on the handle portion of the surgical instrument or in an operating room in which the surgical instrument is being used. Such additional information may inform the user of the degree to which the user should ease up and/or a direction in which the user should move the surgical instrument to mitigate the force.

(94) In some embodiments, the controller may be further configured to determine a corrective action that may be performed by the user in order to mitigate the excessive force. In such embodiments, an indication of the corrective action may be provided to the user, for example via the screen or other display on the handle portion of the surgical instrument or in the operating room in which the surgical instrument is being used.

(95) The embodiments disclosed herein provide a shaft detection system configured to detect movement of the shaft of a surgical instrument relative to another component of the surgical instrument. The movement of the shaft may be indicative of a force, pressure, strain, etc. experienced by the shaft as the surgical instrument is maneuvered inside a body of a patient. The shaft detection system may thus provide indication of when excessive force is being experienced by the shaft and/or provide indications of corrective actions that may be taken to mitigate the force as

the shaft is being maneuvered inside the body of the patient. These and other techniques described herein may reduce chances of causing harm to the patient due to forceful pushing of components of the surgical instrument against anatomy inside the body of the patient, such as during insertion the surgical instrument into or removal of the surgical instrument from the body of the patient.

III. Examples of Combinations

(96) The following examples relate to various non-exhaustive ways in which the teachings herein may be combined or applied. It should be understood that the following examples are not intended to restrict the coverage of any claims that may be presented at any time in this application or in subsequent filings of this application. No disclaimer is intended. The following examples are being provided for nothing more than merely illustrative purposes. It is contemplated that the various teachings herein may be arranged and applied in numerous other ways. It is also contemplated that some variations may omit certain features referred to in the below examples. Therefore, none of the aspects or features referred to below should be deemed critical unless otherwise explicitly indicated as such at a later date by the inventors or by a successor in interest to the inventors. If any claims are presented in this application or in subsequent filings related to this application that include additional features beyond those referred to below, those additional features shall not be presumed to have been added for any reason relating to patentability.

(97) 1. A surgical instrument, comprising: a shaft configured to couple with an actuator at a first mechanical junction between the shaft and the actuator; an end effector coupled with the shaft at a second mechanical junction between the shaft and the end effector, wherein i) the end effector is configured to clamp, staple, and cut tissue and ii) the actuator is configured to operate the end effector via the shaft, and wherein the shaft is one or both i) movable relative to the actuator at the first mechanical junction between the shaft and the actuator or ii) movable relative to the end effector at the second mechanical junction between the shaft and the end effector; and a shaft deflection detection system including one or more sensors positioned at one or both of the first mechanical junction or the second mechanical junction, wherein the one or more sensors are configured to generate signals indicative of movement of the shaft relative to one or both of the actuator or the end effector, wherein the movement of the shaft is caused by an external force experienced by the shaft as the shaft of the surgical instrument is maneuvered inside a body of a patient.

(98) 2. The surgical instrument of claim **1**, wherein: the end effector comprises a circular stapler; and the one or more sensors are configured to detect movement of the shaft relative to the one or both of the actuator or the end effector as the shaft of the surgical instrument is maneuvered inside an anatomical lumen in the body of the patient.

(99) 3. The surgical instrument of claim **1**, wherein the one or more sensors comprise a plurality of sensors distributed among a plurality of points around a circumference of the shaft at one or both of i) the first mechanical junction between the shaft and the actuator or ii) the second mechanical junction between the shaft and the end effector.

(100) 4. The surgical instrument of claim **3**, further comprising a controller communicatively coupled to the shaft deflection detection system, the controller configured to: receive respective signals generated by respective sensors among the plurality of sensors; determine, based on the respective signals generated by respective sensors among the plurality of sensors, respective forces experienced by the shaft at respective points among the plurality of points around the circumference of the shaft; compare the respective forces experienced by the shaft at the respective points to a predetermined threshold; and determine that excessive force is experienced at one or more points around the circumference of the shaft in response to determining that one or more forces, among the respective forces, exceeds the predetermined threshold.

(101) 5. The surgical instrument of claim **4**, wherein the controller is further configured to, in response to determining that excessive force is experienced by the shaft at one or more points around the circumference of the shaft, generate an alert and provide the alert to a user of the

surgical instrument to inform the user that excessive force is experienced by the shaft.
(102) 6. The surgical instrument of claim **5**, wherein the alert is a haptic buzz provided to the user via a handle portion of the surgical instrument.
(103) 7. The surgical instrument of claim **5**, wherein the controller is further configured to determine, based on the respective signals generated by respective sensors among the plurality of sensors, a magnitude and a direction of the external force experienced by the shaft.
(104) 8. The surgical instrument of claim **7**, wherein the controller is further configured to: determine, based on one or both of the magnitude or the direction of the external force, a corrective action to mitigate the excessive force experienced by the shaft; and provide an indication of the corrective action to the user to enable the user to mitigate the excessive force experienced by the shaft.
(105) 9. The surgical instrument of claim **7**, wherein the controller is further configured to: generate real-time graphics illustrating one or both of the direction or the magnitude of the external force experienced by the shaft as the user is maneuvering the shaft of the surgical instrument inside the body of the patient; and cause the real-time graphics to be displayed to the user.
(106) 10. The surgical instrument of claim **4**, wherein: the plurality of sensors comprises a plurality of Hall effect sensors positioned at the first mechanical junction on an outer surface of the shaft at the plurality of points around the circumference of the shaft; and the shaft deflection detection system further includes a plurality of magnets positioned at the first mechanical junction at a plurality of points on an inner surface of the actuator coupled with the shaft such that respective magnets among the plurality of magnets are positioned across from respective sensors among the plurality of Hall effect sensors, and a plurality of springs positioned in spaces between respective sensors among the plurality of Hall effect sensors, the springs being coupled between the outer surface of the shaft and the inner surface of the actuator coupled with the shaft such that the springs compress or decompress with movement of the shaft relative to the actuator coupled with the shaft, wherein the springs are characterized by a predetermined spring force function.
(107) 11. The surgical instrument of claim **10**, wherein the controller is configured to determine respective forces experienced along the shaft at the plurality of points around the circumference of the shaft based on i) the signals indicative of the movement of the shaft received from respective sensors among the plurality of Hall effect sensors and ii) the predetermined spring force function.
(108) 12. The surgical instrument of claim **1**, wherein the actuator comprises a manually operated handle portion coupled with the shaft.
(109) 13. The surgical instrument of claim **1**, wherein the actuator comprises a robotic arm attached to the shaft.
(110) 14. A surgical instrument, comprising: a shaft; a handle portion coupled with the shaft, wherein the shaft is movable relative to the handle portion at a mechanical junction between the handle portion and the shaft; and a shaft deflection detection system including a plurality of sensors positioned at the mechanical junction between the handle portion and the shaft, wherein sensors among the plurality of sensors are distributed at a plurality of points around a circumference of the shaft, and wherein the sensors among the plurality of sensors are configured to generate signals indicative of external forces experienced along the shaft at the plurality of points around the circumference of the shaft as the shaft of the surgical instrument is maneuvered inside a body of a patient.
(111) 15. The surgical instrument of claim **14**, wherein: the surgical instrument further comprises a circular stapler end effector coupled with the shaft; and the plurality of sensors is configured to detect movement of the shaft relative to the handle portion as the shaft of the surgical instrument is maneuvered inside an anatomical lumen in the body of the patient.
(112) 16. The surgical instrument of claim **14**, further comprising a controller communicatively coupled with the shaft deflection detection system, the controller configured to: receive the signals generated by the sensors among the plurality of sensors; detect, based on the signals generated by

the sensors among the plurality of sensors, when excessive force is experienced by the shaft at one or more points among the plurality of points around the circumference of the shaft; and in response to detecting that excessive force is experienced by the shaft at one or more points around the circumference of the shaft, generate an alert and provide the alert to a user of the surgical instrument to inform the user that excessive force is experienced by the shaft.

(113) 17. The surgical instrument of claim **16**, wherein the controller is further configured to: determine, based on the signals generated by the sensors among the plurality of sensors, a magnitude and a direction of the excessive force experienced by the shaft; determine, based on one or both of the magnitude and the direction of the external force, a corrective action to mitigate the excessive force experienced by the shaft; and provide an indication of the corrective action to the user to enable the user to mitigate the excessive force experienced by the shaft.

(114) 18. The surgical instrument of claim **16**, wherein: the plurality of sensors comprises a plurality of Hall effect sensors positioned at the mechanical junction on an outer surface of the shaft at a plurality of points around the circumference of the shaft; the shaft deflection detection system further includes a plurality of magnets positioned at the mechanical junction at a plurality of points on an inner surface of the handle portion coupled with the shaft such that respective magnets among the plurality of magnets are positioned across from respective sensors among the plurality of Hall effect sensors, and a plurality of springs positioned in spaces between respective sensors among the plurality of Hall effect sensors, the springs being coupled between the outer surface of the shaft and the inner surface of the handle portion coupled with the shaft such that the springs compress or decompress with movement of the shaft relative to the handle portion coupled with the shaft, wherein the springs are characterized by a predetermined spring force function; and the controller is configured to determine respective forces experienced along the shaft at the plurality of points around the circumference of the shaft based on i) the signals indicative of the movement of the shaft received from respective sensors among the plurality of Hall effect sensors and ii) the predetermined spring force function.

(115) 19. A method for monitoring force experienced by a shaft of a surgical instrument as the shaft is maneuvered inside a body of a patient, the method comprising: receiving, at a controller of the surgical instrument, a plurality of signals from a plurality of sensors positioned at one or both of i) a first mechanical junction between the shaft and an actuator coupled with the shaft or ii) a second mechanical junction between the shaft and an end effector coupled with the shaft, the plurality of sensors distributed among a plurality of points around a circumference of the shaft at the one or both of the first mechanical junction and the second mechanical junction; detecting, by the controller based on the plurality of signals, that force experienced by the shaft meets a predetermined excessive force criterion as the shaft is maneuvered inside the body of the patient; and in response to detecting that the force experienced by the shaft meets the predetermined excessive force criterion, generating, by the controller, an alert and providing the alert to a user to inform the user that excessive force is experienced by the shaft.

(116) 20. The method of claim **19**, wherein detecting when the force experienced by the shaft meets the predetermined excessive force criterion includes: determining, based on respective signals generated by respective sensors among the plurality of sensors, respective forces experienced by the shaft at a plurality of points around the circumference of the shaft; comparing the respective forces experienced by the shaft at the plurality of points around the circumference of the shaft with a predetermined threshold; and detecting that the force experienced by the shaft meets the predetermined excessive force criterion in response to determining that one or more forces, among the respective forces, exceeds the predetermined threshold.

IV. Miscellaneous

(117) It should be understood that any one or more of the teachings, expressions, embodiments, examples, etc. described herein may be combined with any one or more of the other teachings, expressions, embodiments, examples, etc. that are described herein. The above-described teachings,

expressions, embodiments, examples, etc. should therefore not be viewed in isolation relative to each other. Various suitable ways in which the teachings herein may be combined will be readily apparent to those of ordinary skill in the art in view of the teachings herein. Such modifications and variations are intended to be included within the scope of the claims.

(118) Furthermore, any one or more of the teachings herein may be combined with any one or more of the teachings disclosed in U.S. Pat. App. No. 63/467,622, entitled “Surgical Stapler Cartridge Having Intermediate Raised Tissue Engagement Protrusions,” filed on May 19, 2023; U.S. Pat. App. No. 63/467,623, entitled “Surgical Stapler Cartridge Having Tissue Engagement Protrusions with Enlarged Engagement Surface,” filed on May 19, 2023; U.S. Pat. App. No. 63/467,648, entitled “Surgical Stapler Cartridge Having Raised Surface to Promote Buttress Adhesion,” filed on May 19, 2023; U.S. Pat. App. No. 63/467,469, entitled “Surgical Stapler Cartridge Having Cartridge Retention Features,” filed on May 19, 2023; U.S. Pat. App. No. 63/459,739, entitled “Surgical Stapler Anvil Having Staple Forming Pockets with Laterally Varying Orientations,” filed on May 19, 2023; U.S. Pat. App. No. 63/467,656, entitled “Surgical Stapler With Discretely Positionable Distal Tip,” filed on May 19, 2023; and/or U.S. Pat. App. No. 63/467,615, entitled “Incompatible Staple Cartridge Use Prevention Features for Surgical Stapler,” filed on May 19, 2023.

(119) Additionally, any one or more of the teachings herein may be combined with any one or more of the teachings disclosed in U.S. Pat. App. No. 63/459,739, entitled “Surgical Stapler Anvil Having Staple Forming Pockets with Laterally Varying Orientations,” filed on Apr. 17, 2023. The disclosure of each of these U.S. patent applications is incorporated by reference herein in its entirety.

(120) Additionally, any one or more of the teachings herein may be combined with any one or more of the teachings disclosed in U.S. Pat. No. 11,304,697, entitled “Surgical Stapler with Deflectable Distal Tip,” issued Apr. 19, 2022, the disclosure of which is incorporated by reference herein, in its entirety; U.S. Pat. No. 11,317,912, entitled “Surgical Stapler with Rotatable Distal Tip,” issued May 3, 2022, the disclosure of which is incorporated by reference herein, in its entirety; and/or U.S. Pat. No. 11,439,391, entitled “Surgical Stapler with Toggling Distal Tip,” issued Sep. 13, 2022, the disclosure of which is incorporated by reference herein, in its entirety.

(121) It should be appreciated that any patent, publication, or other disclosure material, in whole or in part, that is said to be incorporated by reference herein is incorporated herein only to the extent that the incorporated material does not conflict with existing definitions, statements, or other disclosure material set forth in this disclosure. As such, and to the extent necessary, the disclosure as explicitly set forth herein supersedes any conflicting material incorporated herein by reference. Any material, or portion thereof, that is said to be incorporated by reference herein, but which conflicts with existing definitions, statements, or other disclosure material set forth herein will only be incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material.

(122) Versions of the devices described above may have application in conventional medical treatments and procedures conducted by a medical professional, as well as application in robotic-assisted medical treatments and procedures. By way of example only, various teachings herein may be readily incorporated into a robotic surgical system such as those made available by Auris Health, Inc. of Redwood City, CA or by Intuitive Surgical, Inc., of Sunnyvale, California.

(123) Versions of the devices described above may be designed to be disposed of after a single use, or they can be designed to be used multiple times. Versions may, in either or both cases, be reconditioned for reuse after at least one use. Reconditioning may include any combination of the steps of disassembly of the device, followed by cleaning or replacement of particular pieces, and subsequent reassembly. In particular, some versions of the device may be disassembled, and any number of the particular pieces or parts of the device may be selectively replaced or removed in any combination. Upon cleaning and/or replacement of particular parts, some versions of the

device may be reassembled for subsequent use either at a reconditioning facility, or by a user immediately prior to a procedure. Those skilled in the art will appreciate that reconditioning of a device may utilize a variety of techniques for disassembly, cleaning/replacement, and reassembly. Use of such techniques, and the resulting reconditioned device, are all within the scope of the present application.
(124) By way of example only, versions described herein may be sterilized before and/or after a procedure. In one sterilization technique, the device is placed in a closed and sealed container, such as a plastic or TYVEK bag. The container and device may then be placed in a field of radiation that can penetrate the container, such as gamma radiation, x-rays, or high-energy electrons. The radiation may kill bacteria on the device and in the container. The sterilized device may then be stored in the sterile container for later use. A device may also be sterilized using any other technique known in the art, including but not limited to beta or gamma radiation, ethylene oxide, or steam.
(125) Having shown and described various embodiments of the present invention, further adaptations of the methods and systems described herein may be accomplished by appropriate modifications by one of ordinary skill in the art without departing from the scope of the present invention. Several of such potential modifications have been mentioned, and others will be apparent to those skilled in the art. For instance, the examples, embodiments, geometrics, materials, dimensions, ratios, steps, and the like discussed above are illustrative and are not required. Accordingly, the scope of the present invention should be considered in terms of the following claims and is understood not to be limited to the details of structure and operation shown and described in the specification and drawings.

Claims

1. A surgical instrument, comprising: a shaft configured to couple with an actuator at a first mechanical junction between the shaft and the actuator; an end effector coupled with the shaft at a second mechanical junction between the shaft and the end effector, wherein i) the end effector is configured to clamp, staple, and cut tissue and ii) the actuator is configured to operate the end effector via the shaft, and wherein the shaft is one or both i) movable relative to the actuator at the first mechanical junction between the shaft and the actuator or ii) movable relative to the end effector at the second mechanical junction between the shaft and the end effector; and a shaft deflection detection system including one or more sensors positioned at one or both of the first mechanical junction or the second mechanical junction, wherein the one or more sensors are configured to generate signals indicative of movement of the shaft relative to one or both of the actuator or the end effector, wherein the movement of the shaft is caused by an external force experienced by the shaft as the shaft of the surgical instrument is maneuvered inside a body of a patient.
2. The surgical instrument of claim 1, wherein: the end effector comprises a circular stapler; and the one or more sensors are configured to detect movement of the shaft relative to the one or both of the actuator or the end effector as the shaft of the surgical instrument is maneuvered inside an anatomical lumen in the body of the patient.
3. The surgical instrument of claim 1, wherein the one or more sensors comprise a plurality of sensors distributed among a plurality of points around a circumference of the shaft at one or both of i) the first mechanical junction between the shaft and the actuator or ii) the second mechanical junction between the shaft and the end effector.
4. The surgical instrument of claim 3, further comprising a controller communicatively coupled to the shaft deflection detection system, the controller configured to: receive respective signals generated by respective sensors among the plurality of sensors; determine, based on the respective signals generated by respective sensors among the plurality of sensors, respective forces

experienced by the shaft at respective points among the plurality of points around the circumference of the shaft; compare the respective forces experienced by the shaft at the respective points to a predetermined threshold; and determine that excessive force is experienced at one or more points around the circumference of the shaft in response to determining that one or more forces, among the respective forces, exceeds the predetermined threshold.
5. The surgical instrument of claim 4, wherein the controller is further configured to, in response to determining that excessive force is experienced by the shaft at one or more points around the circumference of the shaft, generate an alert and provide the alert to a user of the surgical instrument to inform the user that excessive force is experienced by the shaft.
6. The surgical instrument of claim 5, wherein the alert is a haptic buzz provided to the user via a handle portion of the surgical instrument.
7. The surgical instrument of claim 5, wherein the controller is further configured to determine, based on the respective signals generated by respective sensors among the plurality of sensors, a magnitude and a direction of the external force experienced by the shaft.
8. The surgical instrument of claim 7, wherein the controller is further configured to: determine, based on one or both of the magnitude or the direction of the external force, a corrective action to mitigate the excessive force experienced by the shaft; and provide an indication of the corrective action to the user to enable the user to mitigate the excessive force experienced by the shaft.
9. The surgical instrument of claim 7, wherein the controller is further configured to: generate real-time graphics illustrating one or both of the direction or the magnitude of the external force experienced by the shaft as the user is maneuvering the shaft of the surgical instrument inside the body of the patient; and cause the real-time graphics to be displayed to the user.
10. The surgical instrument of claim 4, wherein: the plurality of sensors comprises a plurality of Hall effect sensors positioned at the first mechanical junction on an outer surface of the shaft at the plurality of points around the circumference of the shaft; and the shaft deflection detection system further includes a plurality of magnets positioned at the first mechanical junction at a plurality of points on an inner surface of the actuator coupled with the shaft such that respective magnets among the plurality of magnets are positioned across from respective sensors among the plurality of Hall effect sensors, and a plurality of springs positioned in spaces between respective sensors among the plurality of Hall effect sensors, the springs being coupled between the outer surface of the shaft and the inner surface of the actuator coupled with the shaft such that the springs compress or decompress with movement of the shaft relative to the actuator coupled with the shaft, wherein the springs are characterized by a predetermined spring force function.
11. The surgical instrument of claim 10, wherein the controller is configured to determine respective forces experienced along the shaft at the plurality of points around the circumference of the shaft based on i) the signals indicative of the movement of the shaft received from respective sensors among the plurality of Hall effect sensors and ii) the predetermined spring force function.
12. The surgical instrument of claim 1, wherein the actuator comprises a manually operated handle portion coupled with the shaft.
13. The surgical instrument of claim 1, wherein the actuator comprises a robotic arm attached to the shaft.
14. A surgical instrument, comprising: a shaft; a handle portion coupled with the shaft, wherein the shaft is movable relative to the handle portion at a mechanical junction between the handle portion and the shaft; and a shaft deflection detection system including a plurality of sensors positioned at the mechanical junction between the handle portion and the shaft, wherein sensors among the plurality of sensors are distributed at a plurality of points around a circumference of the shaft, and wherein the sensors among the plurality of sensors are configured to generate signals indicative of external forces experienced along the shaft at the plurality of points around the circumference of the shaft as the shaft of the surgical instrument is maneuvered inside a body of a patient.
15. The surgical instrument of claim 14, wherein: the surgical instrument further comprises a

circular stapler end effector coupled with the shaft; and the plurality of sensors is configured to detect movement of the shaft relative to the handle portion as the shaft of the surgical instrument is maneuvered inside an anatomical lumen in the body of the patient.

16. The surgical instrument of claim 14, further comprising a controller communicatively coupled with the shaft deflection detection system, the controller configured to: receive the signals generated by the sensors among the plurality of sensors; detect, based on the signals generated by the sensors among the plurality of sensors, when excessive force is experienced by the shaft at one or more points among the plurality of points around the circumference of the shaft; and in response to detecting that excessive force is experienced by the shaft at one or more points around the circumference of the shaft, generate an alert and provide the alert to a user of the surgical instrument to inform the user that excessive force is experienced by the shaft.

17. The surgical instrument of claim 16, wherein the controller is further configured to: determine, based on the signals generated by the sensors among the plurality of sensors, a magnitude and a direction of the excessive force experienced by the shaft; determine, based on one or both of the magnitude and the direction of the external force, a corrective action to mitigate the excessive force experienced by the shaft; and provide an indication of the corrective action to the user to enable the user to mitigate the excessive force experienced by the shaft.

18. The surgical instrument of claim 16, wherein: the plurality of sensors comprises a plurality of Hall effect sensors positioned at the mechanical junction on an outer surface of the shaft at a plurality of points around the circumference of the shaft; the shaft deflection detection system further includes a plurality of magnets positioned at the mechanical junction at a plurality of points on an inner surface of the handle portion coupled with the shaft such that respective magnets among the plurality of magnets are positioned across from respective sensors among the plurality of Hall effect sensors, and a plurality of springs positioned in spaces between respective sensors among the plurality of Hall effect sensors, the springs being coupled between the outer surface of the shaft and the inner surface of the handle portion coupled with the shaft such that the springs compress or decompress with movement of the shaft relative to the handle portion coupled with the shaft, wherein the springs are characterized by a predetermined spring force function; and the controller is configured to determine respective forces experienced along the shaft at the plurality of points around the circumference of the shaft based on i) the signals indicative of the movement of the shaft received from respective sensors among the plurality of Hall effect sensors and ii) the predetermined spring force function.

19. A method for monitoring force experienced by a shaft of a surgical instrument as the shaft is maneuvered inside a body of a patient, the method comprising: receiving, at a controller of the surgical instrument, a plurality of signals from a plurality of sensors positioned at one or both of i) a first mechanical junction between the shaft and an actuator coupled with the shaft or ii) a second mechanical junction between the shaft and an end effector coupled with the shaft, the plurality of sensors distributed among a plurality of points around a circumference of the shaft at the one or both of the first mechanical junction and the second mechanical junction; detecting, by the controller based on the plurality of signals, that force experienced by the shaft meets a predetermined excessive force criterion as the shaft is maneuvered inside the body of the patient; and in response to detecting that the force experienced by the shaft meets the predetermined excessive force criterion, generating, by the controller, an alert and providing the alert to a user to inform the user that excessive force is experienced by the shaft.

20. The method of claim 19, wherein detecting when the force experienced by the shaft meets the predetermined excessive force criterion includes: determining, based on respective signals generated by respective sensors among the plurality of sensors, respective forces experienced by the shaft at a plurality of points around the circumference of the shaft; comparing the respective forces experienced by the shaft at the plurality of points around the circumference of the shaft with a predetermined threshold; and detecting that the force experienced by the shaft meets the

predetermined excessive force criterion in response to determining that one or more forces, among the respective forces, exceeds the predetermined threshold.