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(54) **SURGICAL SYSTEMS AND METHODS FOR IDENTIFYING TOOLS GUIDED BY SURGICAL ROBOTS**

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  (Continued)

(52) **U.S. Cl.**
  CPC *A61B 34/20* (2016.02); *A61B 34/10* (2016.02); *A61B 34/30* (2016.02); *A61B 90/361* (2016.02);
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(58) **Field of Classification Search**
  CPC A61B 34/20; A61B 34/10; A61B 34/30; A61B 90/361; A61B 90/90;
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(57)   **ABSTRACT**

Systems and methods for assisting users with accurate tool identification. A tool includes a tool feature, and a navigation system includes a localizer to detect a position of the tool feature. A memory stores identification data associated with a plurality of tools. Controller(s) is/are coupled to the navigation system, the memory and the display. The controller(s) receive, from the localizer, the detected position of the tool feature and compare the detected position of the tool feature with the identification data stored in the memory to determine an identity of the tool. The controller(s) present, on a display, the identity of the tool and an identity of at least one other tool.

20 Claims, 26 Drawing Sheets

Related U.S. Application Data

(60) Provisional application No. 62/631,995, filed on Feb. 19, 2018.

(51) **Int. Cl.**

A61B 34/30	(2016.01)
A61B 90/00	(2016.01)
A61B 90/90	(2016.01)
A61F 2/34	(2006.01)
A61B 34/00	(2016.01)
A61F 2/46	(2006.01)

(52) **U.S. Cl.**

CPC *A61B 90/90* (2016.02); *A61F 2/34* (2013.01); *A61B 2034/2051* (2016.02); *A61B 2034/2055* (2016.02); *A61B 2034/2057* (2016.02); *A61B 2034/2063* (2016.02); *A61B 2034/2068* (2016.02); *A61B 2034/207* (2016.02); *A61B 2034/2074* (2016.02); *A61B 2034/252* (2016.02); *A61B 2034/256* (2016.02); *A61F 2/4607* (2013.01); *A61F 2002/4632* (2013.01)

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CPC A61B 2034/2051; A61B 2034/2055; A61B 2034/2057; A61B 2034/2063; A61B 2034/2068; A61B 2034/207; A61B 2034/2074; A61B 2034/252; A61B 2034/256; A61F 2/34; A61F 2/4607; A61F 2002/4632

See application file for complete search history.

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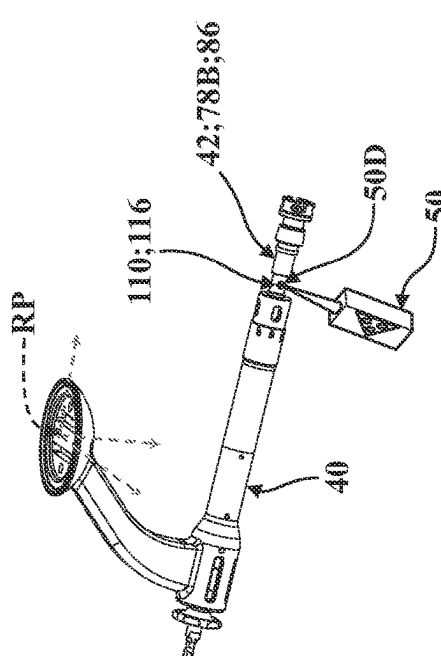
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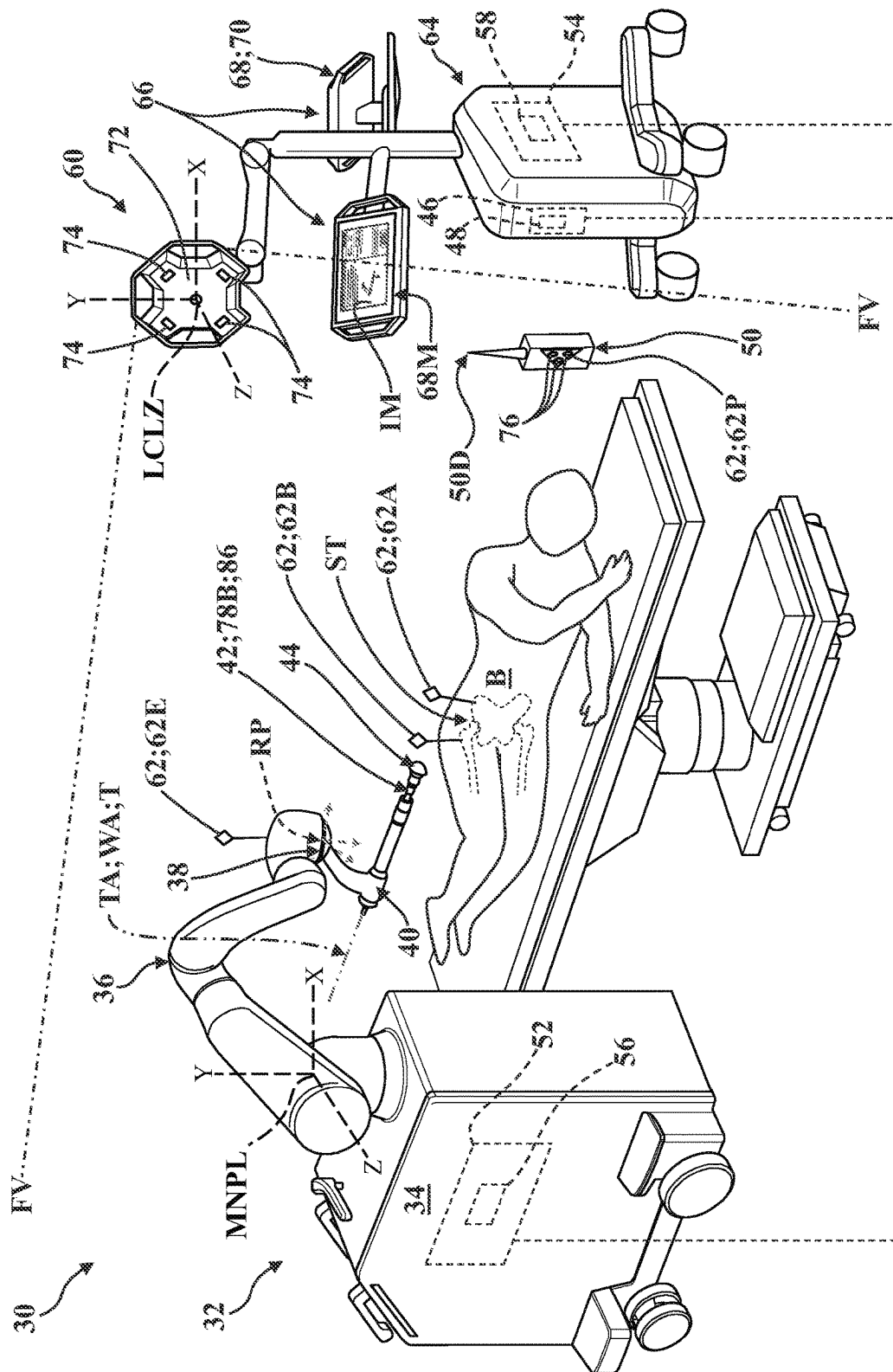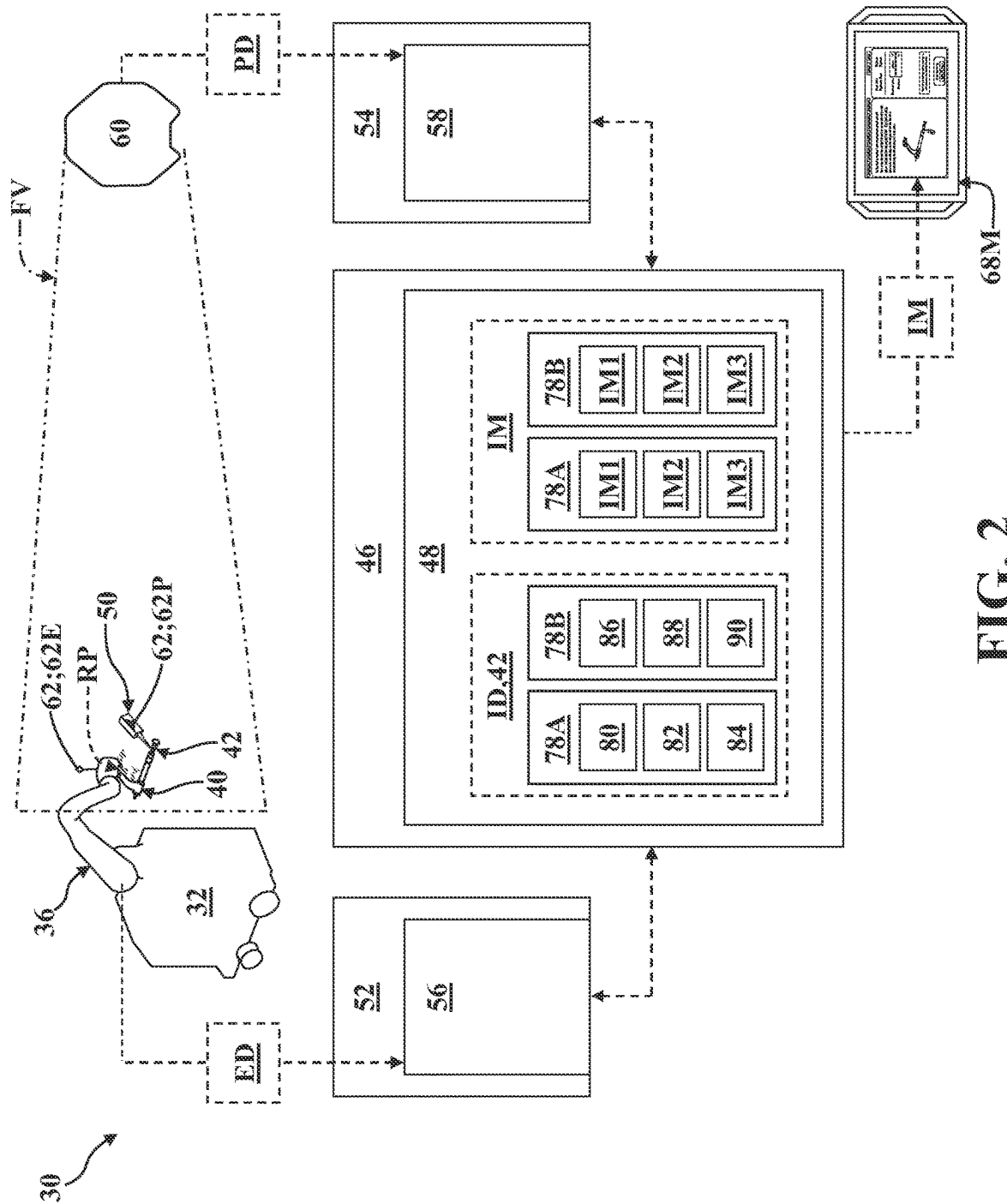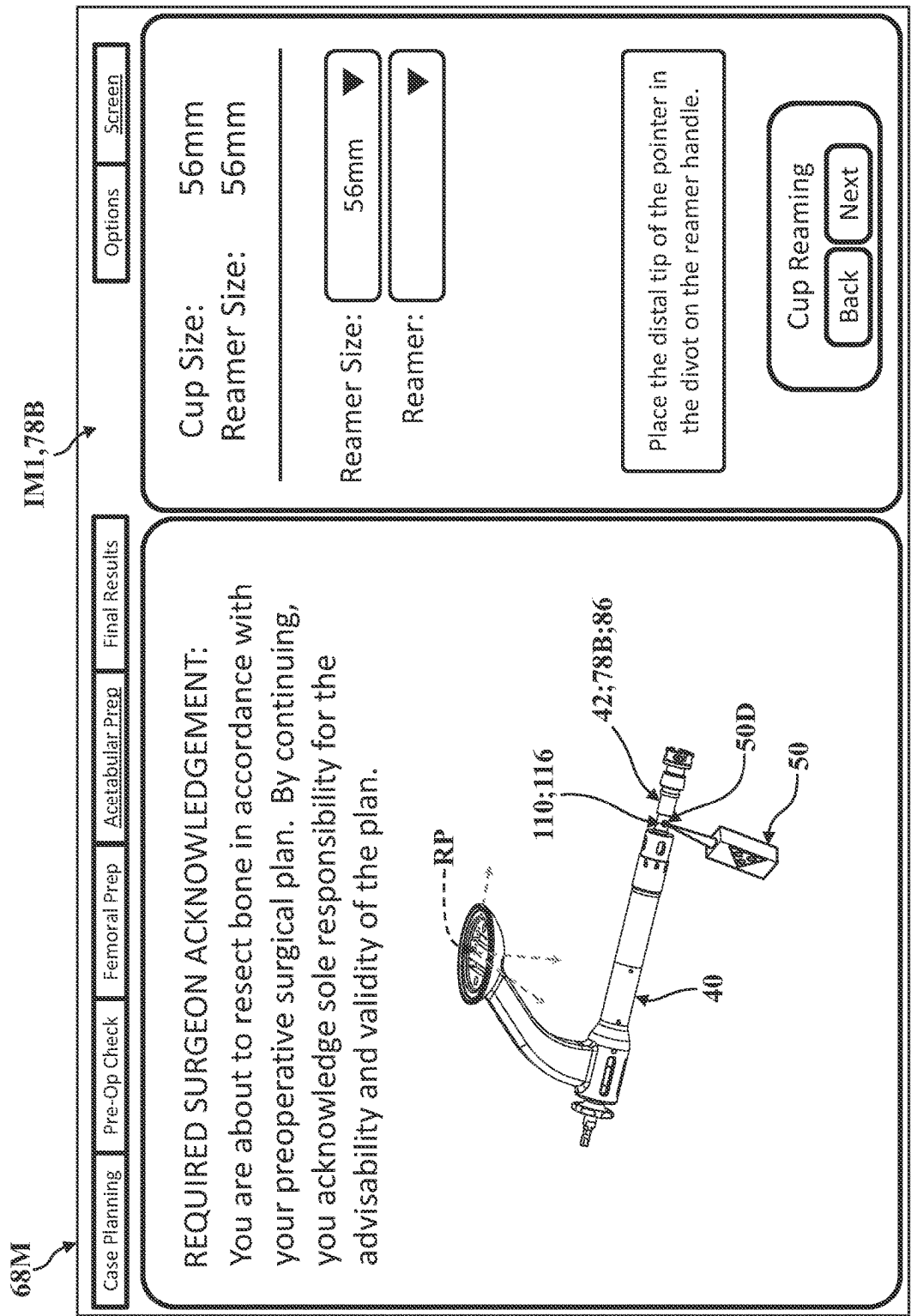
FIG. 1

FIG. 2

IM1,78B

68M

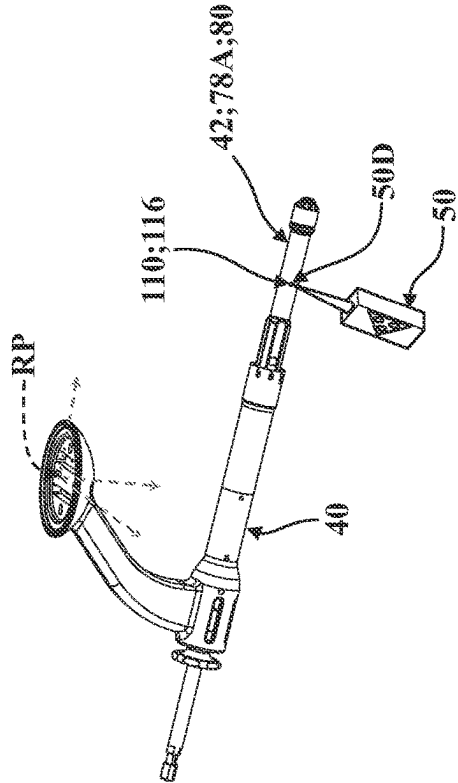| Case Planning | Pre-Op Check | Femoral Prep | Acetabular Prep | Final Results |

Options   Screen

REQUIRED SURGEON ACKNOWLEDGEMENT:

You are about to resect bone in accordance with your preoperative surgical plan. By continuing, you acknowledge sole responsibility for the advisability and validity of the plan.

Cup Size: 56mm

Reamer Size: 56mm

Reamer Size: 56mm ▶

Reamer: ▶

Place the distal tip of the pointer in the divot on the reamer handle.

Cup Reaming

Back   Next

RP

110;116

42;78B;86

50D

50

40

FIG. 3A

IM2,78B

68M

| Case Planning | Pre-Op Check | Femoral Prep | Acetabular Prep | Final Results | | Options | Screen |

REQUIRED SURGEON ACKNOWLEDGEMENT:

You are about to resect bone in accordance with your preoperative surgical plan. By continuing, you acknowledge sole responsibility for the advisability and validity of the plan.
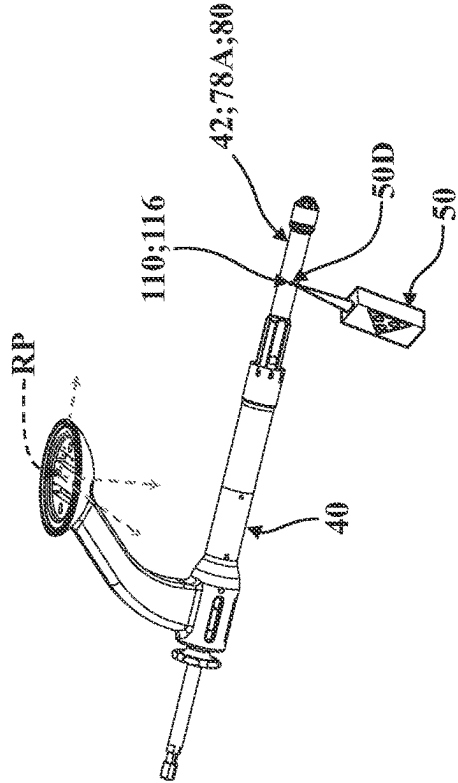
Cup Size: 56mm
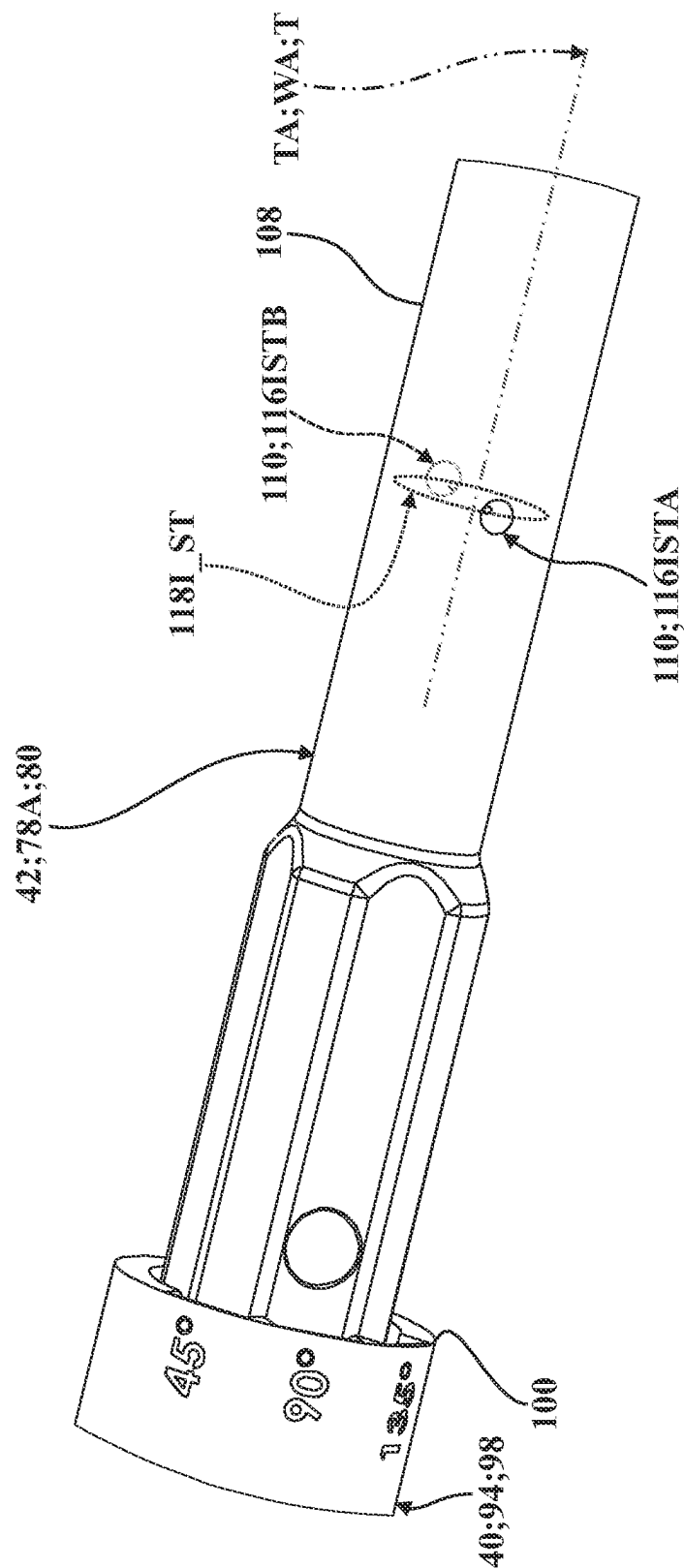
Reamer Size: 56mm

Reamer Size: 56mm ▶

Reamer: Straight ▶

Place the distal tip of the pointer in the divot on the reamer handle.

Cup Reaming

Back   Next

RP

110;116

42;78B;86

50D

50

40

FIG. 3B

IM3,78B

Options | Screen

Cup Size: 56mm
Reamer Size: 56mm
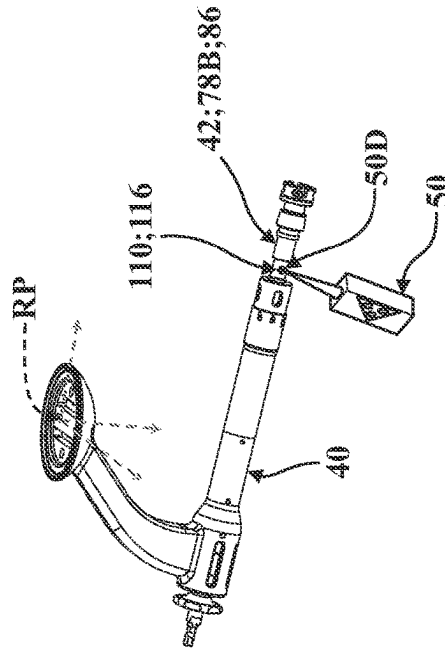
Reamer Size: [56mm ▶]

Reamer: [Straight ▶
               1st Option
               2nd Option 45°
               2nd Option 90°
               2nd Option 135°]

Place the distal tip of the pointer in
the divot on the reamer handle.

Cup Reaming
Back | Next

68M

Case Planning | Pre-Op Check | Femoral Prep | Acetabular Prep | Final Results

REQUIRED SURGEON ACKNOWLEDGEMENT:
You are about to resect bone in accordance with
your preoperative surgical plan. By continuing,
you acknowledge sole responsibility for the
advisability and validity of the plan.

RP

110;116

42;78B;86

50D

50

40

FIG. 3C

IM1,78A

68M

Case Planning | Pre-Op Check | Femoral Prep | Acetabular Prep | Final Results

Options | Screen

REQUIRED SURGEON ACKNOWLEDGEMENT:
You are about to impact the acetabular cup in accordance with your preoperative surgical plan. By continuing, you acknowledge sole responsibility for the advisability and validity of the plan.

Cup Size:　　64mm

Impactor Cup:　　64mm ▶

Impactor:　　▶

Place the distal tip of the pointer in the divot on the cup impactor.

Cup Impaction

Back | Next

RP

110;116

42;78A;80

50D

50

40

FIG. 4A

IM2,78A

68M

| Case Planning | Pre-Op Check | Femoral Prep | Acetabular Prep | Final Results |

Options | Screen

REQUIRED SURGEON ACKNOWLEDGEMENT:
You are about to impact the acetabular cup in accordance with your preoperative surgical plan. By continuing, you acknowledge sole responsibility for the advisability and validity of the plan.

Cup Size: 64mm

Impactor Cup: 64mm ▶

Impactor: Straight ▶

Place the distal tip of the pointer in the divot on the cup impactor.

Cup Impaction

Back   Next

RP

110;116

42;78A;80

50D

50

40

FIG. 4B

IM3,78A

68M

| Case Planning | Pre-Op Check | Femoral Prep | Acetabular Prep | Final Results | | Options | Screen |

REQUIRED SURGEON ACKNOWLEDGEMENT:
You are about to impact the acetabular cup in accordance with your preoperative surgical plan. By continuing, you acknowledge sole responsibility for the advisability and validity of the plan.

Cup Size: 64mm

Impactor Cup: 64mm ▶

Impactor: Straight ▶
     1st Option
     2nd Option

Place the distal tip of the pointer in the divot on the cup impactor.

Cup Impaction
Back   Next

RP

110;116

42;78A;80

50D

50

40

FIG. 4C
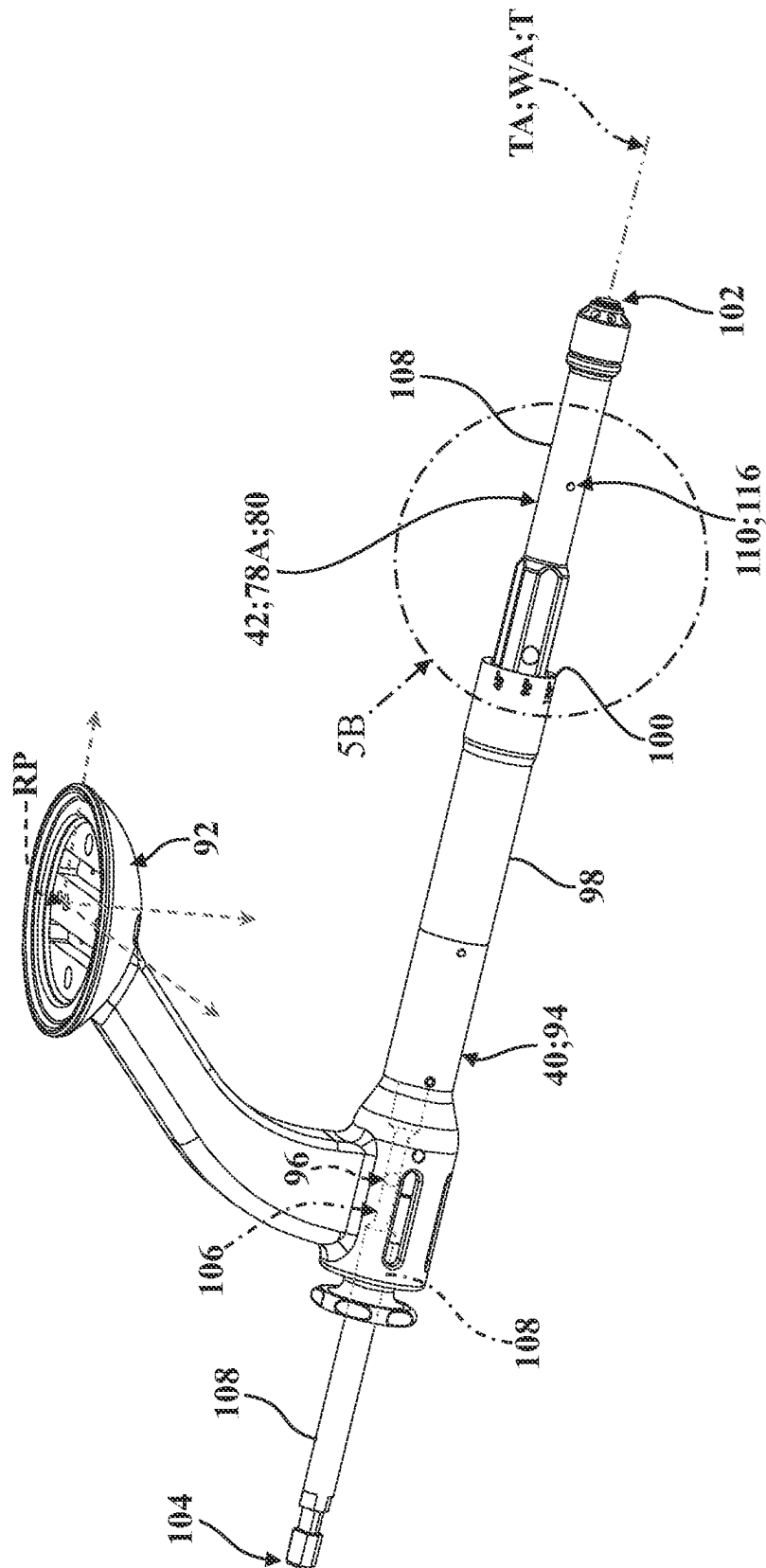
FIG. 5A

FIG. 5B

FIG. 6A

FIG. 6B
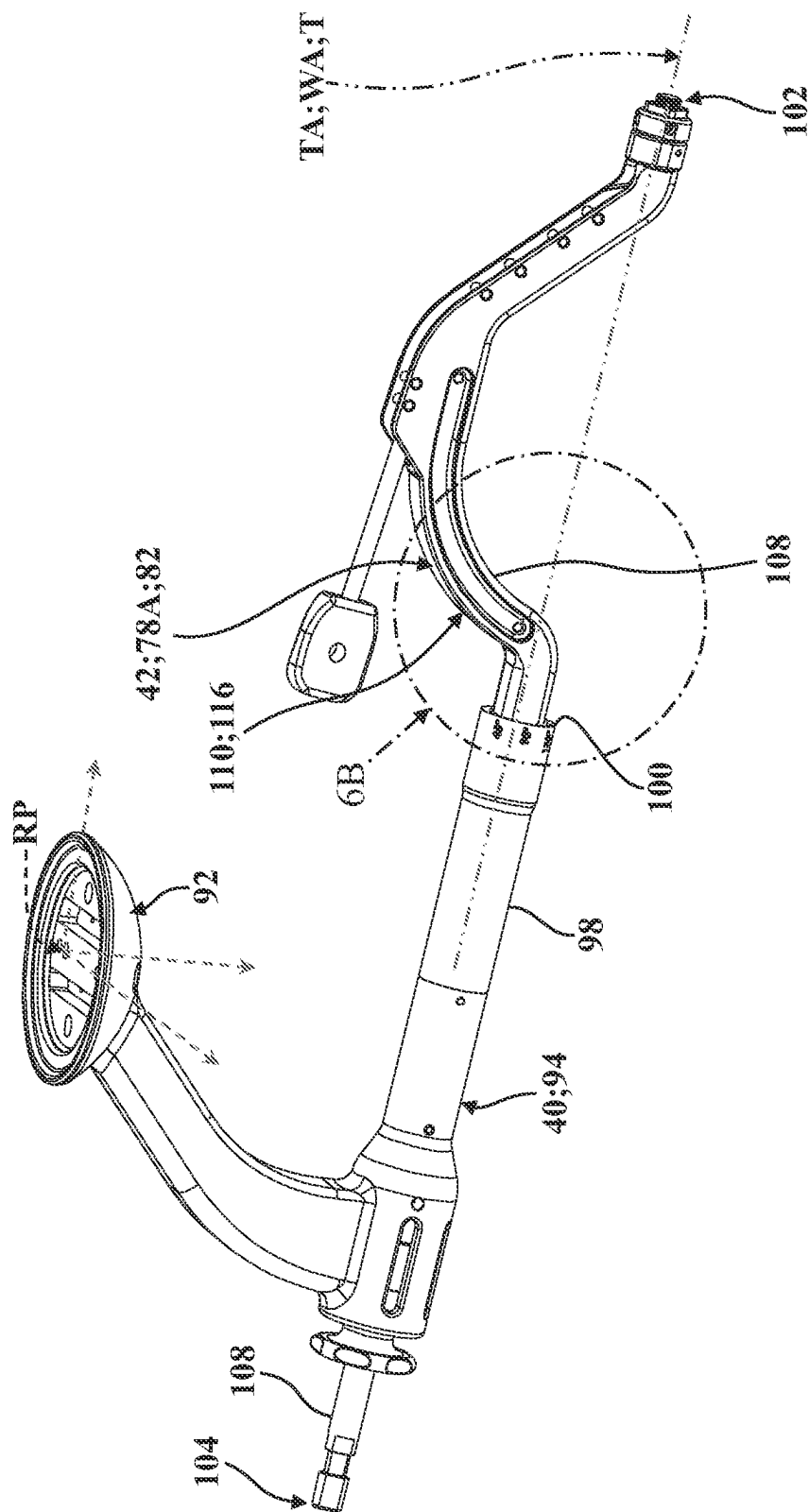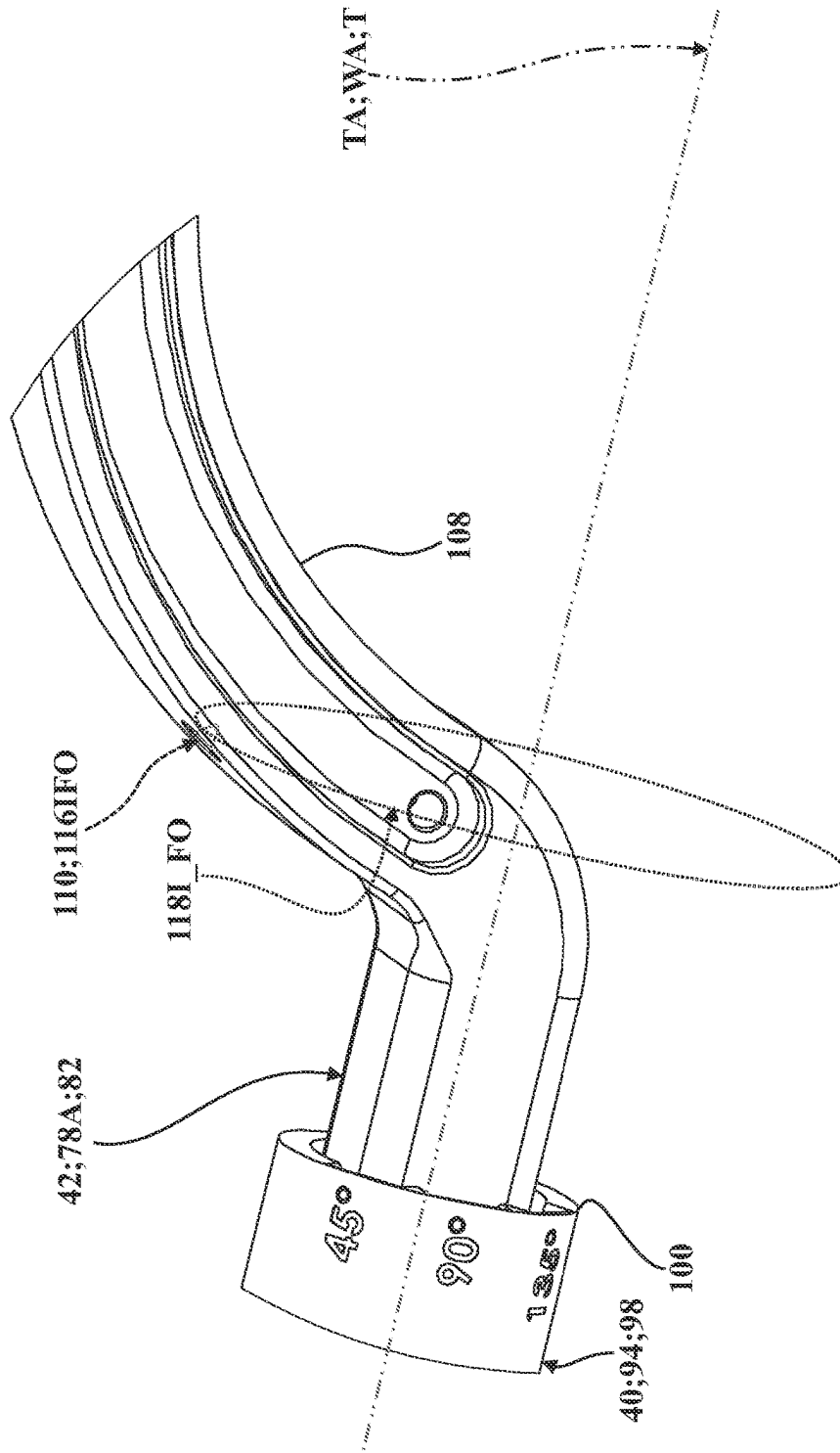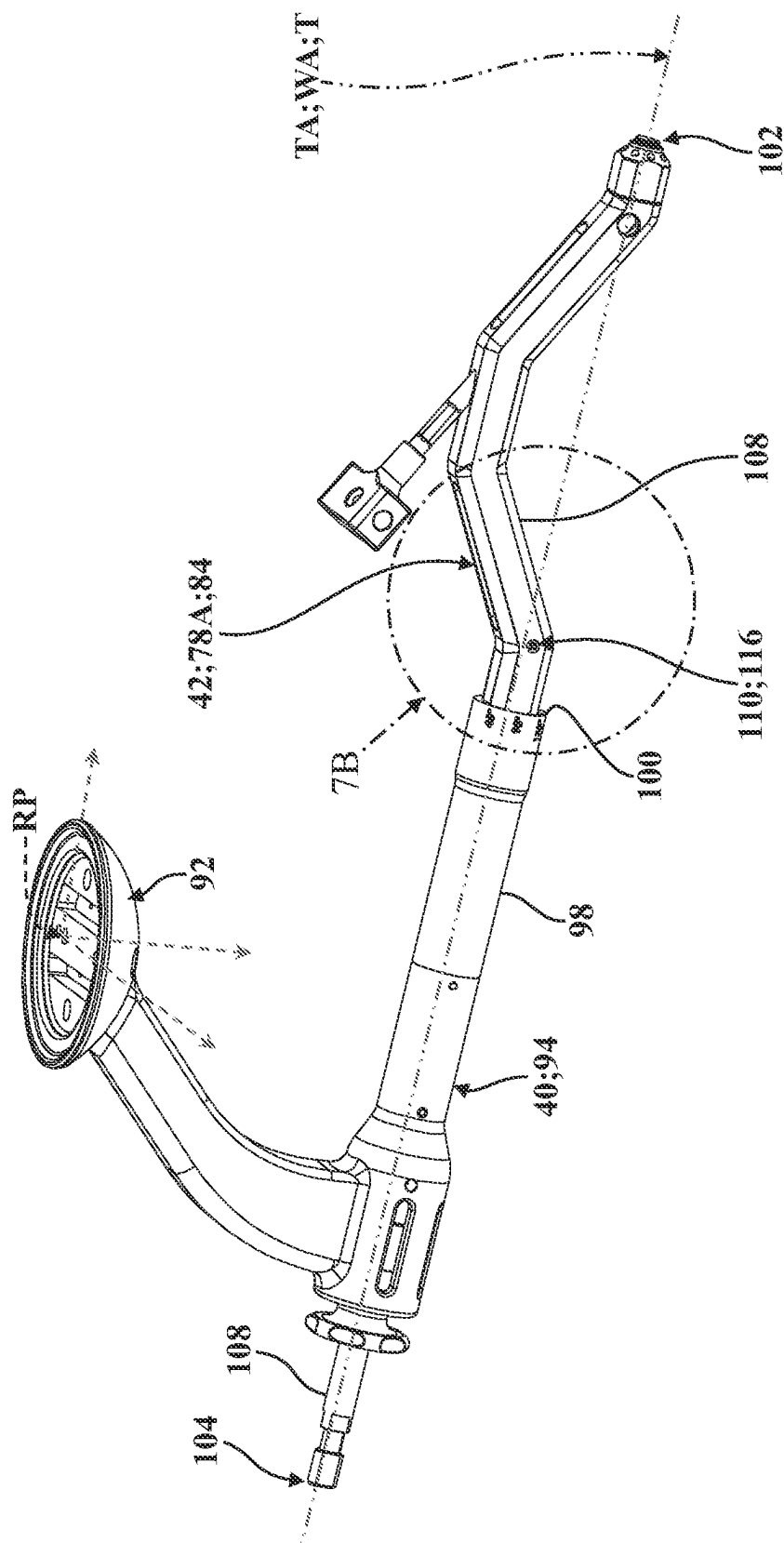
FIG. 7A
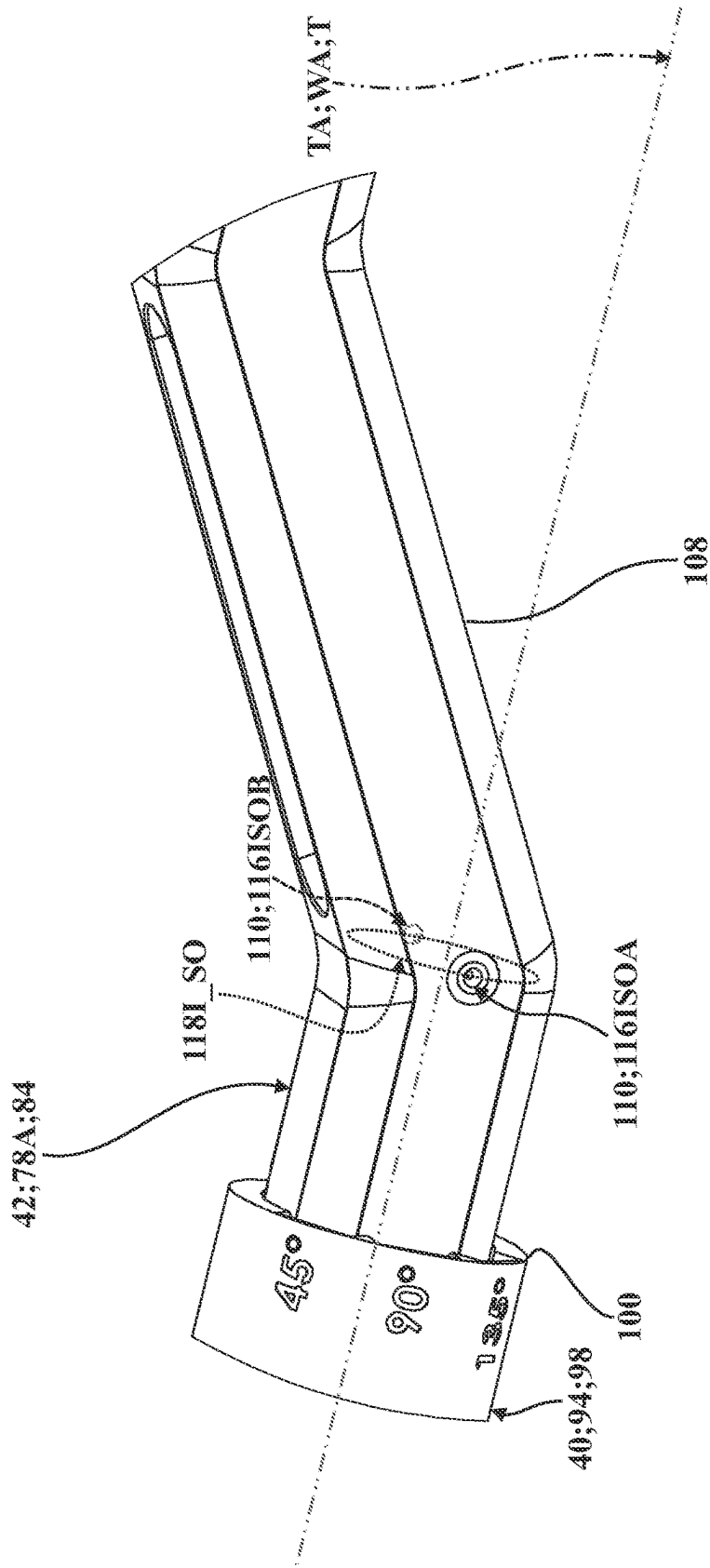
FIG. 7B
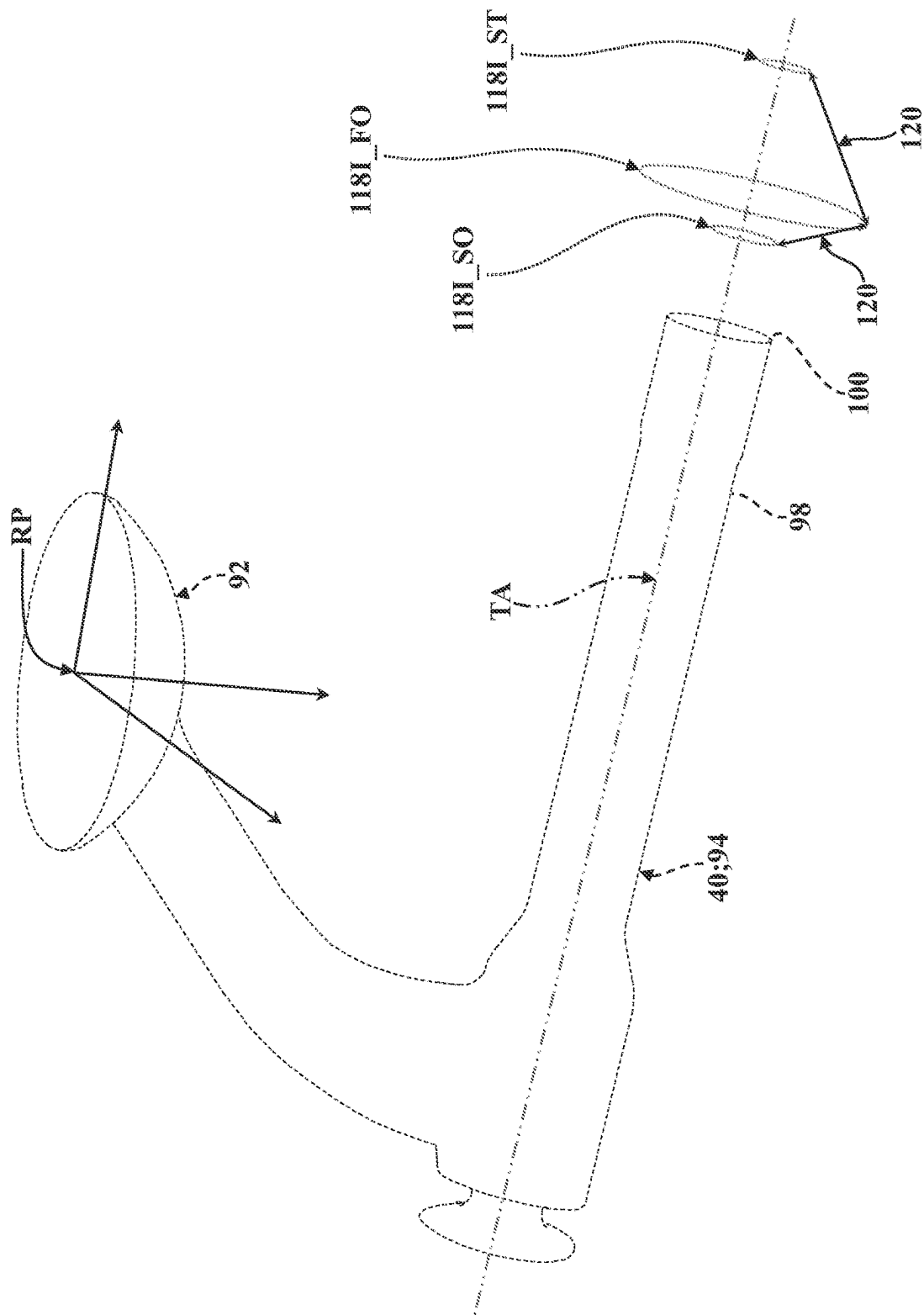
FIG. 8
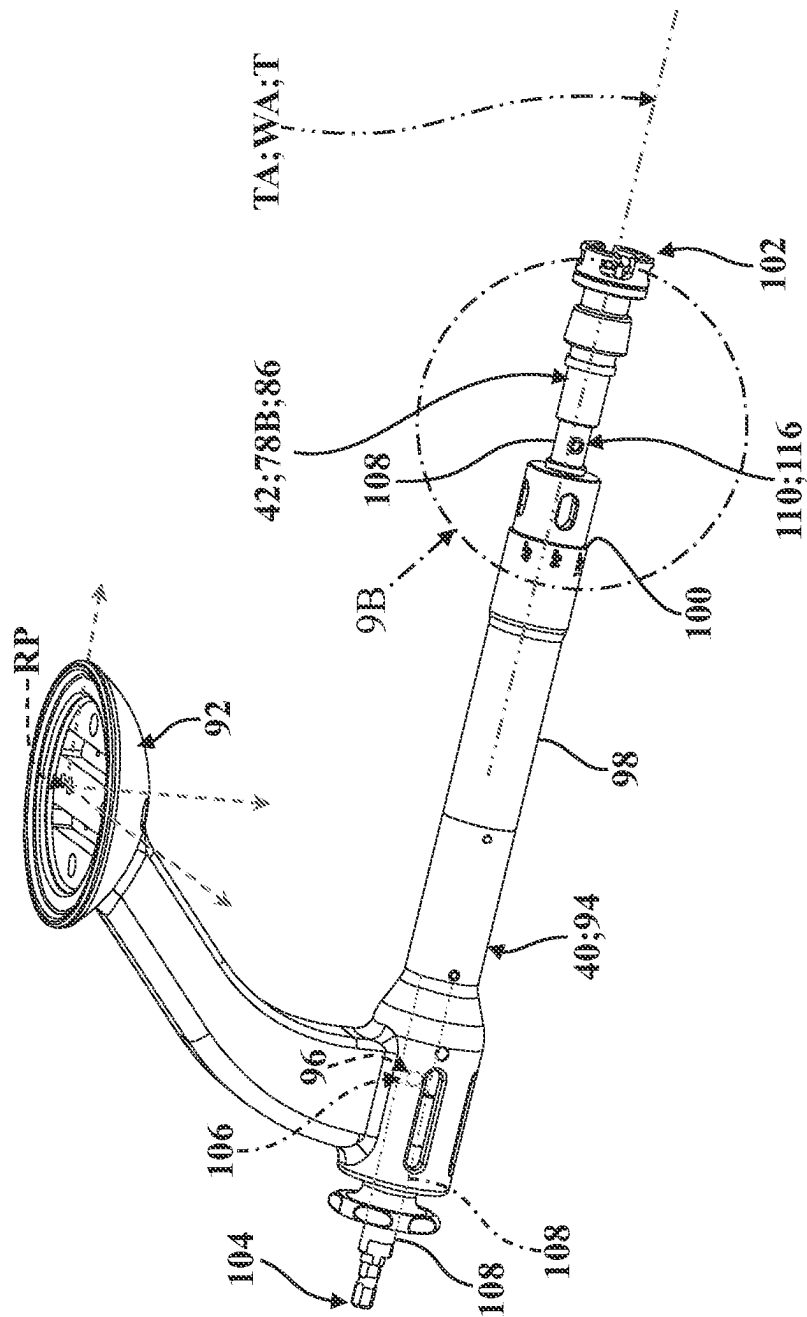
FIG. 9A
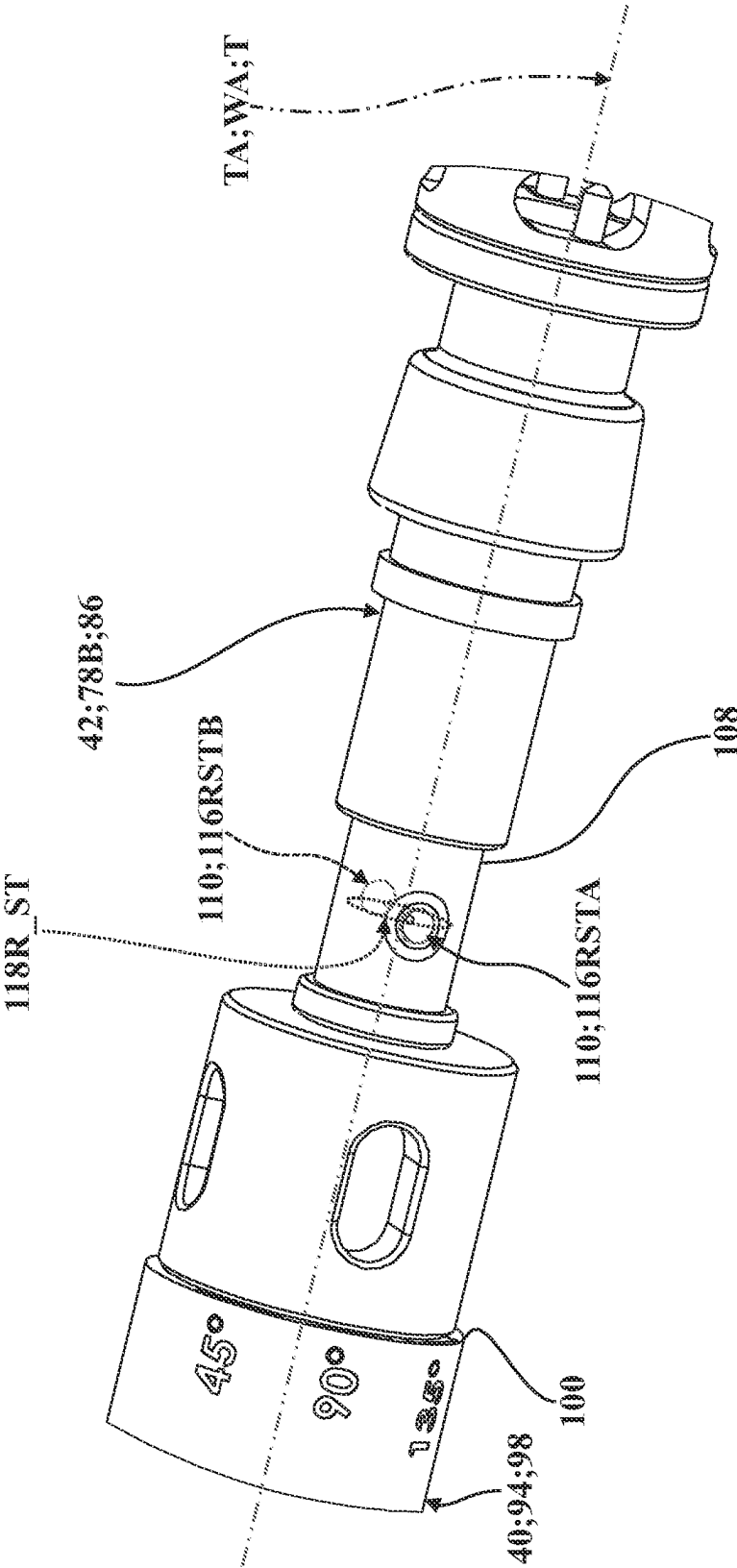
FIG. 9B
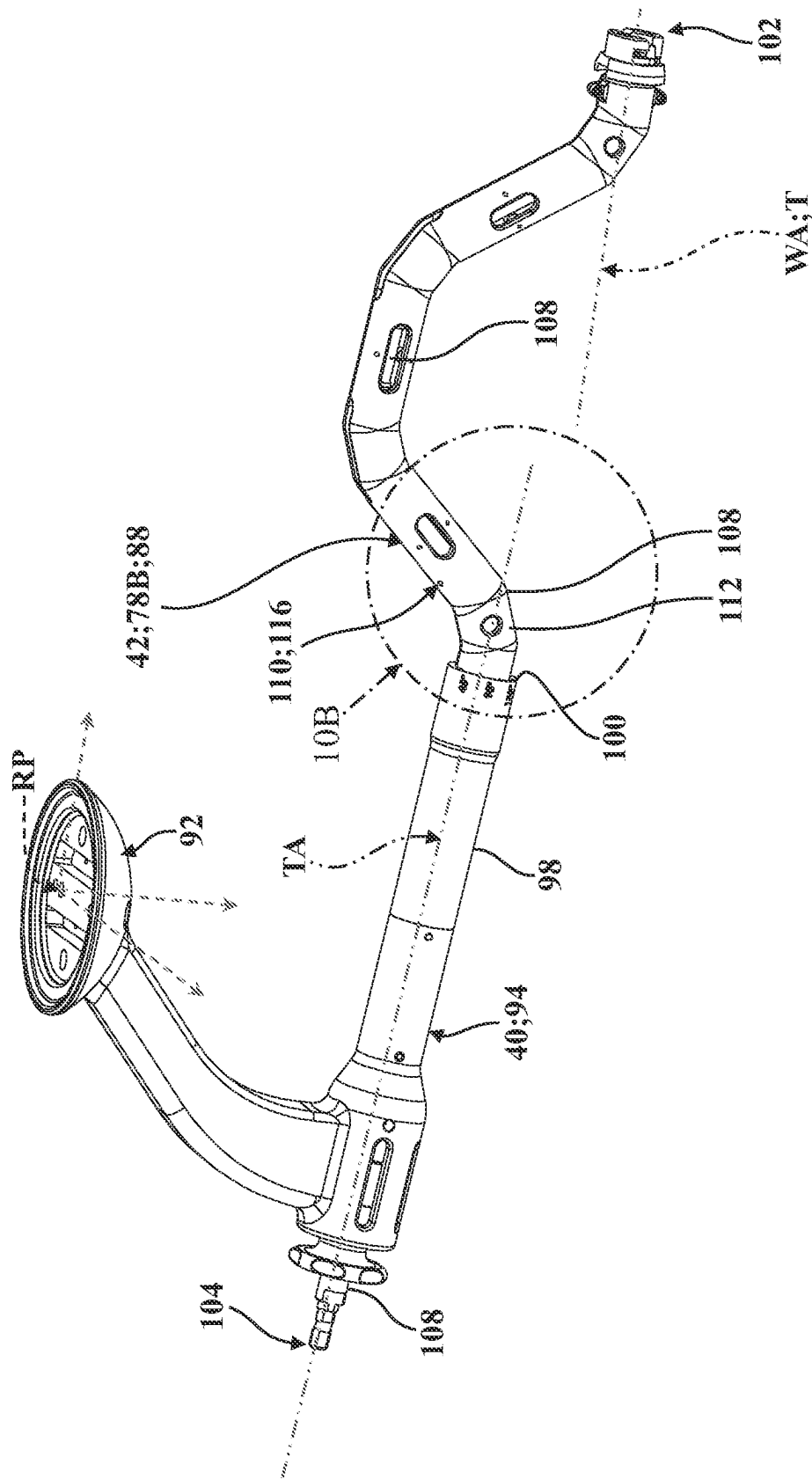
FIG. 10A
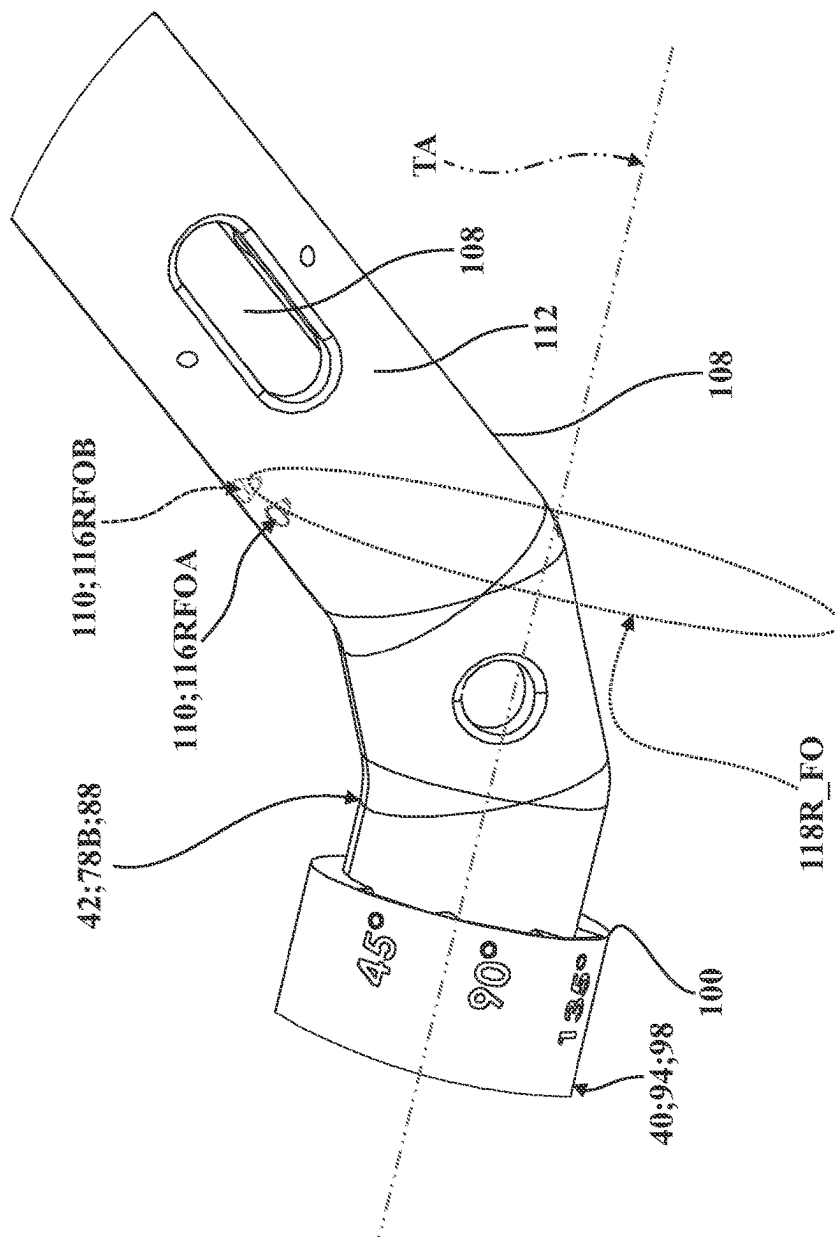
FIG. 10B
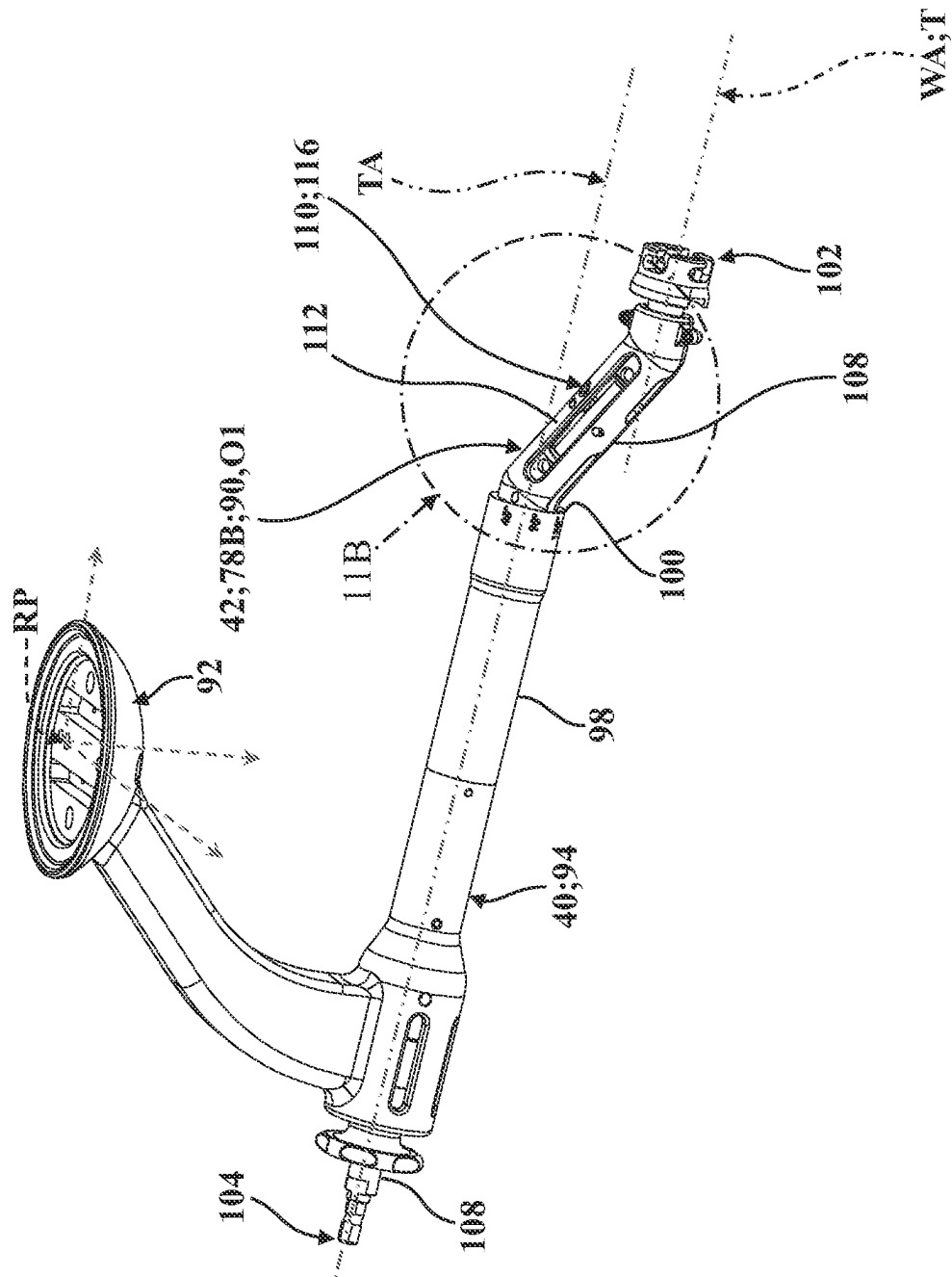
FIG. 11A

FIG. 11B
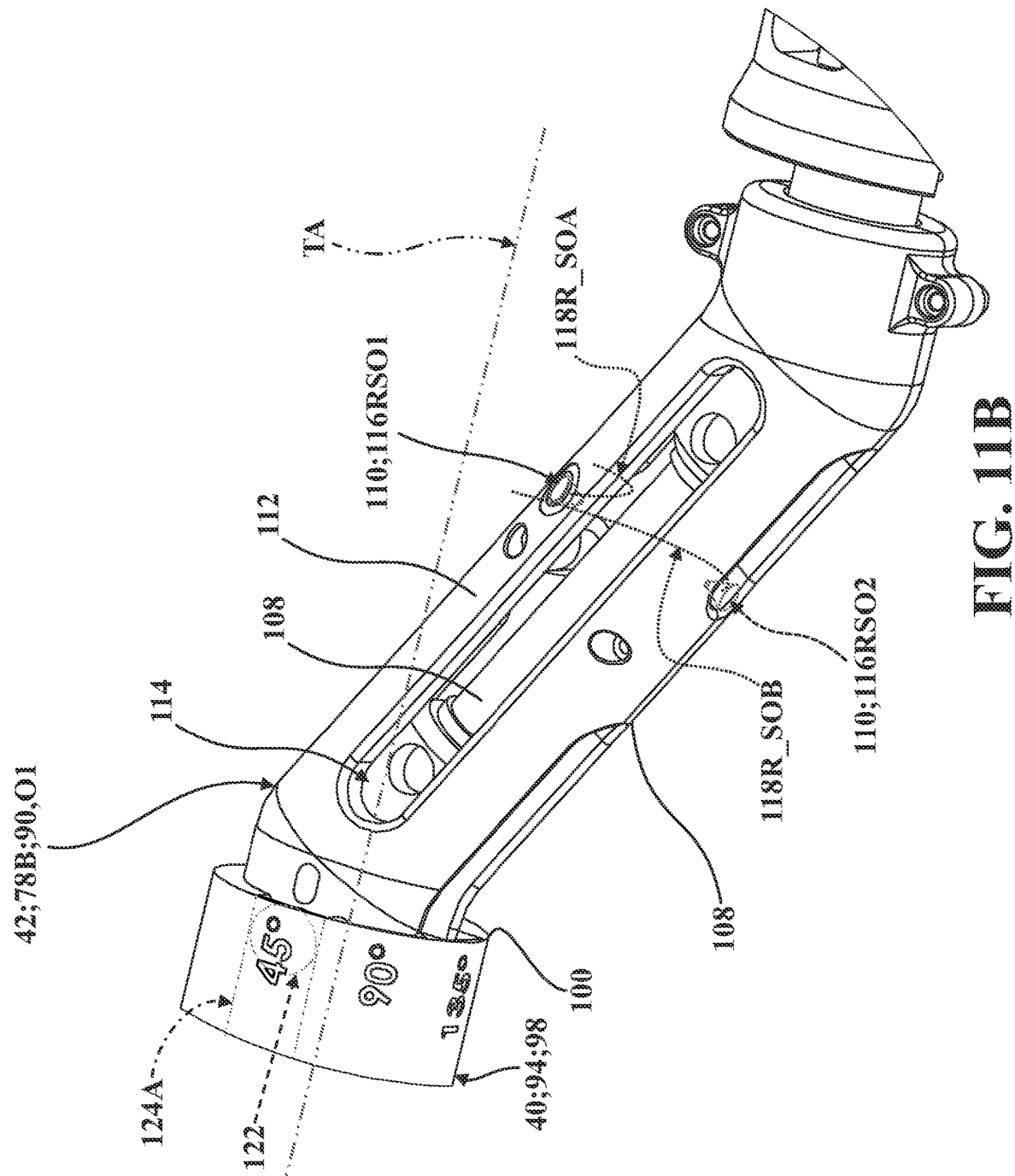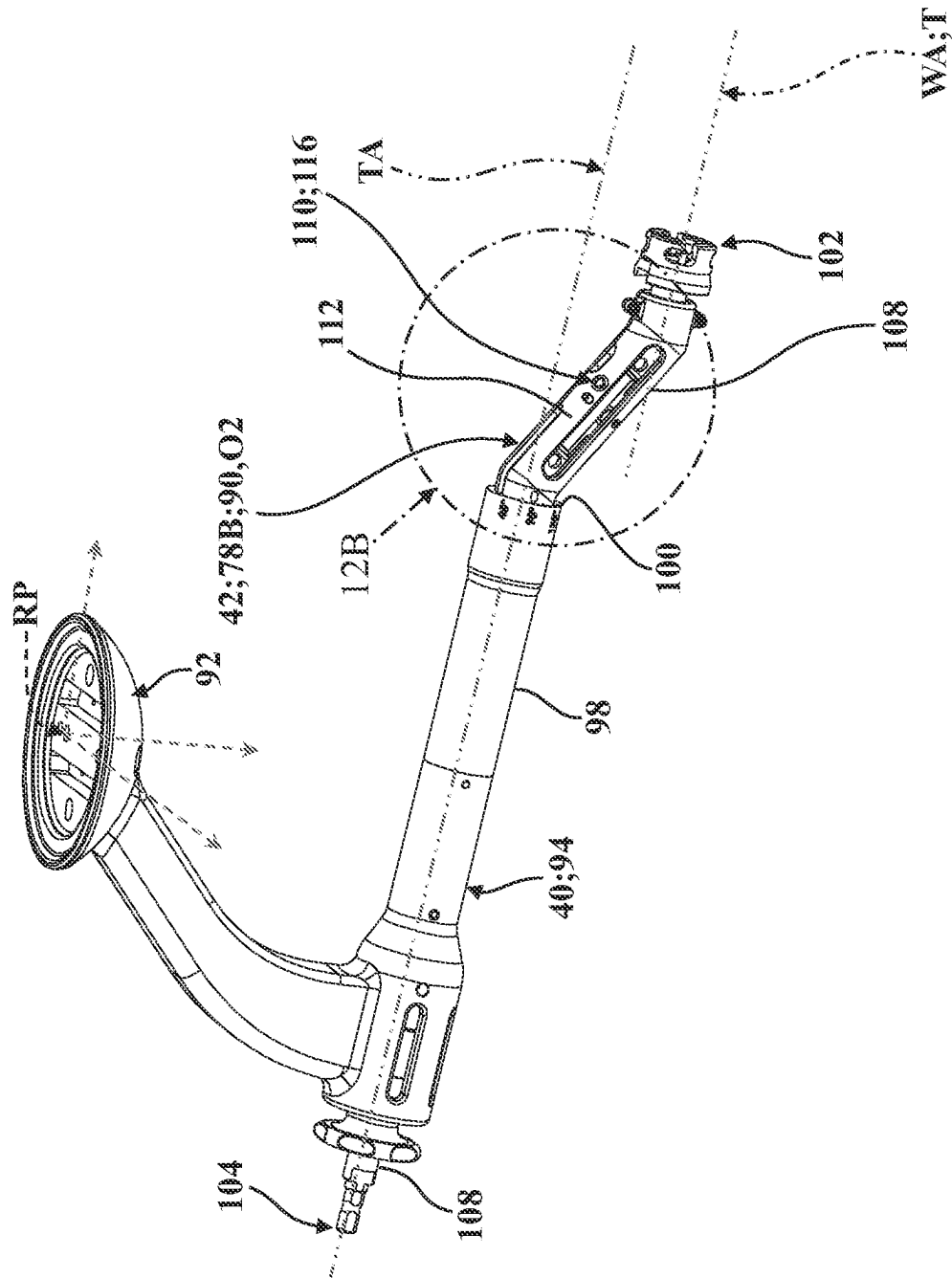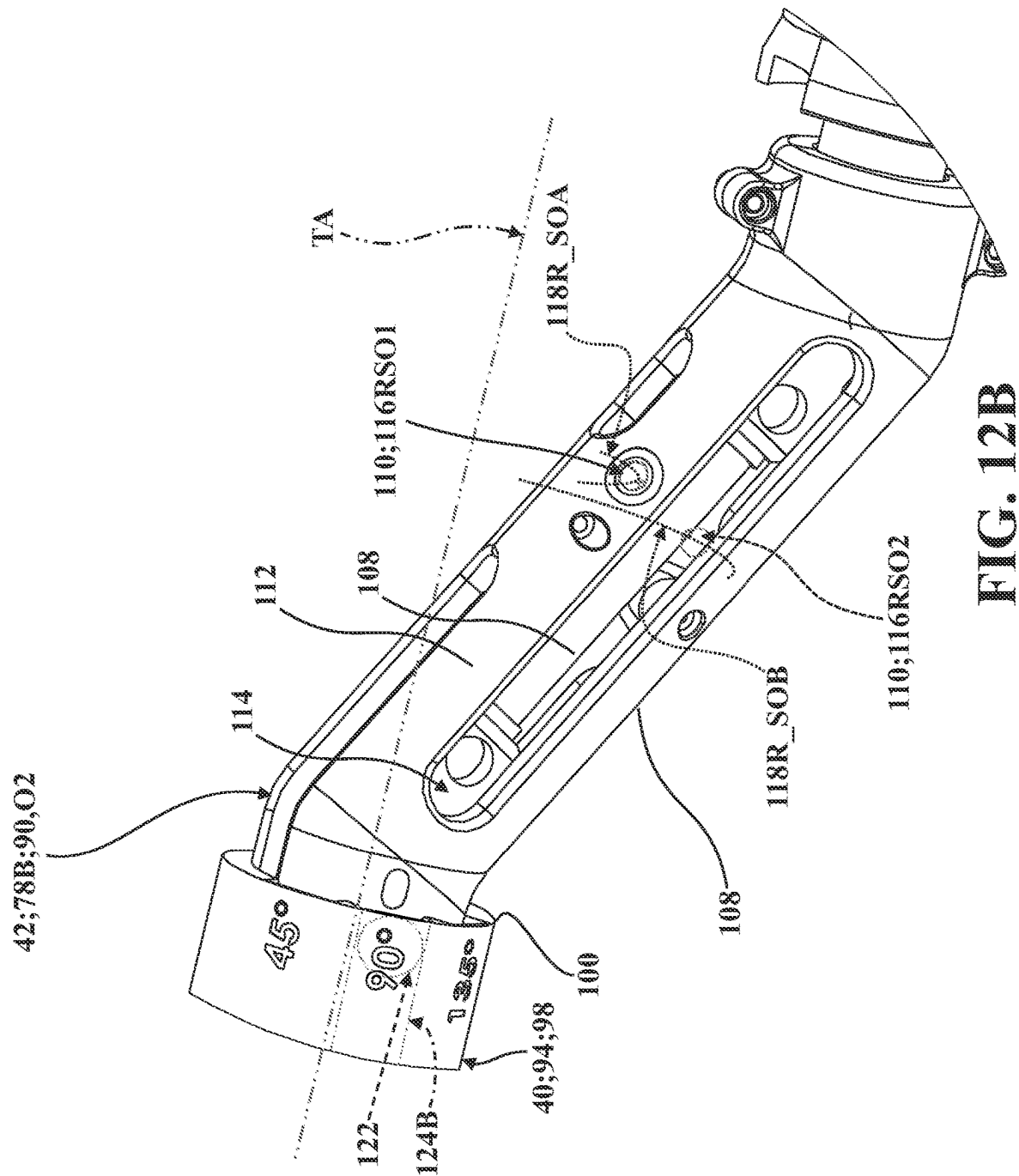
FIG. 12A

FIG. 12B

FIG. 13A

FIG. 13B

118R_ST

118R_SOB

118R_SOA

118R_FO

120

120

120

120

100

RP

92
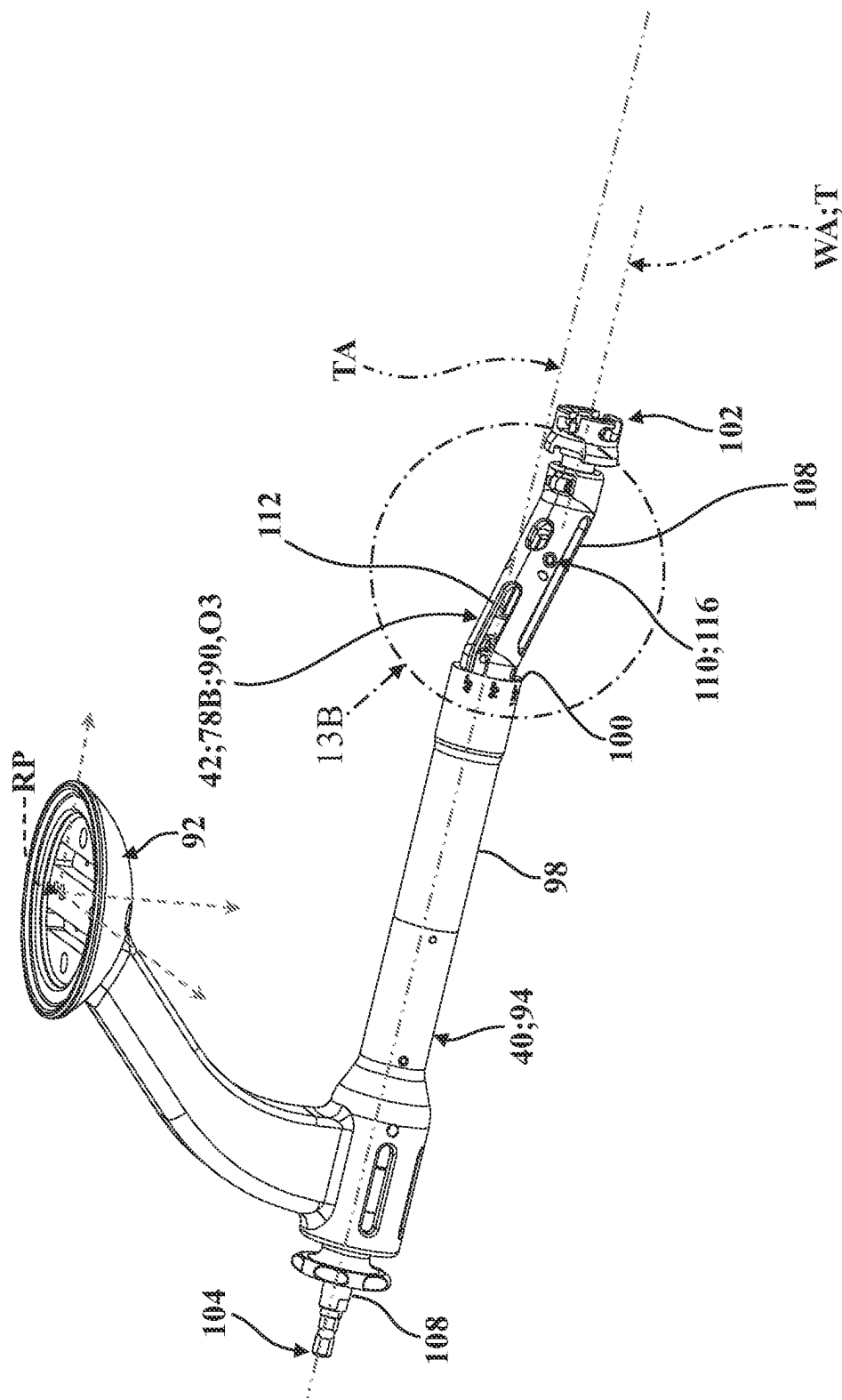
TA

98

40;94

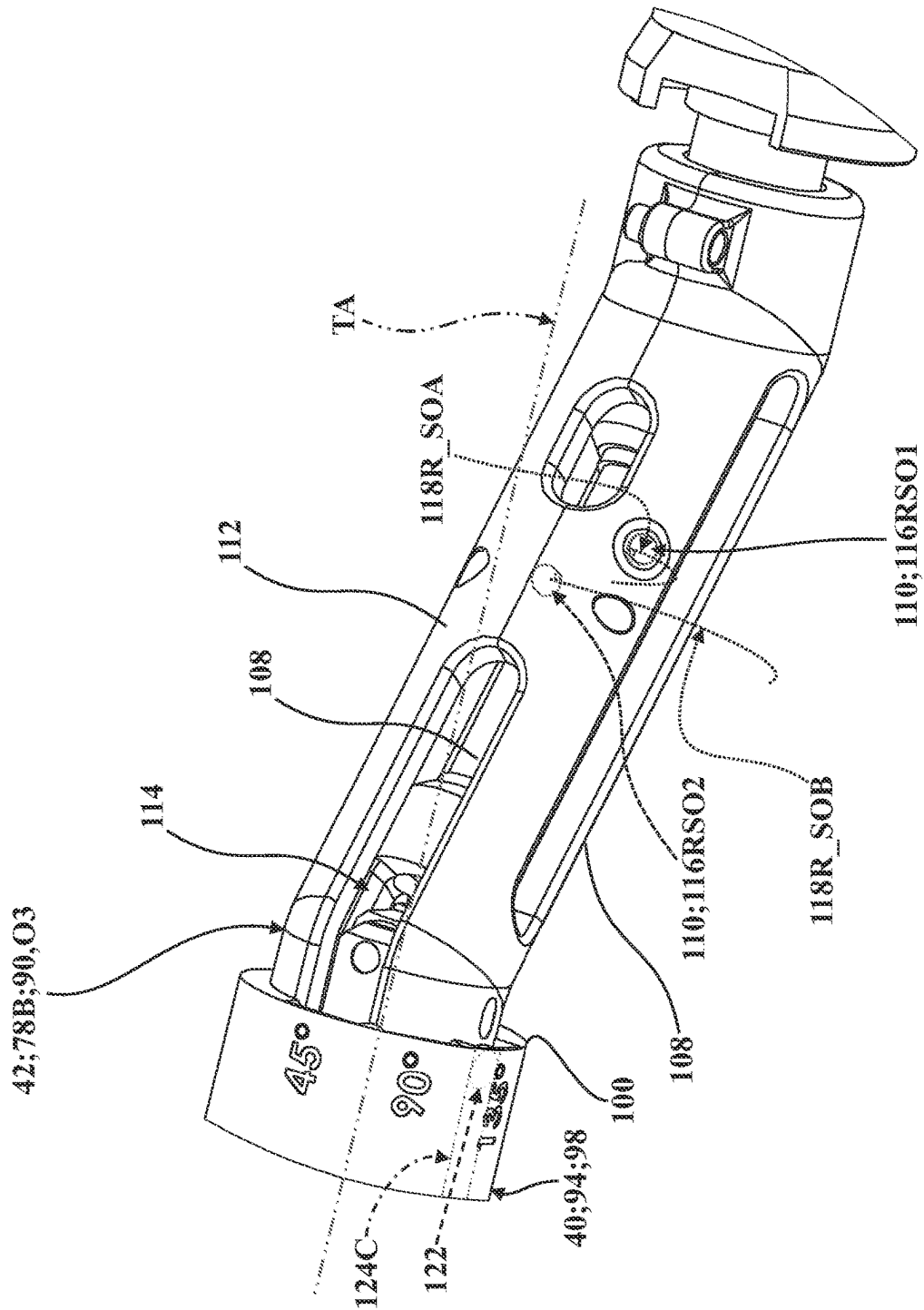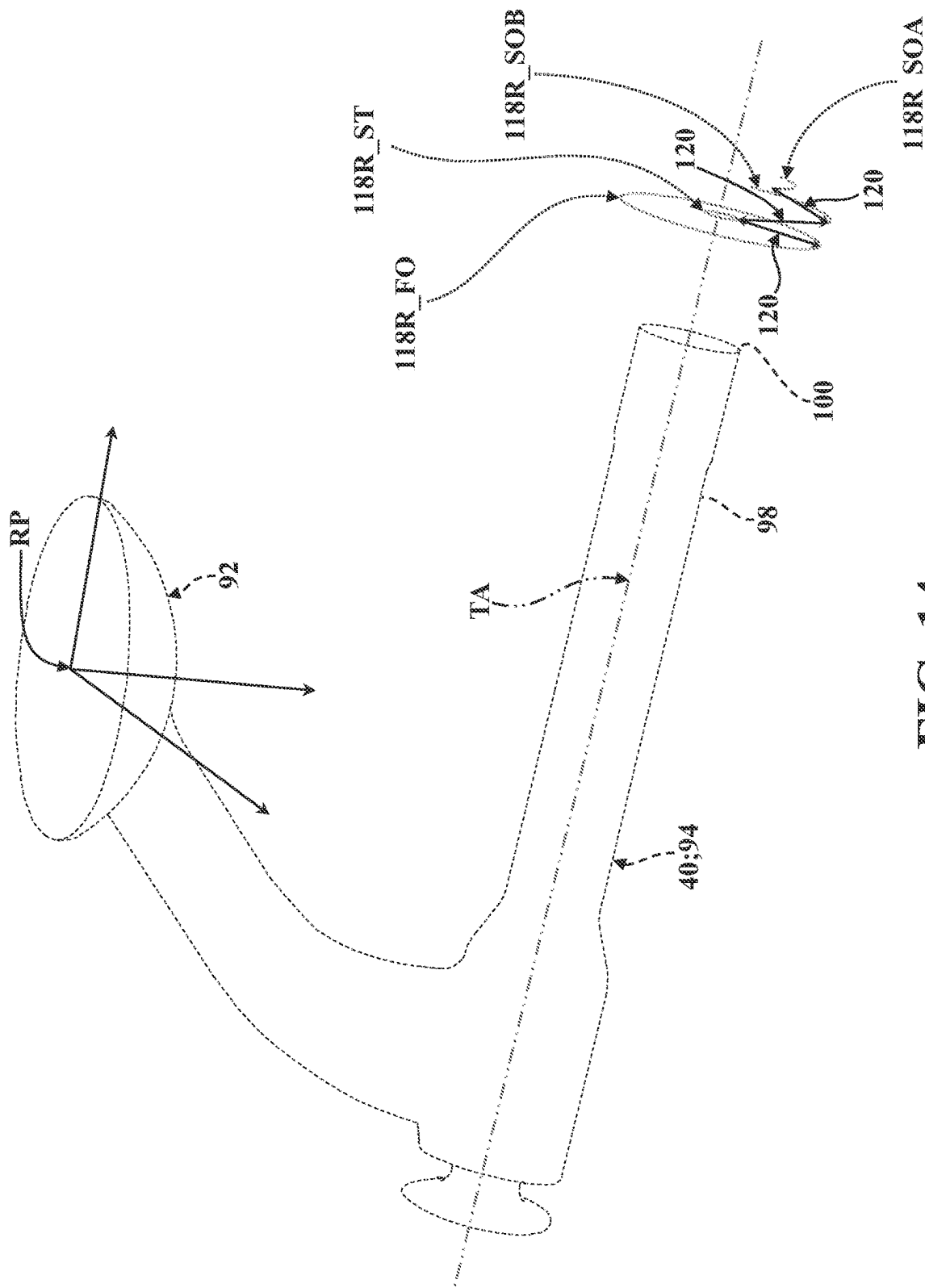**FIG. 14**

SURGICAL SYSTEMS AND METHODS FOR IDENTIFYING TOOLS GUIDED BY SURGICAL ROBOTS

CROSS-REFERENCE TO RELATED APPLICATION

The subject patent application is a continuation of U.S. patent application Ser. No. 16/279,464, filed Feb. 19, 2019, which claims priority to and all the benefits of U.S. Provisional Patent App. No. 62/631,995 filed on Feb. 19, 2018, the entire disclosure of each of the aforementioned applications being hereby incorporated by reference.

BACKGROUND

Surgical robots are frequently used to assist medical professionals in carrying out various conventional surgical procedures. To this end, a surgeon may use a surgical robot to guide, position, move, actuate, or otherwise manipulate various tools, components, prostheses, and the like during surgery.

It will be appreciated that surgical robots can be used to assist surgeons in performing a number of different types of surgical procedures. By way of illustrative example, surgical robots are commonly used in procedures involving the correction, resection, or replacement of degenerated joints to help improve patient mobility and reduce pain. For example, in hip replacement procedures, the surgeon replaces portions of the patient's hip joint with artificial prosthetic components. To this end, in total hip arthroplasty, the surgeon typically removes portions of the patient's femur to accommodate a prosthetic femoral component comprising a head, and resurfaces the acetabulum of the pelvis with a reamer to facilitate installing a prosthetic cup shaped to receive the head of the prosthetic femoral component.

Depending on the specific procedure being performed, the surgeon may attach different types of tools to the surgical robot to help facilitate approaching the surgical site, removing portions of joints and/or bone, installing prosthetic components, and the like. For example, an end effector which supports a reamer tool may be used to resurface the acetabulum of the pelvis, and an end effector which supports an impactor tool may be used to facilitate installing the prosthetic cup into the reamed acetabulum of the pelvis. Here, the surgical robot helps keep the reamer tool and the impactor tool aligned relative to the surgical site along a trajectory, and the surgeon closely monitors the trajectory and depth of reaming and impacting to ensure proper installation and alignment of the cup into the reamed acetabulum.

Depending on the configuration of the prosthetic components, the impaction tools, and the surgical robot, ensuring that the cup is implanted properly can be complicated by a lack of visibility and limited access to the surgical site. Moreover, maintaining a set trajectory can be difficult with certain approaches and surgical techniques. In order to accommodate different approaches and techniques, toolsets are provided to afford the surgeon with options for a particular type of tool. By way of example, a reamer toolset may comprise different sizes, shapes, and/or styles of reamer tools for the surgeon to select from for a particular surgical procedure, and an impactor toolset may comprise different sizes, shapes, and/or styles of impactor tools for the surgeon to select from for a particular surgical procedure.

Because different tools of a given toolset have respectively different configurations, the surgeon generally needs to input the selected tool's identity into one or more controllers in communication with the surgical robot so that the surgical robot can properly maintain the position, orientation, and/or trajectory of the tool with respect to the surgical site. Here, it will be appreciated that the process of properly inputting the identity of the selected tool into the controller takes time and may be susceptible to human error, such as where a toolset comprises a large number of visually-similar tools.

Accordingly, there remains a need in the art for addressing one or more of these deficiencies.

SUMMARY

According to a first aspect, a surgical system is provided, comprising: a tool comprising a tool feature; a navigation system comprising a localizer configured to detect a position of the tool feature; a display; a memory configured to store identification data associated with a plurality of tools; and one or more controllers coupled to the navigation system, the memory, and the display, the one or more controllers being configured to: receive, from the localizer, the detected position of the tool feature; compare the detected position of the tool feature with the identification data stored in the memory to determine an identity of the tool; and present, on the display, the identity of the tool and an identity of at least one other tool.

According to a second aspect, a method is provided of operating a surgical system, the surgical system including a tool comprising a tool feature, a navigation system comprising a localizer, a display, a memory configured to store identification data associated with a plurality of tools, and one or more controllers coupled to the navigation system, the memory and the display, the method comprising: detecting, with the localizer, a position of the tool feature; receiving, with the one or more controllers, the detected position of the tool feature from the localizer; comparing, with the one or more controllers, the detected position of the tool feature with the identification data stored in the memory; in response to comparing, determining an identity of the tool with the one or more controllers; and instructing, with the one or more controllers, the display to present the identity of the tool and an identity of at least one other tool.

According to a third aspect, a navigation system is provided, comprising: a localizer configured to detect a position of a tool feature of a tool; a display; a memory configured to store identification data associated with a plurality of tools; and one or more controllers coupled to the localizer, the display, and the memory, and the one or more controllers being configured to: receive, from the localizer, the detected position of the tool feature; compare the detected position of the tool feature with the identification data stored in the memory to determine an identity of the tool; and present, on the display, the identity of the tool and an identity of at least one other tool.

According to a fourth aspect, a method is provided of operating a navigation system, the navigation system comprising a localizer configured to detect a position of a tool feature of a tool, a display, a memory configured to store identification data associated with a plurality of tools, and one or more controllers coupled the localizer, the display, and the memory, the method comprising: detecting, with the localizer, a position of the tool feature; receiving, with the one or more controllers, the detected position of the tool feature from the localizer; comparing, with the one or more controllers, the detected position of the tool feature with the identification data stored in the memory; in response to

comparing, determining an identity of the tool with the one or more controllers; and instructing, with the one or more controllers, the display to present the identity of the tool and an identity of at least one other tool.

Other features and advantages of the present disclosure will be readily appreciated, as the same becomes better understood, after reading the subsequent description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a surgical system comprising a surgical robot with a robotic arm supporting an end effector to which a tool is supported along a trajectory adjacent to a surgical site on a patient's body, and shown with a pointer, a localizer, and a monitor adjacent to the surgical robot.

FIG. 2 is a schematic diagram of the surgical system shown having a controller in communication with the surgical robot, the localizer, and the monitor of FIG. 1.

FIG. 3A is an exemplary first interface image to be displayed on the monitor of FIGS. 1-2, shown prompting a surgeon to place a distal top of the pointer of FIG. 1 in a divot formed in an end effector tool realized as a reamer.

FIG. 3B is an exemplary second interface image to be displayed on the monitor of FIGS. 1-2, shown presenting an identity of the reamer tool.

FIG. 3C is an exemplary third interface image to be displayed on the monitor of FIGS. 1-2, shown presenting an identity of the reamer tool alongside identities associated with other reamer tools of one toolset.

FIG. 4A is another exemplary first interface image to be displayed on the monitor of FIGS. 1-2, shown prompting a surgeon to place a distal top of the pointer of FIG. 1 in a divot formed in an end effector tool realized as an impactor.

FIG. 4B is another exemplary second interface image to be displayed on the monitor of FIGS. 1-2, shown presenting an identity of the impactor tool.

FIG. 4C is another exemplary third interface image to be displayed on the monitor of FIGS. 1-2, shown presenting an identity of the impactor tool alongside identities associated with other impactor tools of another toolset.

FIG. 5A is a perspective view of an end effector with a tool realized as a straight impactor for use with the surgical system of FIG. 1.

FIG. 5B is a partial, enlarged perspective view taken about indicia 5B in FIG. 5A, showing checkpoint features realized as divots (one divot shown in phantom) arranged about a circular checkpoint space.

FIG. 6A is a perspective view of an end effector with a tool realized as a first-option impactor for use with the surgical system of FIG. 1.

FIG. 6B is a partial, enlarged perspective view taken about indicia 6B in FIG. 6A, showing a checkpoint feature realized as a divot (partially shown in phantom) arranged about a circular checkpoint space.

FIG. 7A is a perspective view of an end effector with a tool realized as a second-option impactor for use with the surgical system of FIG. 1.

FIG. 7B is a partial, enlarged perspective view taken about indicia 7B in FIG. 7A, showing checkpoint features realized as divots (one divot shown in phantom) arranged about a circular checkpoint space.

FIG. 8 is a perspective view of an end effector depicted in phantom, shown with the circular checkpoint spaces of FIGS. 5B, 6B, and 7B spaced from each other and from a reference point.

FIG. 9A is a perspective view of an end effector with a tool realized as a straight reamer for use with the surgical system of FIG. 1.

FIG. 9B is a partial, enlarged perspective view taken about indicia 9B in FIG. 9A, showing checkpoint features realized as divots (one divot shown in phantom) arranged about a circular checkpoint space.

FIG. 10A is a perspective view of an end effector with a tool realized as a first-option reamer for use with the surgical system of FIG. 1.

FIG. 10B is a partial, enlarged perspective view taken about indicia 10B in FIG. 10A, showing checkpoint features realized as divots (one divot shown in phantom) arranged about a circular checkpoint space.

FIG. 11A is a perspective view of an end effector with a tool realized as a second-option reamer for use with the surgical system of FIG. 1, the second-option reamer shown arranged in a first orientation.

FIG. 11B is a partial, enlarged perspective view taken about indicia 11B in FIG. 11A, showing checkpoint features realized as divots (one divot shown in phantom) arranged along respective radial arc checkpoint spaces.

FIG. 12A is another perspective view of the end effector and second-option reamer of FIGS. 11A-11B, shown arranged in a second orientation.

FIG. 12B is a partial, enlarged perspective view taken about indicia 12B in FIG. 12A, showing the checkpoint features realized as divots (one divot shown in phantom) arranged along respective radial arc checkpoint spaces.

FIG. 13A is another perspective view of the end effector and second-option reamer of FIGS. 11A-12B, shown arranged in a third orientation.

FIG. 13B is a partial, enlarged perspective view taken about indicia 13B in FIG. 13A, showing the checkpoint features realized as divots (one divot shown in phantom) arranged along respective radial arc checkpoint spaces.

FIG. 14 is a perspective view of an end effector depicted in phantom, shown with the circular checkpoint spaces of FIGS. 9B and 10B and the radial arc checkpoint spaces of FIGS. 11B, 12B, and 13B spaced from each other and from a reference point.

DETAILED DESCRIPTION

Referring now to the drawings, wherein like numerals indicate like or corresponding parts throughout the several views, a surgical system 30 comprising a surgical robot 32 is shown in FIG. 1. The surgical robot 32 has a base 34, a robotic arm 36, and a coupler 38. As is described in greater detail below, the robotic arm 36 is supported by the base 34 and is configured to move, drive, maintain, or otherwise control the position and/or orientation of the coupler 38 relative to the base 34 during use. The coupler 38 is adapted to releasably secure an end effector 40 which, in turn, supports a tool, generally indicated at 42. The tool 42 is configured to support, position, or otherwise facilitate driving a workpiece, depicted generically at 44 in FIG. 1, at a surgical site ST on a patient's body B along a trajectory T maintained by the surgical robot 32. Thus, the surgical robot 32 moves the workpiece 44, the tool 42, and the end effector 40 via the robotic arm 36 to, among other things, assist medical professionals in carrying out various types of surgical procedures with precise control over movement and positioning of the end effector 40, the tool 42, and the workpiece 44. One exemplary arrangement of the robotic arm 36 is described in U.S. Pat. No. 9,119,655, entitled, "Surgical Robotic arm Capable of Controlling a Surgical

Instrument in Multiple Modes," the disclosure of which is hereby incorporated by reference in its entirety. Another exemplary arrangement of the robotic arm 36 is described in U.S. Pat. No. 8,010,180, entitled, "Haptic Guidance System and Method," the disclosure of which is hereby incorporated by reference in its entirety. It will be appreciated that the robotic arm 36 and other portions of the surgical robot 32 may be arranged in alternative configurations.

While the workpiece 44 is depicted generically in FIG. 1, it will be appreciated that the tool 42 and/or the workpiece 44 could be of a number of different styles, types, and/or configurations, depending on the specific surgical procedure being performed. By way of non-limiting example, surgical procedures such as total hip arthroplasty routinely involve the use of multiple tools 42 to facilitate approaching the surgical site ST, preparing the surgical site ST, and/or installing implants (e.g., prosthetic components), and the like at the surgical site ST. In this illustrative example, one tool 42 could be a reamer used to facilitate preparing the acetabulum by driving a workpiece 44 realized as a reamer head (not shown in detail), and another tool 42 could be an impactor used to facilitate implanting a workpiece 44 realized as a prosthesis (not shown). The Applicant has described these types of reaming, preparing, and impaction processes in greater detail in U.S. Pat. Nos. 8,979,859 and 8,753,346, the disclosures of which are hereby incorporated by reference in their entirety. While the present disclosure describes various orthopedic procedures involving hip joints, it will be appreciated that the subject matter described herein may be applicable to other joints in the patient's body B, such as, for example, shoulders, elbows, wrists, spines, knees, ankles, and the like.

The surgical system 30 is able to monitor, track, and/or determine changes in the relative position and/or orientation of one or more parts of the surgical robot 32, the robotic arm 36, the end effector 40, the tool 42, and/or the workpiece 44, as well as various parts of the patient's body B, within a common coordinate system by utilizing various types of trackers (e.g., multiple degree-of-freedom optical, inertial, and/or ultrasonic sensing devices), navigation systems (e.g., machine vision systems, charge coupled device cameras, tracker sensors, surface scanners, and/or range finders), anatomical computer models (e.g., magnetic resonance imaging scans of the patient's anatomy), data from previous surgical procedures and/or previously-performed surgical techniques (e.g., data recorded while reaming the acetabulum that are subsequently used to facilitate impacting the prosthesis), and the like.

To these ends, and as is depicted schematically in FIGS. 1-2, the surgical system 30 generally comprises a controller 46, a memory 48 comprising identification data ID and interface images IM, a pointer 50 having a distal tip 50D, a robotic control system 52, and a navigation system 54 which cooperate to allow the surgical robot 32 maintain alignment of the tool 42 along the trajectory T. Each of these components will be described in greater detail below.

With continued reference to FIGS. 1-2, the controller 46 is disposed in communication with the robotic control system 52 and the navigation system 54, such as via wired or wireless electronic communication. In the illustrated embodiment depicted in FIG. 1, the controller 46 either communicates with or is realized by a robot controller 56 and/or a navigation controller 58, as described in greater detail below. The robot controller 56 forms part of the robotic control system 52, and the navigation controller 58 forms part of the navigation system 54. The controller 46, the robot controller 56, and/or the navigation controller 58

may be realized as computers, processors, control units, and the like, and may be discrete components, may be integrated, and/or may otherwise share hardware, software, inputs, outputs, and the like.

The surgical system 30 employs the robotic control system 52 to, among other things, articulate the robotic arm 36, maintain the trajectory T, and the like. Here, the robot controller 56 of the robotic control system 52 is configured to articulate the robotic arm 36 by driving various actuators, motors, and the like disposed at joints of the robotic arm 36 (not shown). The robot controller 56 also gathers data from various sensors such as encoders located along the robotic arm 36 (not shown). Because the specific geometry of each of the components of the surgical robot, end effector 40, and tools 42 are known, these sensor data can be used by the robot controller 56 to reliably adjust the position and/or orientation of the end effector 40 and the tool 42 within a manipulator coordinate system MNPL (see FIG. 1). The manipulator coordinate system MNPL has an origin, and the origin is located relative to the robotic arm 36. One example of this type of manipulator coordinate system MNPL is described in U.S. Pat. No. 9,119,655, entitled, "Surgical Robotic Arm Capable of Controlling a Surgical Instrument in Multiple Modes," previously referenced.

The surgical system 30 employs the navigation system 54 to, among other things, track movement of various objects such as the end effector 40, the pointer 50, and parts of the patient's body B (e.g. bones or other anatomy at the surgical site ST). To this end, the navigation system 54 employs a localizer 60 configured to sense the position and/or orientation of trackers 62 fixed to objects within a localizer coordinate system LCLZ. The navigation controller 58 is disposed in communication with the localizer 60 and gathers position and/or orientation data for each tracker 62 sensed within a field of view FV of the localizer 60 in the localizer coordinate system LCLZ. Thus, as is described in greater detail below, the localizer 60 is configured to determine a position of the tool 42 within the field of view FV.

It will be appreciated that the localizer 60 can sense the position and/or orientation of multiple trackers 62 to track correspondingly multiple objects within the localizer coordinate system LCLZ. By way of example, and as is depicted in FIG. 1, trackers 62 may comprise a pointer tracker 62P coupled to the pointer 50, an end effector tracker 62E coupled to the end effector 40, a first patient tracker 62A, and/or a second patient tracker 62B, as well as additional patient trackers, trackers for additional medical and/or surgical tools, and the like. In FIG. 1, the end effector tracker 62E is firmly affixed to the end effector 40, the first patient tracker 62A is firmly affixed to one bone of the patient's body B at the surgical site ST (e.g., to the pelvis adjacent to the acetabulum), and the second patient tracker 62B is firmly affixed to a different bone (e.g., to the femur adjacent to the head). The end effector tracker 62E could be fixed to the end effector 40 in different ways, such as by integration into the end effector 40 during manufacture or by releasable attachment to the end effector 40. The patient trackers 62A, 62B are firmly affixed to different bones in the patient's body B, such as by threaded engagement, clamping, or by other techniques. It will be appreciated that various trackers 62 may be firmly affixed to different types of tracked objects (e.g., discrete bones, tools, pointers, and the like) in a number of different ways.

The position of the trackers 62 relative to the anatomy to which they are attached can be determined by known registration techniques, such as point-based registration in which the distal tip 50D of the pointer 50 is used to touch off

on bony landmarks on bone or to touch off on several points across the bone for surface-based registration as the localizer **60** monitors the position and orientation of the pointer tracker **62P**. Conventional registration techniques can then be employed to correlate the pose of the patient trackers **62A**, **62B** to the patient's anatomy (e.g., to each of the femur and acetabulum). Other types of registration are also possible, such as by using patient trackers **62A**, **62B** with mechanical clamps that attach to bone and have tactile sensors (not shown) to determine a shape of the bone to which the clamp is attached. The shape of the bone can then be matched to a 3D model of bone for registration. A known relationship between the tactile sensors and the three or more markers on the patient tracker **62A**, **62B** may be entered into or otherwise known by the navigation controller **58**. Based on this known relationship, the positions of the markers relative to the patient's anatomy can be determined.

Position and/or orientation data may be gathered, determined, or otherwise handled by the navigation controller **58** using conventional registration/navigation techniques to determine coordinates of each tracker **62** within the localizer coordinate system LCLZ. These coordinates are communicated to the robotic control system **52** to facilitate articulation of the robotic arm **36** and/or to otherwise assist the surgeon in performing the surgical procedure, as described in greater detail below.

In the representative embodiment illustrated in FIG. **1**, the robot controller **56** is operatively attached to the surgical robot **32**, and the navigation controller **58**, the localizer **60**, the controller **46**, and the memory **48** are supported on a mobile cart **64** which is movable relative to the base **34** of the surgical robot **32**. The mobile cart **64** also supports a user interface, generally indicated at **66**, to facilitate operation of the surgical system **30** by displaying information to, and/or by receiving information from, the surgeon or another user. The user interface **66** is disposed in communication with the controller **46**, the memory **48**, the navigation system **54**, and/or the robotic control system **52**, and may comprise one or more output devices **68** (e.g., monitors, indicators, display screens, and the like) to present information to the surgeon (e.g., images, video, data, a graphics, navigable menus, and the like), and one or more input devices **70** (e.g., buttons, touch screens, keyboards, mice, gesture or voice-based input devices, and the like). In the illustrated embodiment, the user interface **66** comprises an output device **68** realized as a monitor **68M** to display interface images IM, as described in greater detail below. One type of mobile cart **64** and user interface **66** is described in U.S. Pat. No. 7,725,162, entitled "Surgery System," the disclosure of which is hereby incorporated by reference in its entirety.

Because the mobile cart **64** and the base **34** of the surgical robot **32** can be positioned relative to each other and also relative to the patient's body B, the surgical system **30** transforms the coordinates of each tracker **62** within the field of view FV from the localizer coordinate system LCLZ into the manipulator coordinate system MNPL, or vice versa, so that articulation of the robotic arm **36** can be performed based at least partially on the relative positions and orientations of each tracker **62** within a single, common coordinate system (the manipulator coordinate system MNPL, the localizer coordinate system LCLZ, or another common coordinate system). It will be appreciated that coordinates within the localizer coordinate system LCLZ can be transformed into coordinates within the manipulator coordinate system MNPL, and vice versa, using a number of different conventional coordinate system transformation techniques.

In the illustrated embodiment, the localizer **60** is an optical localizer and includes a camera unit **72** with one or more optical position sensors **74**. The navigation system **54** employs the optical position sensors **74** of the camera unit **72** to sense the position and/or orientation of the trackers **62** within the localizer coordinate system LCLZ. In the representative embodiment illustrated herein, the trackers **62** each employ markers **76** which can be sensed by the optical position sensors **74** of the camera unit **72**. One example of a navigation system **54** of this type is described in U.S. Pat. No. 9,008,757, entitled, "Navigation System Including Optical and Non-Optical Sensors," the disclosure of which is hereby incorporated by reference in its entirety. In some embodiments, the markers **76** are active markers (e.g., light emitting diodes "LEDs") which emit light that is sensed by the optical position sensors **74**. In other embodiments, the markers **76** may be passive markers (e.g., reflectors) which reflect light emitted from the camera unit **72** or another light source. It should be appreciated that other suitable tracking systems and methods not specifically described herein may be utilized (e.g., ultrasonic, electromagnetic, radio frequency, and the like).

In some embodiments, the surgical system **30** is capable of displaying a virtual representation of the relative positions and orientations of tracked objects to the surgeon or other users of the surgical system **30**, such as with images and/or graphical representations of the anatomy of the patient's body B, the end effector **40**, and/or the tool **42** presented on one or more output devices **68**, such as the monitor **68M**. The controller **46**, the robot controller **56**, and/or navigation controller **58** may also utilize the user interface **66** to display instructions or request information such that the surgeon or other users may interact with the robotic control system **52** to facilitate articulation of the robotic arm **36**. By way of example, the controller **46** is configured to send different interface images IM stored in the memory **48** to the monitor **68M** as described in greater detail below. Other configurations are contemplated.

It will be appreciated that the robotic control system **52** and the navigation system **54** can cooperate to facilitate control over the position and/or orientation of the end effector **40** and/or tool **42** in different ways. By way of example, in some embodiments, the robot controller **56** is configured to control the robotic arm **36** (e.g., by driving joint motors) to provide haptic feedback to the surgeon via the robotic arm **36**. Here, haptic feedback helps constrain or inhibit the surgeon from manually moving the end effector **40** and/or tool **42** beyond predefined virtual boundaries associated with the surgical procedure (e.g., to maintain alignment of the tool **42** along the trajectory T). One type of haptic feedback system and associated haptic objects that define virtual boundaries are described, for example, in U.S. Pat. No. 8,010,180, "entitled, "Haptic Guidance System and Method," the disclosure of which is hereby incorporated by reference in its entirety. In one embodiment, the surgical system **30** is the RIO™ Robotic Arm Interactive Orthopedic System manufactured by MAKO Surgical Corp. of Fort Lauderdale, FL, USA.

Referring now to FIGS. **1-14**, as noted above, the surgical system **30** employs the end effector **40** to position the tool **42** at the surgical site ST along the trajectory T maintained by the surgical robot **32** to assist the surgeon in carrying out various types of surgical procedures with precise control over the relative position and orientation of the workpiece **44** attached to the tool **42** with respect to the patient's body B. Those having ordinary skill in the art will appreciate that different types of surgical procedures routinely involve the

use of a number of different types of surgical devices, tools, and the like. Thus, for surgical procedures carried out in connection with surgical robots 32, different end effectors 40 and/or tools 42, of various types, sizes, and/or configurations, may be utilized during a single surgical procedure. Here, the surgical system 30 is configured so as to allow the surgeon to attach different types of end effectors 40 and/or tools 42 to the coupler 38 of the surgical robot 32, and also to allow the surgeon to select between variations of the same type of end effector 40 and/or tool 42. To this end, and in the representative embodiment illustrated herein, the surgical system 30 comprises first and second toolsets 78A, 78B, each of which includes first, second, and third tools 42 which, as described in greater detail below, are variations of the same general type of tool 42.

FIGS. 5A-8 generally depict the first toolset 78A, which includes first, second, and third variations of tools 42 configured as impactors: a straight impactor 80 (see FIGS. 5A-5B), a first-option impactor 82 (see FIGS. 6A-6B), and a second-option impactor 84 (see FIGS. 7A-7B). Furthermore, FIGS. 9A-14 generally depict the second toolset 78B, which includes first, second, and third variations of tools 42 configured as reamers: a straight reamer 86 (see FIGS. 9A-9B), a first-option reamer 88 (see FIGS. 10A-10B), and a second-option reamer 90 (see FIGS. 11A-13B). It will be appreciated that the types of first and second toolsets 78A, 78B illustrated and described herein, as well as the variations 80, 82, 84; 86, 88, 90 of tools 42 in the toolsets 78A, 78B, are exemplary and non-limiting. Thus, while the present disclosure is directed toward an impactor toolset 78A and a reamer toolset 78B each having three variations 80, 82, 84; 86, 88, 90 of tools 42, other configurations are contemplated and the surgical system 30 could comprise any suitable number of toolsets each having any suitable number of variations of tools 42 configured for use in any type of surgical procedure where surgical robots 32 are employed.

Those having ordinary skill in the art will appreciate that the variations 80, 82, 84; 86, 88, 90 of tools 42 within the toolsets 78A, 78B affords the surgeon with flexibility in carrying out different types of surgical procedures in different ways. By way of non-limiting example, the surgeon may select a variation 80, 82, 84; 86, 88, 90 of one or more types of tools 42 to facilitate a particular approach, improve visibility of the surgical site ST, accommodate handling and/or orientation preferences, and the like. While this flexibility is advantageous, variations 80, 82, 84; 86, 88, 90 of tools 42 generally position workpieces 44 (e.g., a prosthetic cup for the impactors 80, 82, 84, and a reamer head for the reamers 86, 88, 90) in different ways with respect to the coupler 38 of the surgical robot 34. As is described in greater detail below, the controller 46 cooperates with the memory 48, the pointer 50, the localizer 60, and the monitor 68M to ensure that the surgical system 30 can distinguish between variations 80, 82, 84; 86, 88, 90 of tools 42 and thereby determine the position and orientation of the workpiece 44 based on the identity of the tool 42 being utilized.

Referring now to FIGS. 5A-14, the illustrated tools 42 are each configured for releasable attachment to a common end effector 40. Put differently, in one embodiment, the end effector 40 is configured to releasably secure the straight impactor 80 (see FIG. 5A), the first-option impactor 82 (see FIG. 6A), the second-option impactor 84 (see FIG. 7A), the straight reamer 86 (see FIG. 9A), the first-option reamer 88 (see FIG. 10A), and/or the second-option reamer 90 (see FIGS. 11A, 12A, and 13A). While this configuration advantageously allows the surgeon to quickly change between different tools 42 without detaching the end effector 40 from

the coupler 38 of the surgical robot 32, it will be appreciated that each toolset 78A, 78B or even each individual tool 42 could be provided with its own end effector 40 in certain embodiments.

In order to facilitate releasable attachment of the tools 42 to the end effector 40, the end effector 40 generally comprises a mount 92, a guide 94, and a receiver 96. The mount 92 is adapted to releasably attach to the coupler 38 of the surgical robot 32 (see FIG. 1). The guide 94 is coupled to the mount 92 and comprises the receiver 96 which, in turn, is configured to releasably secure the tool 42 to the guide 94. Examples of this type of guide 94 and receiver 96 are described in U.S. Pat. No. 8,753,346, previously referenced.

The guide 94 has a generally cylindrical region 98 which defines a tool axis TA and extends to a distal guide end 100. The receiver 96 (depicted schematically as a sphere in FIGS. 5A and 9A) is configured to restrict movement of the tool 42 relative to the guide 94 in different ways depending on the type of tool 42. By way of illustrative example, the receiver 96 is generally configured to permit free rotation of the impactors 80, 82, 84 about the tool axis TA, and to permit limited translation along the tool axis TA (not shown in detail). By way of further illustrative example, the receiver 96 is generally configured to inhibit translation of the reamers 86, 88, 90 along the tool axis TA (see FIGS. 5A, 6A, and 7A), to permit free rotation of the straight reamer 86 and the first-option reamer 88 about the tool axis TA (see FIGS. 9A and 10A), and to permit selective positioning of the second-option reamer 90 about the tool axis TA between first, second, and third orientations O1, O2, O3 (see FIGS. 11A, 12A, and 13A) as described in greater detail below.

The tools 42 each generally comprise a respective working end 102, a proximal end 104, a coupling 106, a tool body 108, and a checkpoint feature 110. The working end 102 is configured to releasably secure and support the workpiece 44 (e.g., a prosthetic cup for the impactors 80, 82, 84, and a reamer head for the reamers 86, 88, 90). The coupling 106 of the tool 42 (depicted schematically as an elongated recess in FIG. 5A and as an indent in FIG. 9A) is formed in the tool body 110 and is configured to engage the receiver 96 of the guide 94 of the end effector 40 to restrict or inhibit axial translation of the tool 42, as noted above. The tool body 108 extends between the working end 102 and the proximal end 104, with the coupling 106 arranged adjacent to the proximal end 104. The checkpoint feature 110 is generally formed in the tool body 108, and is arranged relative to a common reference point RP at a predetermined location that is specific to each tool 42, as described in greater detail below.

The working end 102 of each tool 42 defines a respective workpiece axis WA, which may be coincident with the tool axis TA for some tools 42 (e.g., the straight impactor 80 depicted in FIG. 5A), parallel to and offset from the tool axis TA for some tools 42 (e.g., the second-option reamer 90 depicted in FIGS. 11A, 12A, and 13A), or angled with respect to the tool axis TA (e.g., the first-option reamer 88 depicted in FIG. 10A). Generally, the workpiece axis WA is coincident with the trajectory T maintained by the surgical robot 32.

The working ends 102 of the tools 42 each generally rotate and translate concurrently with their respective tool bodies 108. For the impactors 80, 82, 84, a head (not shown) may be coupled to the proximal end 104 to receive external impact force, such as from a mallet (not shown) to translate the tool body 108 and the working end 102 relative to the guide 94 and thereby facilitate installing the prosthetic cup (not shown) at the surgical site ST. For the reamers 86, 88, 90, a rotary instrument (not shown) may be coupled to the

proximal end **104** to rotate the tool body **108** and the working end **102** relative to the guide **94** and thereby facilitate reaming (not shown) or otherwise preparing the surgical site ST for impaction. The tool bodies **108** of the reamers **86, 88, 90** also comprise handles, generally indicated at **112**, and may include one or more universal joints, generally indicated at **114** where the tool axis TA is not coincident with the workpiece axis WA (see FIGS. **10A, 11A, 12A,** and **13A**). The handles **112** may be grasped by the surgeon and do not rotate concurrently with the working end **102** in response to rotational torque applied to the proximal end **104**. The checkpoint features **110** of the reamers **86, 88, 90** are formed in the handles **112** of the tool bodies **108**, as described in greater detail below. The universal joints **114** are employed in the first-option reamer **88** and the second-option reamer **90** to allow the tool body **108**, which may be comprised of discrete sections (not shown in detail) to rotate between the proximal end **104** and the working end **102**.

Referring again to FIGS. **1-14**, the tools **42** within each toolset **78A, 78B** each comprise one or more checkpoint features **110** formed in the tool body **108** at respective predetermined locations relative to the common reference point RP, as noted above. In the representative embodiment illustrated herein, the reference point RP is established when the coupling **106** of the tool **42** is engaged with the receiver **96** of the guide **94**, and the end effector **40** is attached to the coupler **38** of the surgical robot **32**. While the reference point RP could be defined or otherwise established in a number of different ways, because each of the exemplary tools **42** described and illustrated herein can be releasably attached to the same end effector **40**, the reference point RP depicted in the drawings is located adjacent to the mount **92** of the end effector **40**. As will be appreciated from the subsequent description below, because the surgical system **30** is able to determine the specific position and orientation of the coupler **38** of the surgical robot **32** within either coordinate system MNPL, LCLZ (e.g., via encoder data ED from the robotic arm **36** and/or via location data from the localizer **60** about the end effector tracker **62E**), the location of the reference point RP is similarly known by the surgical system **30** during use. The reference point RP may also be known in a tool coordinate system associated with the end effector tracker **62E**, with the reference point RP being stored as a coordinate, plane, line, or the like in the tool coordinate system and capable of being tracked by virtue of tracking the end effector tracker **62E**. The relationship of the reference point RP to the end effector tracker **62E** can be established by calibration, such as during manufacture or intraoperatively, or may be measured.

The surgical system **30** is configured to differentiate between the tools **42** of one or more toolsets **78A, 78B** based on the location of the checkpoint features **110** with respect to the reference point RP to, among other things, ensure proper operation of the robotic control system **52** and/or the navigation system **54** by correctly positioning the tool **42** and/or workpiece **44**. Here, each tool **42** comprises one or more checkpoint features **110** arranged at predetermined locations which are unique to that particular tool **42** within its respective toolset **78A, 78B**. In the representative embodiment illustrated herein, the checkpoint features **110** are realized as divots **116** formed in the respective tool bodies **108**: the straight impactor **80** comprises two divots **116ISTA, 116ISTB** (see FIG. **5B**); the first-option impactor **82** comprises one divot **116IFO** (see FIG. **6B**); the second-option impactor **84** comprises two divots **116ISOA, 116ISOB** (see FIG. **7B**); the straight reamer **86** comprises two divots **116RSTA, 116RSTB** (see FIG. **9B**); the first-

option reamer **88** comprises two divots **116RFOA, 116RFOB** (see FIG. **10B**); and the second-option reamer **90** comprises two divots **116RSO1, 116RSO2** (see FIGS. **11B, 12B,** and **13B**). The divots **116** each have a generally frustoconical profile which is shaped to receive the distal tip **50B** of the pointer **50**, as described in greater detail below. However, it will be appreciated that the checkpoint features **110** could be configured in other ways, with or without the use of divots **116**, sufficient to differentiate between tools **42** relative to the reference point RP. For the purposes of clarity and consistency, the arrangement, orientation, and configuration of the divots **116** will be described for each toolset **78A, 78B** separately.

Referring now to FIGS. **5A-8**, the impactors **80, 82, 84** of the first toolset **78A** are shown. The straight impactor **80** is depicted in FIGS. **5A-5B**. As shown in FIG. **5B**, the checkpoint feature **110** of the straight impactor **80** comprises two divots **116ISTA, 116ISTB** which are each formed in the tool body **108** at respective predetermined locations relative to the reference point RP. Because the tool body **108** of the straight impactor **80** is arranged for rotation about the tool axis TA relative to the mount **92** of the end effector **40**, as noted above, movement of the tool body **108** effects corresponding movement of the checkpoint feature **110** relative to the reference point RP within a predetermined checkpoint space **118**. In the illustrated embodiment of the straight impactor **80**, the checkpoint space **118I_ST** is defined by a circle disposed about and concentrically aligned with the tool axis TA (see FIGS. **5B** and **8**). Thus, irrespective of how the straight impactor **80** is rotated about the tool axis TA, its divots **116ISTA, 116ISTB** will be positioned somewhere along the circular checkpoint space **118I_ST**.

The first-option impactor **82** is depicted in FIGS. **6A-6B**. As shown in FIG. **6B**, the checkpoint feature **110** of the first-option impactor **82** comprises one divot **116IFO** which is formed in the tool body **108** at a predetermined location relative to the reference point RP. Here too, because the tool body **108** of the first-option impactor **82** is arranged for rotation about the tool axis TA relative to the mount **92** of the end effector **40**, movement of the tool body **108** effects corresponding movement of the checkpoint feature **110** relative to the reference point RP within a predetermined checkpoint space **118I_FO** defined by a circle disposed about and concentrically aligned with the tool axis TA (see FIGS. **6B** and **8**). Thus, irrespective of how the first-option impactor **82** is rotated about the tool axis TA, its divot **116IFO** will be positioned somewhere along the circular checkpoint space **118I_FO**.

The second-option impactor **84** is depicted in FIGS. **7A-7B**. As shown in FIG. **7B**, the checkpoint feature **110** of the second-option impactor **84** comprises two divots **116ISOA, 116ISOB** which are each formed in the tool body **108** at respective predetermined locations relative to the reference point RP. Here too, because the tool body **108** of the second-option impactor **84** is arranged for rotation about the tool axis TA relative to the mount **92** of the end effector **40**, movement of the tool body **108** effects corresponding movement of the checkpoint feature **110** relative to the reference point RP within a predetermined checkpoint space **118I_SO** defined by a circle disposed about and concentrically aligned with the tool axis TA (see FIGS. **7B** and **8**). Thus, irrespective of how the second-option impactor **80** is rotated about the tool axis TA, its divots **116ISOA, 116ISOB** will be positioned somewhere along the circular checkpoint space **118I_SO**.

In FIG. **8**, the checkpoint space **118I_ST** of the straight impactor **80**, the checkpoint space **118I_FO** of the first-

option impactor **82**, and the checkpoint space **118I_SO** of the second-option impactor **84** are each shown at their respective predetermined locations relative to the reference point RP established or otherwise defined by the end effector **40**, as noted above. Each of the checkpoint spaces **118I_ST**, **118I_FO**, **118I_SO** shown in FIG. **8** are spaced from each other such that a predetermined distance **120** (or more) separates adjacent checkpoint spaces **118I_ST**, **118I_FO**, **118I_SO** from each other. Put differently, the predetermined location of the checkpoint feature **110** of each of the impactors **80**, **82**, **84** are arranged so as to be spaced from the checkpoint features **110** of each of the other impactors **80**, **82**, **84** at a minimum of the predetermined distance **120**. Here, because the impactors **80**, **82**, **84** are each arranged for rotation about the tool axis TA, it will be appreciated that the predetermined distance **120** extends in 3D space between any point along two adjacent checkpoint spaces **118I_ST**, **118I_FO**, **118I_SO** (see FIG. **8**). In one embodiment, the predetermined distance **120** is at least 10 mm.

Referring now to FIGS. **9A-14**, the reamers **86**, **88**, **90** of the second toolset **78B** are shown. The straight reamer **86** is depicted in FIGS. **9A-9B**. As shown in FIG. **9B**, the checkpoint feature **110** of the straight reamer **86** comprises two divots **116RSTA**, **116RSTB** which are each formed in the tool body **108** at respective predetermined locations relative to the reference point RP. Because the tool body **108** of the straight reamer **86** is arranged for rotation about the tool axis TA relative to the mount **92** of the end effector **40**, as noted above, movement of the tool body **108** effects corresponding movement of the checkpoint feature **110** relative to the reference point RP within a predetermined checkpoint space **118**. In the illustrated embodiment of the straight reamer **86**, the checkpoint space **118R_ST** is defined by a circle disposed about and concentrically aligned with the tool axis TA (see FIGS. **9B** and **14**). Thus, irrespective of how the straight reamer **86** is rotated about the tool axis TA, its divots **116RSTA**, **116RSTB** will be positioned somewhere along the circular checkpoint space **118R_ST**.

The first-option reamer **88** is depicted in FIGS. **10A-10B**. As shown in FIG. **10B**, the checkpoint feature **110** of the first-option reamer **88** comprises two divots **116RFOA**, **116RFOB** which are formed in the tool body **108** at respective predetermined locations relative to the reference point RP. Here too, because the tool body **108** of the first-option reamer **88** is arranged for rotation about the tool axis TA relative to the mount **92** of the end effector **40**, movement of the tool body **108** effects corresponding movement of the checkpoint feature **110** relative to the reference point RP within a predetermined checkpoint space **118R_FO** defined by a circle disposed about and concentrically aligned with the tool axis TA (see FIGS. **10B** and **14**). Thus, irrespective of how the first-option reamer **88** is rotated about the tool axis TA, its divots **116RFOA**, **116RFOB** will be positioned somewhere along the circular checkpoint space **118R_FO**.

The second-option reamer **90** is depicted in FIGS. **11A-13B**. As shown in FIGS. **11B**, **12B**, and **13B**, the checkpoint feature **110** of the second-option reamer **90** comprises two divots **116RSO1**, **116RSO2** which are each formed in the tool body **108** at respective predetermined locations relative to the reference point RP. As noted above, the second-option reamer **90** does not freely rotate about the tool axis TA relative to the mount **92** of the end effector **40**. Rather, in this embodiment, as is depicted schematically in FIGS. **11B**, **12B**, and **13B**, the handle **112** of the second-option reamer **90** comprises a key **122** which can be received in either a first, second, or third keyways **124A**, **124B**, **124C** formed in the cylindrical region **98** of the guide **94** adjacent to the

distal guide end **100**. Thus, the surgeon can position the key **122** in the first keyway **124A** to place the second-option reamer **90** in the first orientation O1 (see FIGS. **11A-11B**), in the second keyway **124B** to place the second-option reamer **90** in the second orientation O2 (see FIGS. **12A-12B**), or in the third keyway **124C** to place the second-option reamer **90** in the third orientation O3 (see FIGS. **13A-13B**). Furthermore, the illustrated embodiment of the second-option reamer **90** comprises different checkpoint features **110** respectively defined by the divots **116RSO1**, **116RSO2**. Here, movement between the first, second, and third orientations O1, O2, O3 effects corresponding movement of the checkpoint features **110** relative to the reference point RP within respective predetermined checkpoint spaces **118R_SOA**, **118R_SOB** each defined by a radial arc disposed about and concentrically aligned with the tool axis TA (see FIGS. **11B**, **12B**, **13B**, and **14**). Thus, irrespective of which orientation O1, O2, O3 the second-option impactor **80** is placed in, its divots **116RSO1**, **116RSO2** will be positioned somewhere along the respective radial arc checkpoint spaces **118R_SOA**, **118R_SOB**. Furthermore, while the checkpoint features **110** of the illustrated embodiment of the second-option impactor **80** are configured such that the checkpoint spaces **118R_SOA**, **118R_SOB** are also spaced from each other at the predetermined distance **120**, it is conceivable that the checkpoint spaces **118R_SOA**, **118R_SOB** could be arranged differently in some embodiments.

In FIG. **14**, the checkpoint space **118R_ST** of the straight reamer **86**, the checkpoint space **118R_FO** of the first-option reamer **88**, and the checkpoint spaces **118R_SOA**, **118R_SOB** of the second-option reamer **90** are each shown at their respective predetermined locations relative to the reference point RP established or otherwise defined by the end effector **40**, as noted above. Each of the checkpoint spaces **118R_ST**, **118R_FO**, **118R_SOA**, **118R_SOB** shown in FIG. **14** are similarly spaced from each other such that the predetermined distance **120** (or more) separates adjacent checkpoint spaces **118R_ST**; **118R_FO**; **118R_SOA**, **118R_SOB** from each other. Put differently, the predetermined location of the checkpoint features **110** of each of the reamers **86**, **88**, **90** are arranged so as to be spaced from the checkpoint features **110** of each of the other reamers **86**, **88**, **90** at a minimum of the predetermined distance **120**. Here, because the reamers **86**, **88**, **90** are each arranged for some form of movement about the tool axis TA (either free rotation or movement between discrete positions), it will be appreciated that the predetermined distance **120** similarly extends in 3D space between any point along two adjacent checkpoint spaces **118R_ST**; **118R_FO**; **118R_SOA**, **118R_SOB** (see FIG. **14**).

While some of the tools **42** described above are able to freely rotate about the tool axis TA such that their checkpoint feature **110** could be disposed in a number of different predetermined locations about its respective circular checkpoint space **118**, it will be appreciated that other configurations are contemplated. By way of non-limiting example, while the handle **112** of the second-option reamer **90** does not freely rotate about the tool axis TA and can be moved between the three orientations O1, O2, O3, it is conceivable that only a single orientation could be utilized in some embodiments such that the checkpoint feature **110** is defined by a point in space as opposed to a point along a circle or a radial arc. Furthermore, while some of the tools **42** described above employ checkpoint features **110** defined by multiple divots **116** that can occupy a common checkpoint space **118**, only a single divot **116** could be employed in some embodi-

ments. Moreover, multiple checkpoint features **110** with one or more divots **116** that occupy respective checkpoint spaces **118** could also be employed. Other configurations are contemplated.

Referring again to FIGS. **1-14**, as noted above, the surgical system **30** is configured to differentiate between the tools **42** of one or more toolsets **78A, 78B** based on the location of the checkpoint features **110** with respect to the reference point RP via the controller **46**. Here, the controller **46** is configured to identify the tool **42** that is attached to the coupler **38** of the end effector **40** by monitoring the position and orientation of the pointer tracker **62P** of the pointer **50** via the localizer **60** under certain operating conditions.

The controller **46** is configured to send different interface images IM (see FIGS. **3A-4C**) stored in the memory **48** to the monitor **68M** to assist the surgeon (or another user) in performing the surgical procedure. The interface images IM may be static images or may be defined as a part of a dynamic, navigable graphical user interface. In one embodiment, the controller **46** is configured to send a first interface image IM1 (see FIGS. **3A** and **4A**) to the monitor **68M** prompting the surgeon (or another user) to position the distal tip **50D** of the pointer **50** at the checkpoint feature **110** of the tool **42** attached to the coupler **38** of the surgical robot **32**. Here, the controller **46** is further configured to receive position data PD (see FIG. **2**) from the localizer **60** associated with the pointer tracker **62P** of the pointer **50** within the field of view FV, and use this position data PD in order to compare the current position of the checkpoint feature **110** against the identification data ID stored in the memory **48** to determine the identity of (or "recognize") the tool **42**.

In some embodiments, the coordinates of the distal tip **50D** of the pointer **50** relative to its pointer tracker **62P** is calibrated or known to the localizer **60** or the navigation controller **58** via calibration data stored in memory and accessible by the localizer **60** and/or the navigation controller **58**. As a result, the localizer **60** and/or the navigation controller **58** are able to determine coordinates of the distal tip **50D** of the pointer **50** in the localizer coordinate system LCLZ, the manipulator coordinate system MNPL, the tool coordinate system (via transformation techniques described above), or in some other common coordinate system. Current coordinates of the reference point RP can similarly be determined using position data PD associated with the end effector tracker **62E**. For example, coordinates of the reference point RP relative to the end effector tracker **62E** can be calibrated or known to the localizer **60** or the navigation controller **58** via calibration data stored in memory and accessible by the localizer **60** and/or the navigation controller **58**. Thus, by knowing the current coordinates of the reference point RP and the current coordinates of the checkpoint feature **110** in the common coordinate system, the localizer **60** and/or the navigation controller **58** can compare the relationship (e.g., positional relationship between coordinates) of the reference point and the checkpoint feature **110** and compare this relationship to stored, expected relationships for each of the different tools **42**, e.g., the identification data ID.

In some embodiments, the identification data ID associated with the tools **42** and stored in the memory **48** comprise coordinates of the predetermined locations associated with the checkpoint features **110** of each tool **42** within the respective toolset **78A, 78B**. More specifically, the identification data ID may comprise coordinates and/or areas disposed along the checkpoint spaces **118** of each tool **42** within the respective toolset **78A, 78B**, and relative to the reference point RP. In some cases, these coordinates and/or areas,

along with the coordinates of the reference point RP, can be stored in the tool coordinate system to establish a known relationship between the reference point RP and the checkpoints **110** and/or checkpoint spaces **118**. Thus, the actual coordinates of the checkpoint **110** determined by the pointer **50** can be determined in the tool coordinate system (e.g., via transformation techniques described above), compared to the stored, possible coordinates of the checkpoint **110** in the tool coordinate system, with the best fit selected to thereby identify the correct tool **42**. If no match is found because the measured coordinates differ beyond a predetermined threshold from each of the stored coordinates, then the surgeon may be prompted with instructions on the monitor **68M** to recalibrate the pointer **50** or to ensure that the tool **42** is fully seated in the receiver **96**.

Once the controller **46** has determined the identity of the tool **42**, it sends a second interface image IM2 (see FIGS. **3B** and **4B**) to the monitor **68M** to present the surgeon (or another user) with the identity of the tool **42**. In some embodiments, the controller **46** is further configured to send a third interface image IM3 (see FIGS. **3C** and **4C**) to the monitor **68M** to present the surgeon (or another user) with the identity of the tool **42** alongside a predetermined number of identities associated with the other tools **42** in the respective toolset **78A, 78B** based on the identification data ID stored in the memory **48**. In the embodiment illustrated in FIGS. **3A-4C**, the second interface image IM2 (see FIGS. **3B** and **4B**) presents the identity of the tool **42** as a selection of a "drop down" list of identities (see FIGS. **3C** and **4C**). It will be appreciated that this configuration affords advantages in situations where the localizer **60** operates with less than optimal accuracy, such as where the field of view FV is narrow or obscured, where user error places the distal tip **50D** of the pointer **50** out of alignment with the pointer tracker **62P**, and the like. In such situations, the surgical system **30** could still be configured to present the surgeon (or another user) with the assumed identity of the tool **42** while, at the same time, requesting the surgeon to manually verify the identity of the tool **42** and notifying the surgeon to check for misalignment or to use a different pointer **50**. Other configurations are contemplated.

It should be appreciated that the controller **46** may be configured to receive position data PD from the localizer **60** associated with the tool **42** within the field of view FV by tracking a base tracker (not shown) attached to the robotic arm **36**, such as by monitoring the position and/or orientation of the base tracker, with the base tracker being registered to the manipulator coordinate system MNPL, and with encoder data ED being additionally used to determine a position of the reference point RP in the manipulator coordinate system MNPL. Similarly, the controller **46** can then compare the current position of the checkpoint **110** in the manipulator coordinate system MNPL relative to the current position of the reference point RP to the stored, possible positions of the checkpoint **110** based on its stored relationship to the reference point RP, e.g., against the identification data ID stored in the memory **48**, to determine the identity of the tool **42**. In some embodiments, position data PD associated with the tool **42** may be at least partially determined using encoder data ED from the robot controller **56**.

The present disclosure is also directed toward a method of assisting the surgeon (or another user) in performing the surgical procedure with the surgical system **30**. The method comprises different steps, including attaching the tool **42** having the checkpoint feature **110** to the surgical robot **32**, and sending the first interface image IM1 to the monitor **68M** prompting the surgeon to position the distal tip **50D** of

the pointer 50 at the checkpoint feature 110 of the tool 42. The method also comprises tracking the pointer 50 with the localizer 60 to determine position data PD associated with the pointer 50, identifying the tool 42 by comparing the position data PD from the localizer 60 with stored identification data ID, and sending a second interface image IM2 to the monitor 68M presenting the surgeon with the identity of the tool 42.

The embodiments of the surgical system 30, end effector 40, tools 42, and methods described herein afford advantages in connection with a broad number of medical and/or surgical procedures including, for example, where surgical robots 32 are utilized in connection with total hip arthroplasty. Specifically, it will be appreciated that the embodiments described and illustrated herein are configured to facilitate identification of different variations of tools 42 in one or more toolsets 78A, 78B quickly, reliably, and efficiently while, at the same time, affording the surgeon with guided assistance in carrying out different types of surgical procedures.

It will be further appreciated that the terms "include," "includes," and "including" have the same meaning as the terms "comprise," "comprises," and "comprising." Moreover, it will be appreciated that terms such as "first," "second," "third," and the like are used herein to differentiate certain structural features and components for the non-limiting, illustrative purposes of clarity and consistency.

Several configurations have been discussed in the foregoing description. However, the configurations discussed herein are not intended to be exhaustive or limit the invention to any particular form. The terminology which has been used is intended to be in the nature of words of description rather than of limitation. Many modifications and variations are possible in light of the above teachings and the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A surgical system, comprising:
a tool comprising a tool feature;
a navigation system comprising a localizer configured to detect a position of the tool feature;
a display;
a memory configured to store identification data associated with a plurality of tools; and
one or more controllers coupled to the navigation system, the memory, and the display, the one or more controllers being configured to:
receive, from the localizer, the detected position of the tool feature;
compare the detected position of the tool feature with the identification data stored in the memory to determine an identity of the tool; and
present, on the display, the identity of the tool and an identity of at least one other tool.

2. The surgical system of claim 1, wherein the memory is further configured to store identification data associated with a plurality of toolsets, each toolset comprising a group of tools, and each tool of the toolset being a variation of a same type of tool.

3. The surgical system of claim 2, wherein the one or more controllers are configured to:
compare the detected position of the tool feature with the identification data stored in the memory to determine:
the identity of the tool, an identity of the toolset of the tool, and an identity of at least one other tool of the toolset; and
present, on the display, the identity of the tool and the identity of the at least one other tool of the toolset.

4. The surgical system of claim 3, wherein:
the tool is a first reamer of a reamer toolset, the reamer toolset comprising the first reamer and at least one other reamer; and
the one or more controllers are configured to present, on the display, the identity of the first reamer and the identity of the at least one other reamer of the reamer toolset.

5. The surgical system of claim 3, wherein:
the tool is a first impactor of an impactor toolset, the impactor toolset comprising the first impactor and at least one other impactor; and
the one or more controllers are configured to present, on the display, the identity of the first impactor and the identity of the at least one other impactor of the impactor toolset.

6. The surgical system of claim 1, further comprising a surgical robot, and wherein:
the tool is adapted to attach to the surgical robot;
when attached to the surgical robot, the tool feature is arranged at a first location with respect to a reference point located on the surgical robot; and
the identification data comprises expected coordinates of the first location with respect to the reference point.

7. The surgical system of claim 6, further comprising:
a second tool comprising a second tool feature;
the second tool adapted to attach to the surgical robot;
when attached to the surgical robot, the second tool feature is arranged at a second location with respect to the reference point located on the surgical robot, wherein the first location and the second location are spaced from each other by a known distance; and
the identification data comprises expected coordinates of the second location with respect to the reference point.

8. The surgical system of claim 6, wherein:
the navigation system further comprises a tracker coupled to the surgical robot, the tracker comprising a known relationship relative to the reference point located on the surgical robot;
the localizer is configured to detect a position of the tracker and detect the position of the tool feature in a common coordinate system;
the one or more controllers are configured to utilize the detected position of the tracker, the detected position of the tool feature, and the known relationship to determine actual coordinates of the first location with respect to the reference point; and
the one or more controllers are configured to compare, with respect to the reference point, the actual coordinates of the first location with the expected coordinates of the first location to determine the identity of the tool.

9. The surgical system of claim 1, wherein the one or more controllers are configured to:
receive a user selection to manually verify the identity of the tool presented on the display, wherein the user selection comprises selection of the identity of the tool or selection of the identity of the at least one other tool.

10. The surgical system of claim 1, wherein the localizer of the navigation system is further defined as one or more of: a machine vision system, a surface scanner, and a range finder.

11. A method of operating a surgical system, the surgical system including a tool comprising a tool feature, a navigation system comprising a localizer, a display, a memory configured to store identification data associated with a

plurality of tools, and one or more controllers coupled to the navigation system, the memory and the display, the method comprising:

detecting, with the localizer, a position of the tool feature;

receiving, with the one or more controllers, the detected position of the tool feature from the localizer;

comparing, with the one or more controllers, the detected position of the tool feature with the identification data stored in the memory;

in response to comparing, determining an identity of the tool with the one or more controllers; and

instructing, with the one or more controllers, the display to present the identity of the tool and an identity of at least one other tool.

12. The method of claim 11, comprising the memory storing identification data associated with a plurality of toolsets, each toolset comprising a group of tools, and each tool of the toolset being a variation of a same type of tool.

13. The method of claim 12, comprising:

comparing, with the one or more controllers, the detected position of the tool feature with the identification data stored in the memory for determining: the identity of the tool, an identity of the toolset of the tool, and an identity of at least one other tool of the toolset; and

instructing, with the one or more controllers, the display to present the identity of the tool and the identity of the at least one other tool of the toolset.

14. The method of claim 13, wherein the tool is a first reamer of a reamer toolset, the reamer toolset comprising the first reamer and at least one other reamer, the method comprising:

instructing, with the one or more controllers, the display to present the identity of the first reamer and the identity of the at least one other reamer of the reamer toolset.

15. The method of claim 13, wherein the tool is a first impactor of an impactor toolset, the impactor toolset comprising the first impactor and at least one other impactor, the method comprising:

instructing, with the one or more controllers, the display to present the identity of the first impactor and the identity of the at least one other impactor of the impactor toolset.

16. The method of claim 11, wherein the surgical system further comprises a surgical robot, the method comprising:

attaching the tool to the surgical robot for arranging the tool feature at a first location with respect to a reference point located on the surgical robot; and

obtaining, with the one or more controllers, the identification data comprising expected coordinates of the first location with respect to the reference point.

17. The method of claim 16, wherein the navigation system further comprises a tracker coupled to the surgical robot, the tracker comprising a known relationship relative to the reference point located on the surgical robot, the method comprising:

detecting, with the localizer, a position of the tracker and the position of the tool feature in a common coordinate system;

utilizing, with the one or more controllers, the detected position of the tracker, the detected position of the tool feature, and the known relationship for determining actual coordinates of the first location with respect to the reference point; and

comparing, with the one or more controllers, with respect to the reference point, the actual coordinates of the first location with the expected coordinates of the first location; and

in response to comparing, determining the identity of the tool with the one or more controllers.

18. The method of claim 11, comprising:

receiving, with the one or more controllers, a user selection for manually verifying the identity of the tool presented on the display, wherein the user selection comprises selecting the identity of the tool or selecting the identity of the at least one other tool.

19. A navigation system, comprising:

a localizer configured to detect a position of a tool feature of a tool;

a display;

a memory configured to store identification data associated with a plurality of tools; and

one or more controllers coupled to the localizer, the display, and the memory, and the one or more controllers being configured to:

receive, from the localizer, the detected position of the tool feature;

compare the detected position of the tool feature with the identification data stored in the memory to determine an identity of the tool; and

present, on the display, the identity of the tool and an identity of at least one other tool.

20. A method of operating a navigation system, the navigation system comprising a localizer configured to detect a position of a tool feature of a tool, a display, a memory configured to store identification data associated with a plurality of tools, and one or more controllers coupled the localizer, the display, and the memory, the method comprising:

detecting, with the localizer, a position of the tool feature;

receiving, with the one or more controllers, the detected position of the tool feature from the localizer;

comparing, with the one or more controllers, the detected position of the tool feature with the identification data stored in the memory;

in response to comparing, determining an identity of the tool with the one or more controllers; and

instructing, with the one or more controllers, the display to present the identity of the tool and an identity of at least one other tool.

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