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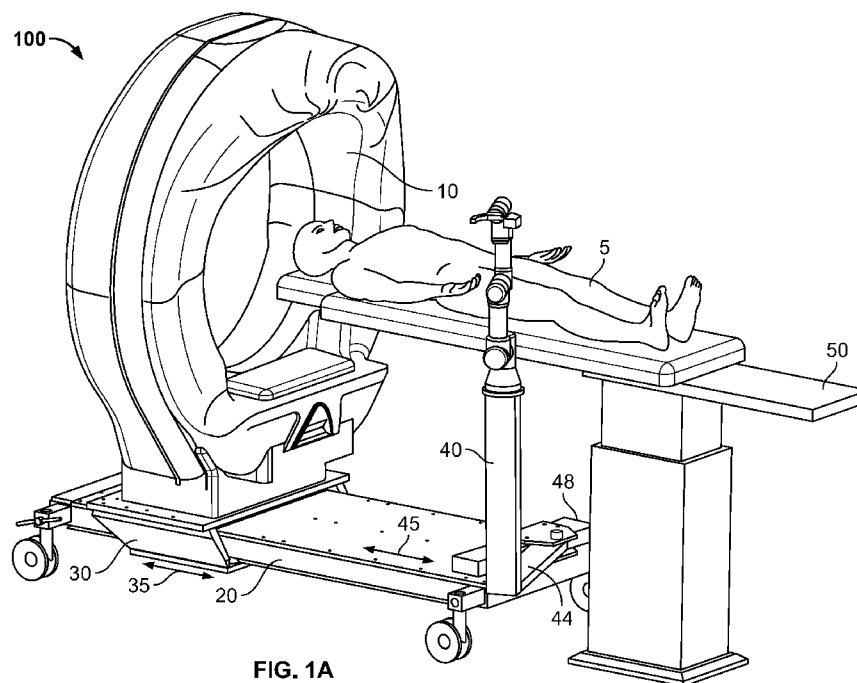


FIG. 1A

(57) Abstract: A system for performing robotic surgery on a patient disposed on a bed includes a gantry comprising a computed tomography (CT) diagnostic device, a platform supporting the gantry, and a robotic arm assembly attached to the platform. The gantry slides along the platform via a first carriage to allow entry of at least part of the patient into the bore of the CT device. The robotic arm assembly is attached to the platform via a pivot arm and a second carriage to allow the assembly to slide along the platform to enable surgery to be performed on the patient. The pivot arm is substantially parallel to the upper surface of the platform.



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SYSTEM FOR PERFORMING ROBOTIC SURGERY

CLAIM OF PRIORITY

[0001] This application claims priority from U.S. Provisional Application No. 62/666,035, filed on May 2, 2018, and U.S. App. Ser. No. 16/402,002, filed on May 2, 2019, both of which are incorporated by reference in their entireties.

BACKGROUND

[0002] X-ray computed tomography (CT) may be used to scan and image an area of a patient prior to or during surgery. Such imaging has recently been supplemented with a robotic arm to perform or assist with the surgery. The arrangement of the gantry and the robotic arm may make it difficult in some situations to perform surgery on the patient.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0003] FIG. 1A is a system for performing robotic surgery, according to an embodiment of the present invention;
- 15 [0004] FIGS. 1B and 1C are more detailed diagrams of the robotic arm assembly of the system of FIG. 1A, according to embodiments of the present invention;
- [0005] FIG. 1D is a top view of the system of FIG. 1A, showing four possible locations for the robotic arm assembly, according to embodiments of the present invention;
- 20 [0006] FIGS. 2A and 2B show uses of the system of FIG. 1A during abdominal cavity operations, according to embodiments of the invention;
- [0007] FIGS. 3A-3C show uses of the system of FIG. 1A during thoracic operations, according to embodiments of the invention;
- [0008] FIGS. 4A-4C show uses of another system for performing robotic surgery, according to embodiments of the invention;
- 25

[0009] FIGS. 5A-5B are diagrams of another system for performing robotic surgery, according to embodiments of the present invention;

[0010] FIGS. 6A-6D show uses of the systems of FIGS. 5A-5B during robotic surgery, according to embodiments of the invention;

5 [0011] FIGS. 7A-7C show additional uses of the systems of FIGS. 5A-5B during robotic surgery, according to embodiments of the invention;

[0012] FIGS. 8A-8D show additional uses of the systems of FIGS. 5A-5B during robotic surgery, according to embodiments of the invention;

[0013] FIGS. 9A-9F are diagrams of another system for performing robotic surgery,
10 according to embodiments of the present invention; and

[0014] FIGS. 10A-10C show uses of the systems of FIGS. 9A-9F during robotic surgery, according to embodiments of the invention.

[0015] Where considered appropriate, reference numerals may be repeated among the drawings to indicate corresponding or analogous elements. Moreover, some of
15 the blocks depicted in the drawings may be combined into a single function.

DETAILED DESCRIPTION

[0016] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of embodiments of the invention.

20 However, it will be understood by those of ordinary skill in the art that the embodiments of the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components, and circuits have not been described in detail so as not to obscure the present invention.

[0017] The inventors have developed a system that allows a surgeon to operate on a variety of locations on a patient, including left and right thoracic cavity; left and
25 right abdominal cavity; left, right, and center of the brain; and areas of the neck. The system includes a gantry including a CT, a platform supporting the gantry, and a robotic arm assembly attached to the platform or the gantry via a pivot arm.

Depending on the bore diameter of the gantry, various embodiments have been made to allow the robotic arm to access different parts of the body.

[0018] Reference is now made to FIG. 1A, which shows a system 100 for performing robotic surgery, according to an embodiment of the present invention.

5 System 100 includes gantry 10, which contains within it a CT scanning and imaging device, platform 20 that supports gantry 10, and robotic arm assembly 40. Gantry 10 may move along direction 35 via carriage 30 in order to engage and disengage the CT with patient 5, who is disposed on bed 50. Patient 5 may be human or may be an animal, in the event that the CT device is used for veterinary purposes. Gantry
10 10 may have a bore diameter of 95 cm or more to allow patient 5 to have full body access to the CT device. Bed 50 may be a poly-articulated operating bed, e.g., the TruSystem[®] 7500 Hybrid Operating Room Table manufactured by Trumpf Medical, of Germany, a subsidiary of Hill-Rom Holdings, Inc. Other operating beds may also be used, including those that are not fixed in place (e.g., those with wheels that lock).
15 An example of a radiological bed has been described in PCT International Publication No. WO 2018/047052, "Radiological bed," published March 15, 2018, and subject to an assignment to the applicant of this application or to an affiliate of the applicant, the entirety of which is incorporated herein by reference to the extent applicable. Platform 20 may have wheels in order to move the whole system if
20 needed, for example to allow for more space for surgical staff to perform surgery. Robotic arm assembly 40 may be attached via pivot arm 44 to a second carriage 48, which is attached to platform 20 and may move along direction 45.

[0019] Pivot arm 44 is substantially parallel to the upper surface of platform 20. Pivot arm 44 allows robotic arm assembly 40 to be placed in multiple positions to
25 allow better access to patient 5. As shown in FIG. 1B, pivot arm 44 may be attached to second carriage 48 via pivot 41, which may be pivoted by a surgeon. As shown in FIG. 1C, pivot 41 may be replaced by motor shaft 43 attached to motor 42, which may be a stepper motor, which may allow for more precise positioning and control of robotic arm assembly 40 around the pivot point, including to lock pivot arm 44 in
30 place. The pivot/motor assembly may also include optical encoder 47 and multiple solenoids (not shown), brushless torque actuators (BTA), or other alternative means, such as ratcheting devices, or gear arrangements, to enhance the precision, control,

and locking abilities. The motion of second carriage 48 along direction 45 may be “sensorized” (i.e., have sensors) in order to know its position with respect one of the ends of platform 20. Second carriage 48 could also be motorized in order to be positioned electronically along direction 45. In this case there will be two positioning
5 axes (the translation along direction 45 and the rotation about pivot 41) plus six axes for the robot for a total of eight axes.

[0020] Robotic arm assembly 40, which may be a six-axis robot, may perform the surgical procedure itself. The robotic arm assembly may include a sensorized guide, which may be used as a surgical instrument holder that is placed automatically in the
10 right locations using the proper orientation. The surgical instrument may be inserted directly into the patient or into a cannula attached to the robotic arm assembly or sensorized guide at a single access point. The surgical procedure may be monitored using CT or fluoroscopy. Examples of robotic arm assemblies have been described in the following documents that are subject to an assignment to the applicant of this
15 application or to an affiliate of the applicant: (1) U.S. Pat. App. Ser. No. 62/572,986, “Robot Assisted Surgical Guide System for Performing Surgery,” filed October 16, 2017; (2) U.S. Pat. App. Ser. No. 62/627,565, “Apparatus and Method for Controlling the Use of Surgical Instruments During Surgery,” filed February 7, 2018; (3) U.S. Pat. App. Ser. No. 16/160,575, “Robot-Assisted Surgical Guide System for
20 Performing Surgery,” filed October 15, 2018; (4) U.S. Pat. App. Ser. No. 62/630,612, “Method for Determination of Surgical Procedure Access,” filed February 14, 2018, and (5) U.S. Pat. App. Ser. No. 16/275,313, “Method for Determination of Surgical Procedure Access,” filed February 13, 2019. The entireties of U.S. Pat. App. Ser. Nos. 62/572,986, 62/627,565, 16/160,575, 62/630,612, and 16/275,313 are
25 incorporated herein by reference to the extent applicable.

[0021] FIG. 1D is a top view of system 100, showing four possible locations for robotic arm assembly 40 – 40a, 40b, 40c, 40d. Locations 40a, 40d may be realized with second carriage 48 in the position shown in FIG. 1A; locations 40b, 40c may be realized with second carriage 48 in a second position, translated towards gantry 10
30 in direction 45. Location 40a may allow easier access to the patient’s lower left side during surgery; location 40b may allow easier access to the patient’s upper left side during surgery; location 40c may allow easier access to the patient’s upper right side

during surgery; and location 40d may allow easier access to the patient's lower right side during surgery.

[0022] The operation of system 100, and other systems described in this specification, are generally consistent with the operation of systems described in the following documents that are subject to an assignment to the applicant of this application or to an affiliate of the applicant: (1) PCT International Publication No. WO 2017/134546, "Radiological Imaging Device," published August 10, 2017; (2) U.S. Pat. Pub. No. 2019/038240, "Radiological Imaging Device," published February 7, 2019; (3) U.S. Pat. No. 9,510,793, "Radiological Imaging Device with Advanced Sensors," issued Dec. 6, 2016; (4) U.S. Pat. No. 10,016,171, "Radiological imaging device with improved functionality," issued July 10, 2018; and (5) U.S. Pat. No. 10,265,042, "Radiological imaging device with improved functioning," issued April 23, 2019. The entireties of WO 2017/134546, U.S. Pat. Pub. No. 2019/038240, and U.S. Pat. Nos. 9,510,793, 10,016,171, and 10,265,042 are incorporated herein by reference to the extent applicable.

[0023] FIGS. 2A and 2B show uses of system 100 during abdominal cavity operations, according to embodiments of the invention. In FIG. 2A, gantry 10 may move forward on platform 20 in order to perform a scan or a fluoroscopy, either prior to or during surgery. In FIG. 2B, after the scan, gantry 10 may move back, and robotic arm assembly 40 may move via movement of second carriage 48 and pivot arm 44 so that the robot may perform (or assist in) surgery.

[0024] FIGS. 3A-3C show uses of system 100 during thoracic operations (on the patient's spine), according to embodiments of the invention. In FIG. 3A, gantry 10 may move forward on platform 20 in order to perform a scan or a fluoroscopy, either prior to or during surgery. In FIG. 3B, after the scan, gantry 10 may move back, and robotic arm assembly 40 may move via movement of second carriage 48 and pivot arm 44 so that the robot may perform (or assist in) surgery. FIG. 3C shows a top view of FIG. 3B in which robotic arm assembly 40 has pivoted to the other side of bed 50 to perform an operation from the right side of the patient.

[0025] FIGS. 4A-4C show uses of a system 150 during brain operations, according to embodiments of the invention. System 150 is a modified version of system 100, in which gantry 110 includes x-ray source 112 and x-ray detector 114,

which are movable toward and away from each other. Having the source and detector movable increases the scan resolution, which is important for brain surgery. In FIGS. 4A-4C, patient 5 and bed 50 approach system 150 from the opposite direction illustrated in previous figures.

5 [0026] In FIG. 4A, gantry 110 may move forward on platform 20 in order to perform a scan or a fluoroscopy, either prior to or during surgery. In FIG. 4B, after the scan, gantry 110 may move back, x-ray source 112 and x-ray detector 114 may retract, and robotic arm assembly 40 may move via movement of second carriage 48 and pivot arm 44 so that the robot may perform (or assist in) surgery. FIG. 4C
10 shows that robotic arm assembly 40, via movement of second carriage 48 and pivot arm 44, may move out of the operating area if desired.

[0027] FIG. 5A shows a system 200 for performing robotic surgery, according to an embodiment of the present invention. System 200 varies from systems 100 and 150 in a few ways. First, the bore diameter of gantry 210 is generally smaller than that of gantries 10 and 110 – on the order of 60 cm rather than 95 cm or more. Such
15 gantries are more suited for brain operations, and possibly for pediatric and veterinary operations. Gantry 210 also contains within it a CT scanning and imaging device, is supported by platform 220, and may move via carriage 230 in order to engage and disengage the CT with patient 5 disposed on bed 50. Platform 220 may
20 have wheels as did platform 20. An example of a CT device to be used within system 200 is Epica International's Vimago™ CT scanner.

[0028] Second, system 200 includes robotic arm assembly 240, which may be attached via pivot arm 244 to pivot 241 at the top center of gantry 210. Pivot 241 and pivot arm 244 may operate in the same manner as pivot 41 and pivot arm 44 in
25 system 100. Pivot 241 may also be replaced by a motor shaft and a motor and control system as described with respect to system 100. In these ways, robotic arm assembly 240 may operate on either side of gantry 210, and may operate on the right or left side of the patient's body.

[0029] FIG. 5B shows a system 300 for performing robotic surgery, according to
30 an embodiment of the present invention. System 300 varies from system 200 in that robotic arm assembly 340 is attached via pivot arm 344 at the bottom center of gantry 210. Except for the placement of the pivot, robotic arm assembly 340

operates in the same manner as robotic arm assembly 240. In addition, any of the drawings that follow that show the robotic arm assembly being attached at the top of the gantry may be modified by having the robotic arm assembly attached to the bottom of the gantry, as shown in FIG. 5B.

5 [0030] FIGS. 6A-6D show uses of system 200 (and 300) during operations with robotic arm assembly 240 and pivot arm 244 disposed on the front side of gantry 210, according to embodiments of the invention. In these embodiments, the patient's area of interest (e.g., brain) may be within the CT analysis zone of gantry 210. FIG. 6A shows robotic arm assembly 240 and pivot arm 244 in the front center
10 position, and FIG. 6B shows robotic arm assembly 240 and pivot arm 244 in the front right position. FIG. 6C shows a side view of an operation with robotic arm assembly 240 and pivot arm 244 on the front side of gantry 210. FIG. 6D shows a top view of three different positions for robotic arm assembly 240 and pivot arm 244 – location 244a, front left; location 244b, front center; and location 244c, front right. There may
15 be more than three positions on the front side of gantry 210 into which robotic arm assembly 240 may be placed, the mechanics of which were described with respect to FIGS. 1B and 1C.

[0031] FIGS. 7A-7C show uses of system 200 (and 300) during operations with robotic arm assembly 240 and pivot arm 244 disposed on the back side of gantry
20 210, according to embodiments of the invention. In those examples, gantry 210 may move forward on platform 220 out of the way of the patient. FIG. 7A shows robotic arm assembly 240 and pivot arm 244 in the back left position, and FIG. 7B shows robotic arm assembly 240 and pivot arm 244 in the back right position. FIG. 7C shows a side view of an operation with robotic arm assembly 240 and pivot arm 244
25 on the back side of gantry 210. Robotic arm assembly 240 may be placed in more than these positions on the back side of gantry 210, the mechanics of which were described with respect to FIGS. 1B and 1C.

[0032] FIGS. 8A-8D show uses of system 200 (and 300) during operations with robotic arm assembly 240 and pivot arm 244 again disposed on the front side of
30 gantry 210, according to embodiments of the invention. The patient and table are located on the front side of gantry 210 rather than on the back side, as was shown in FIGS. 6A-6D. In FIGS. 8A (perspective view) and 8B (side view), the patient's area

of interest (e.g., brain) may be within the CT analysis zone of gantry 210 during the operation. In FIGS. 8C (perspective view) and 8D (side view), platform 220 and gantry 210 have been moved so that the patient is no longer within the CT analysis zone of gantry 210 during the operation.

5 [0033] FIGS. 9A-9F show a system 400 for performing robotic surgery, according to an embodiment of the present invention. System 400 varies from systems 200 and 300 in that platform 420 is smaller, and there is no carriage separate from the platform that can move gantry 410. Instead, platform 420 itself can be moved if
10 desired. System 400 may be locked in the chosen position using four pins that can shunt the four wheels when the CT is in position. The four pins can be moved by hand or hydraulically. The bore diameter of gantry 410 is comparable to that of gantry 210 – on the order of 60 cm – and thus used for brain, pediatric, and veterinary operations. FIG. 9A shows the patient not yet within the CT analysis zone of gantry 410. FIG. 9B shows that bed 50 can extend the patient into the CT analysis
15 zone of gantry 410. In FIGS. 9C (perspective view) and 9D (top view), the patient's area of interest (e.g., brain) may be within the CT analysis zone of gantry 410 during the operation, with robotic arm assembly 440 and pivot arm 444 in the front left position. In FIGS. 9E (perspective view) and 9F (top view), the patient's area of interest (e.g., brain) may be within the CT analysis zone of gantry 410 during the
20 operation, with robotic arm assembly 440 and pivot arm 444 in the front right position. An example of a CT device to be used within system 400 is Epica International's Pico™ CT scanner.

[0034] FIGS. 10A-10C show uses of system 400 during operations with robotic arm assembly 440 and pivot arm 444 again disposed on the front side of gantry 410,
25 according to embodiments of the invention. The patient and table are located on the front side of gantry 410 rather than on the back side, as was shown in FIGS. 9A-9F. In FIGS. 10A (perspective view), 10B (side view), and 10C (top view), the patient's area of interest (e.g., neck and/or brain) may be within the CT analysis zone of gantry 410 during the operation. Robotic arm assembly 440 and pivot arm 444 can
30 reach either side of the patient's body.

[0035] Accordingly, systems for performing robotic surgery have been described that provide increased access to surgical areas on a patient who is subject to CT

scanning and/or imaging. The systems incorporate a CT gantry, a platform supporting the gantry, and a robotic arm assembly attached to the platform or gantry via a pivot arm. The pivot arm increases the surgical angles for the robotic arm. The pivot arm and associated motors may also help lock the robotic arm into position for more precise surgery.

5

[0036] The above discussion is meant to illustrate the principles and various embodiments of the present invention. Numerous variations and modifications will become apparent to those skilled in the art once the above disclosure is fully appreciated. It is intended that the following claims be interpreted to embrace all

10

such variations and modifications.

CLAIMS

1. A system for performing robotic surgery on a patient disposed on a bed, comprising:
 - a gantry comprising a computed tomography (CT) diagnostic device;
 - a platform supporting the gantry, the platform having an upper surface,wherein the gantry is configured to slide along the platform via a first carriage to allow entry of at least part of the patient into the bore of the CT device; and
 - a robotic arm assembly attached to the platform via a pivot arm and a second carriage, to allow the assembly to slide along the platform to enable surgery to be performed on the patient, wherein the pivot arm is substantially parallel to the upper surface of the platform.

2. The system of claim 1, wherein the gantry comprises a movable x-ray source and movable x-ray detector.

3. A system for performing robotic surgery on a patient disposed upon a bed, comprising:
 - a gantry comprising a computed tomography (CT) diagnostic device;
 - a platform supporting the gantry, the platform having an upper surface,wherein the gantry is configured to slide along the platform via a first carriage to allow entry of at least part of the patient into the bore of the CT device; and
 - a robotic arm assembly attached to the gantry via a pivot arm substantially parallel to the upper surface of the platform.

4. The system of claim 3, wherein the robotic arm assembly is attached to the top of the gantry.

5. The system of claim 3, wherein the robotic arm assembly is attached to the bottom of the gantry.

6. A system for performing robotic surgery on a patient disposed on a bed, comprising:
 - a gantry comprising a computed tomography (CT) diagnostic device;
 - a platform supporting the gantry, the platform having an upper surface; and
 - a robotic arm assembly attached to the gantry via a pivot arm substantially parallel to the upper surface of the platform.

7. The system of claim 6, wherein the robotic arm assembly is attached to the top of the gantry.

8. The system of claim 6, wherein the robotic arm assembly is attached to the bottom of the gantry.

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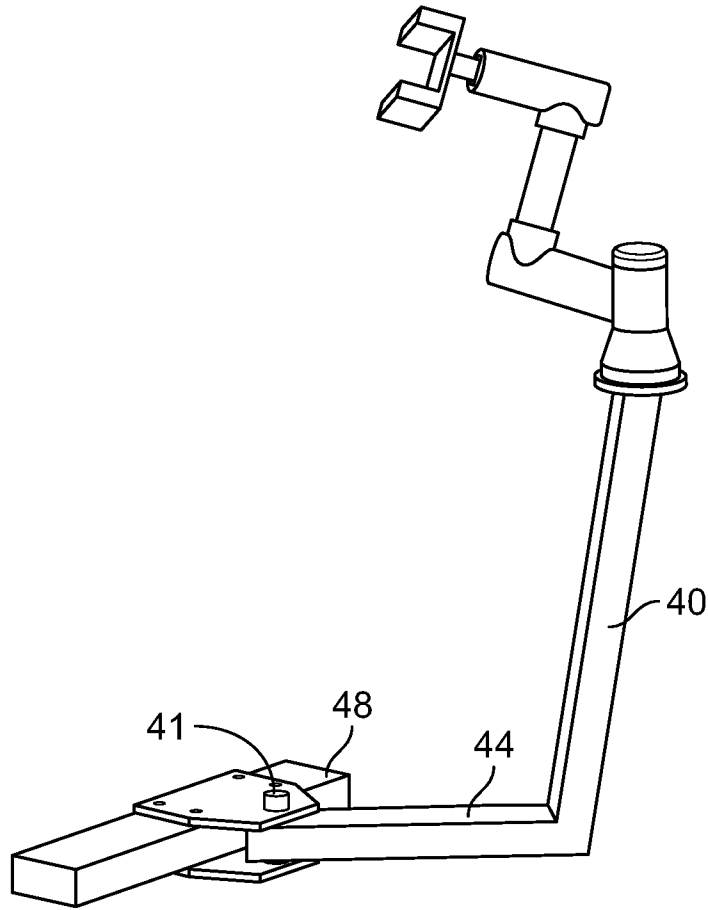


FIG. 1B

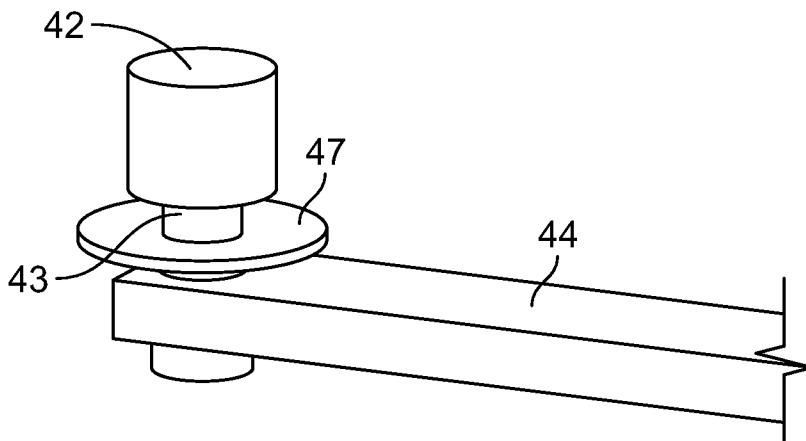


FIG. 1C

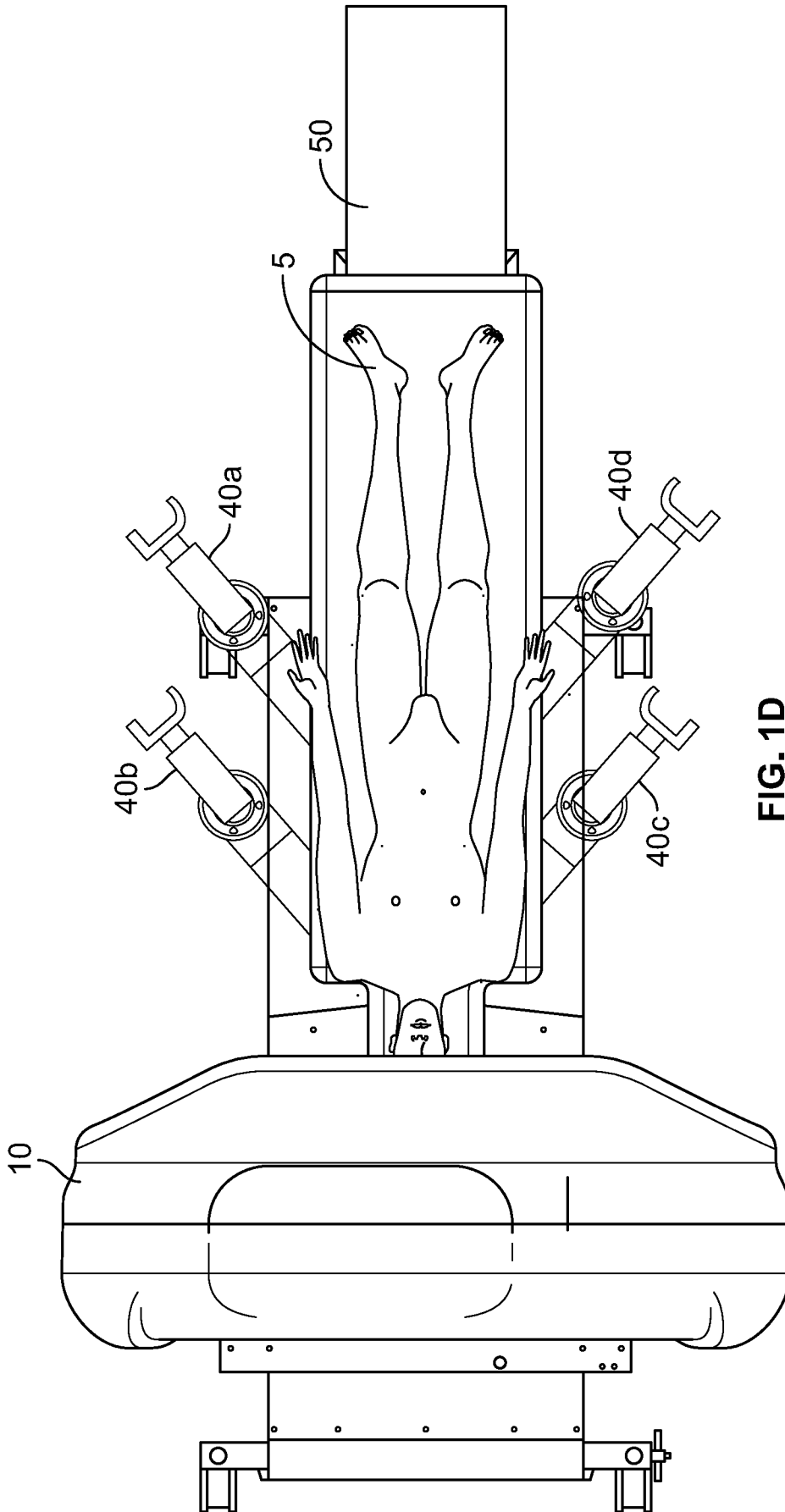


FIG. 1D

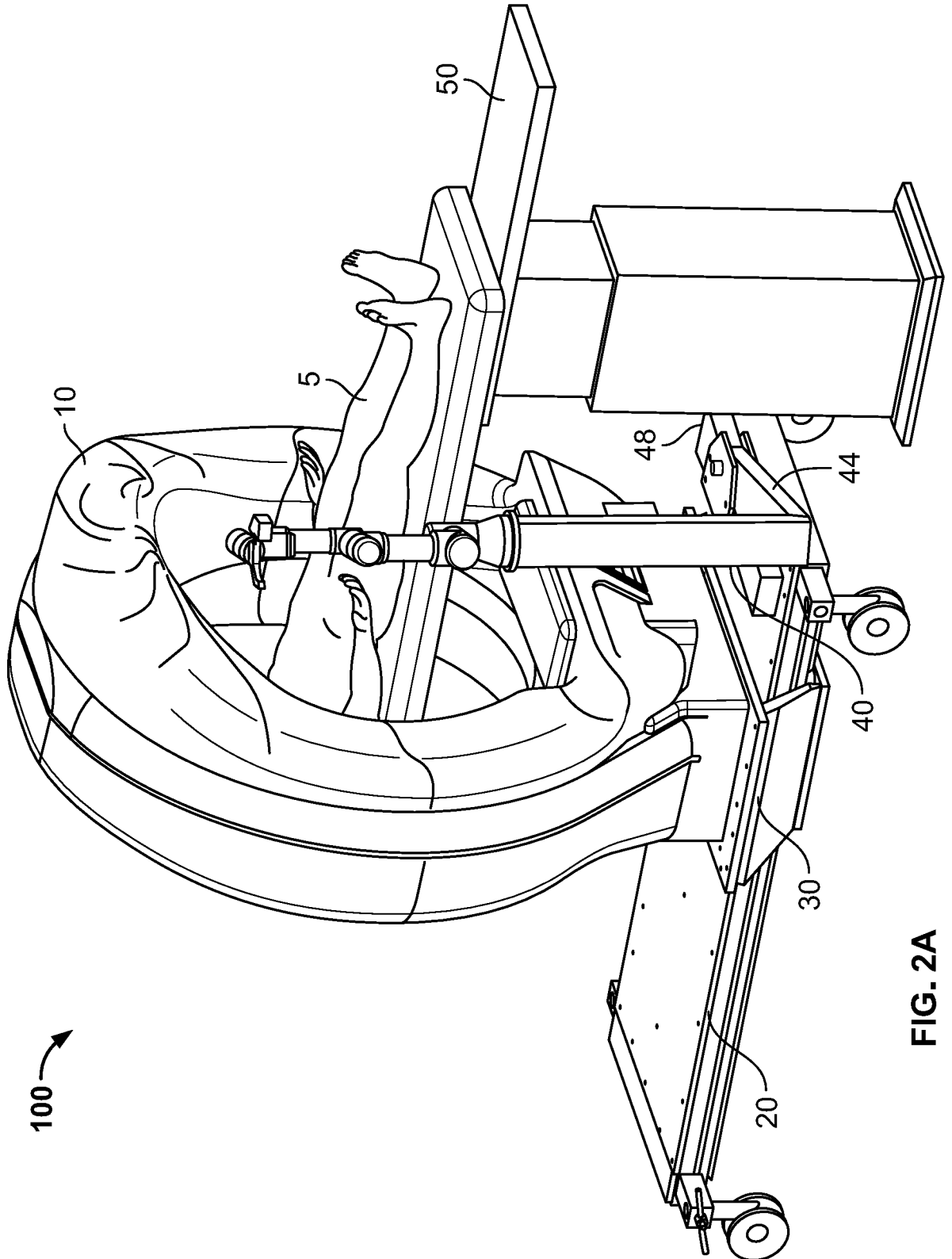


FIG. 2A

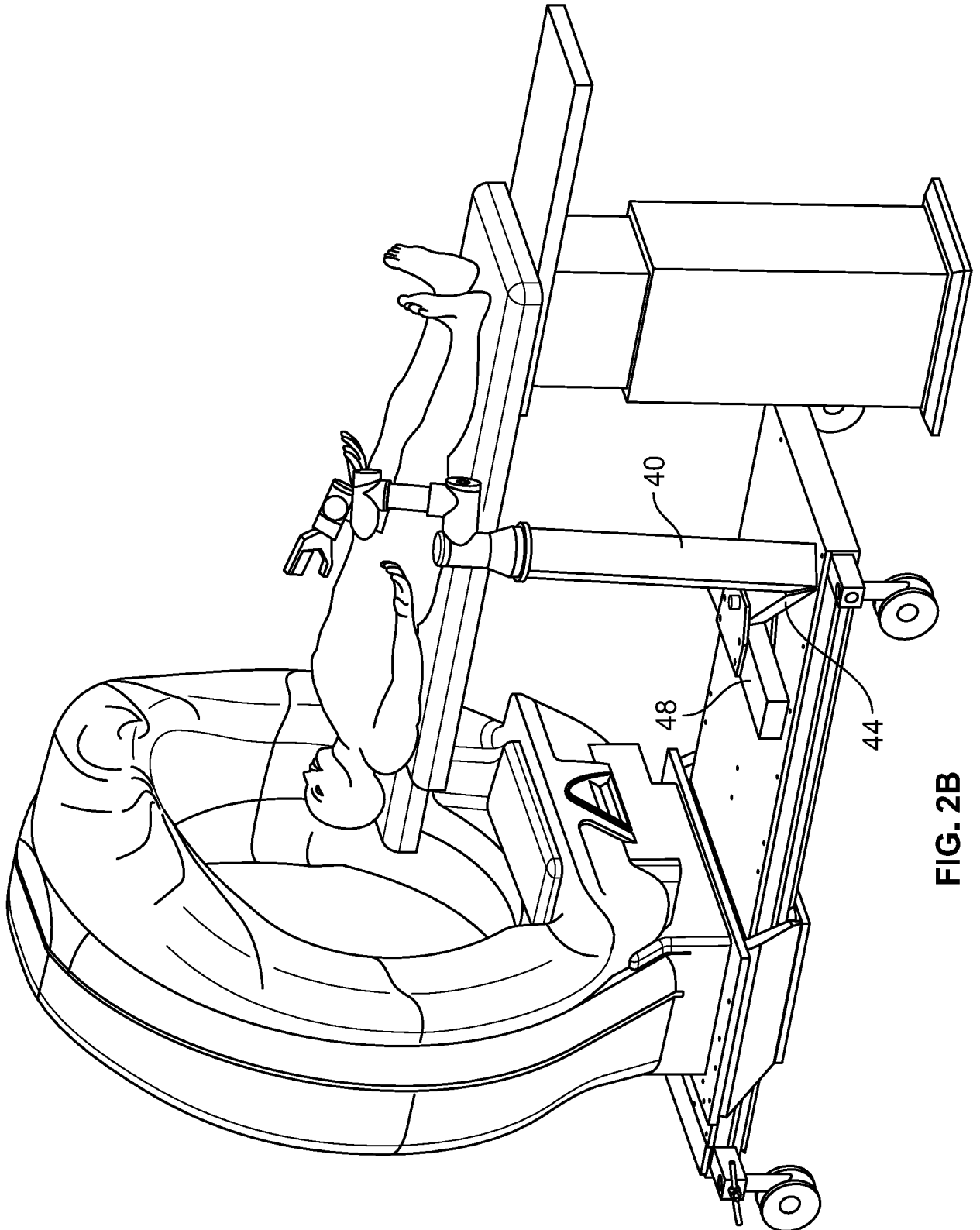


FIG. 2B

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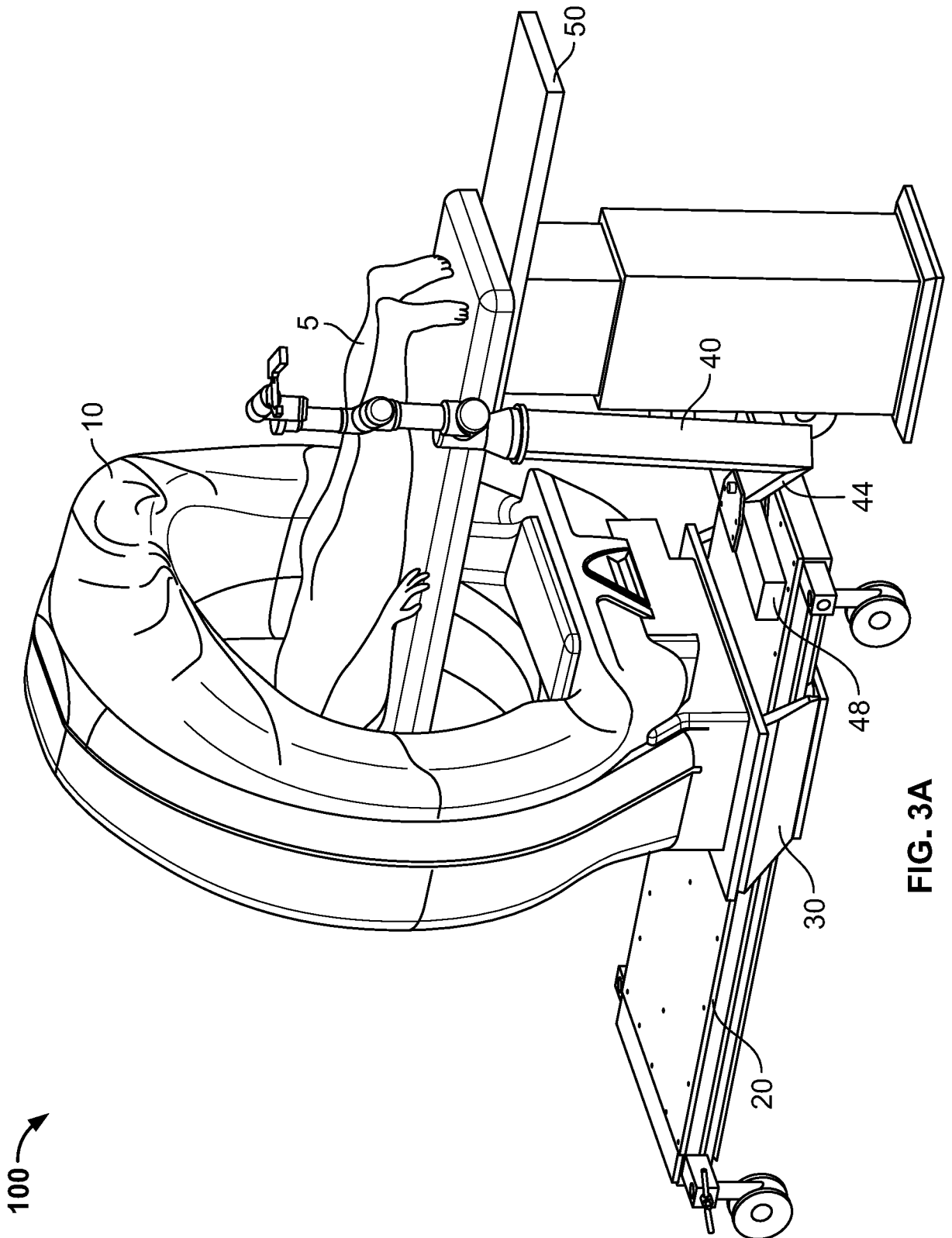


FIG. 3A

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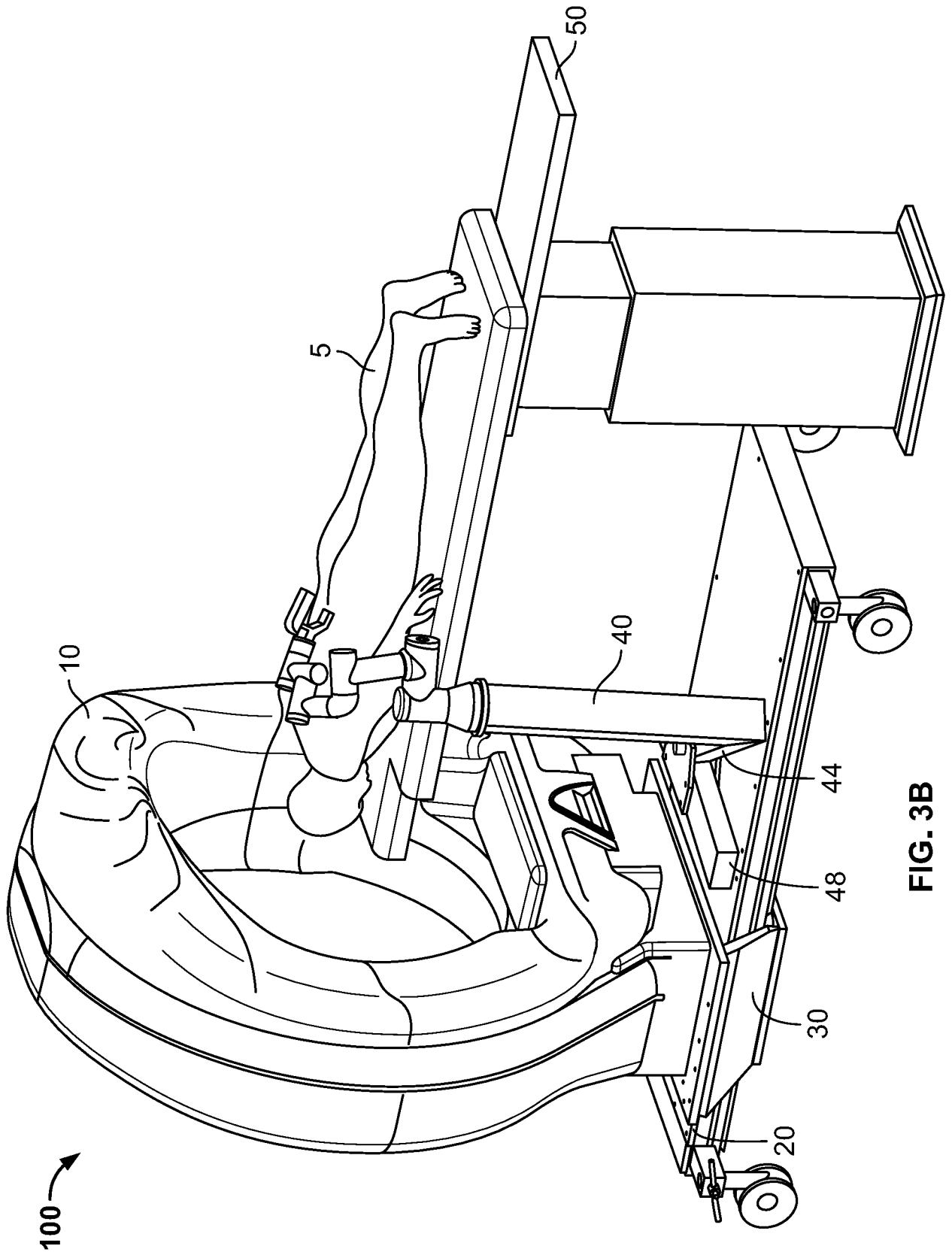


FIG. 3B

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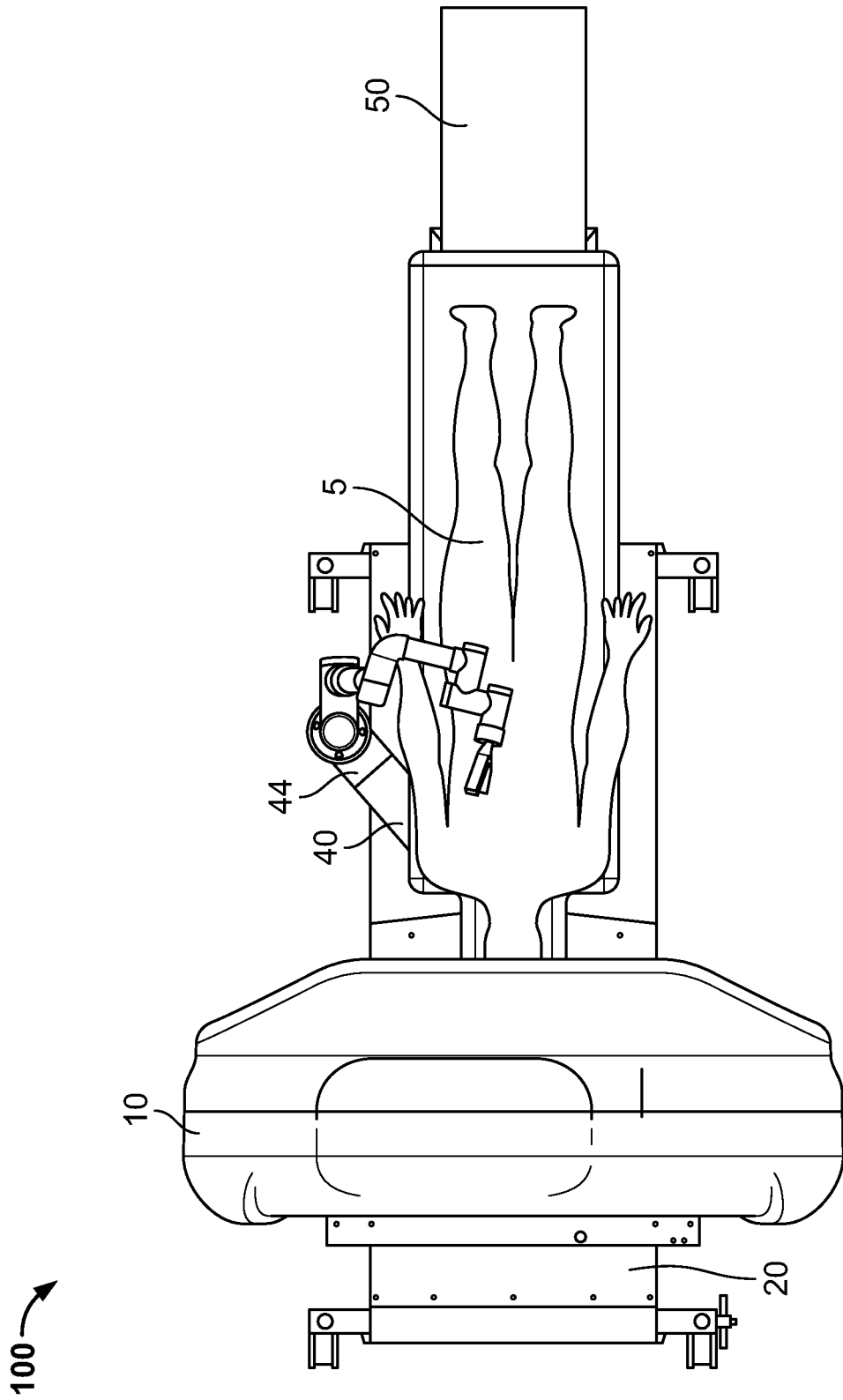


FIG. 3C

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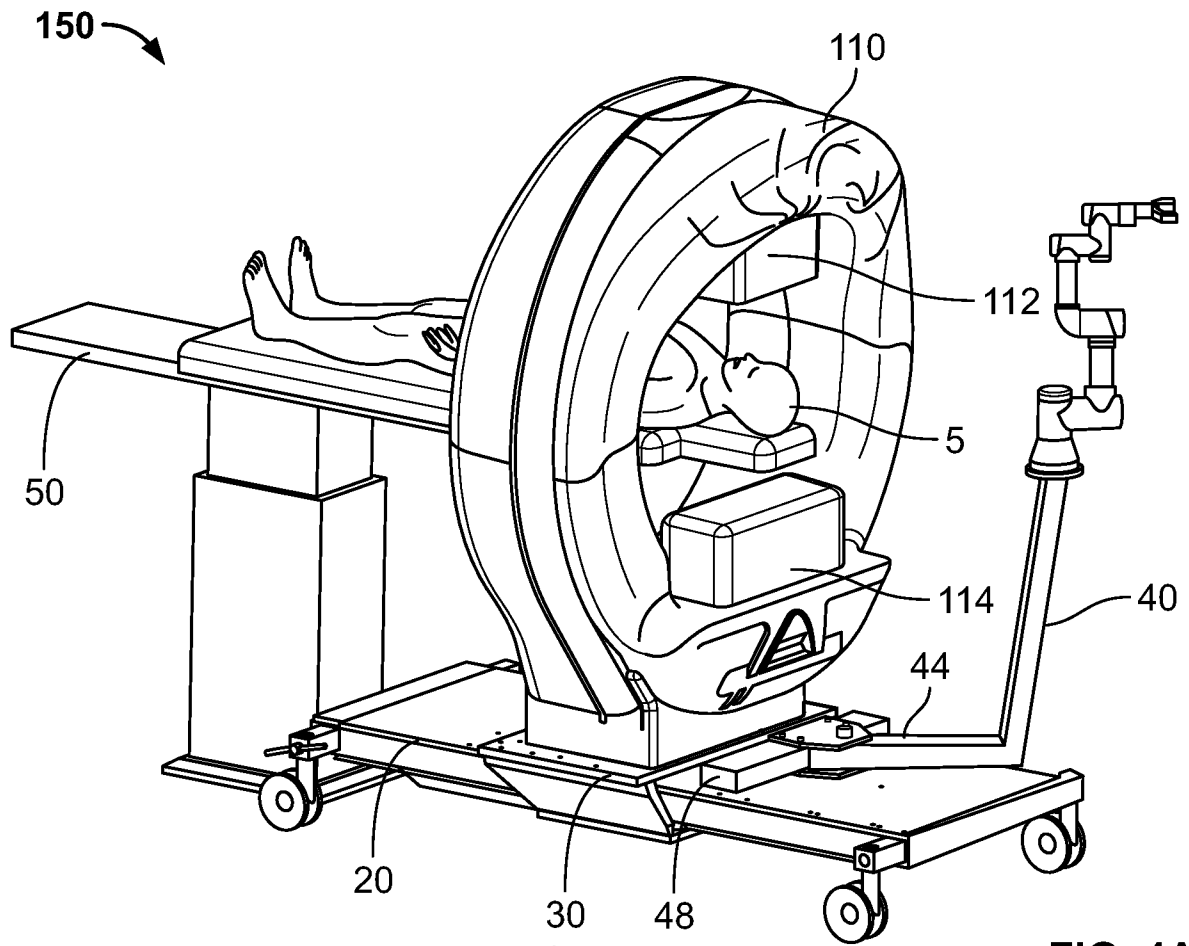


FIG. 4A

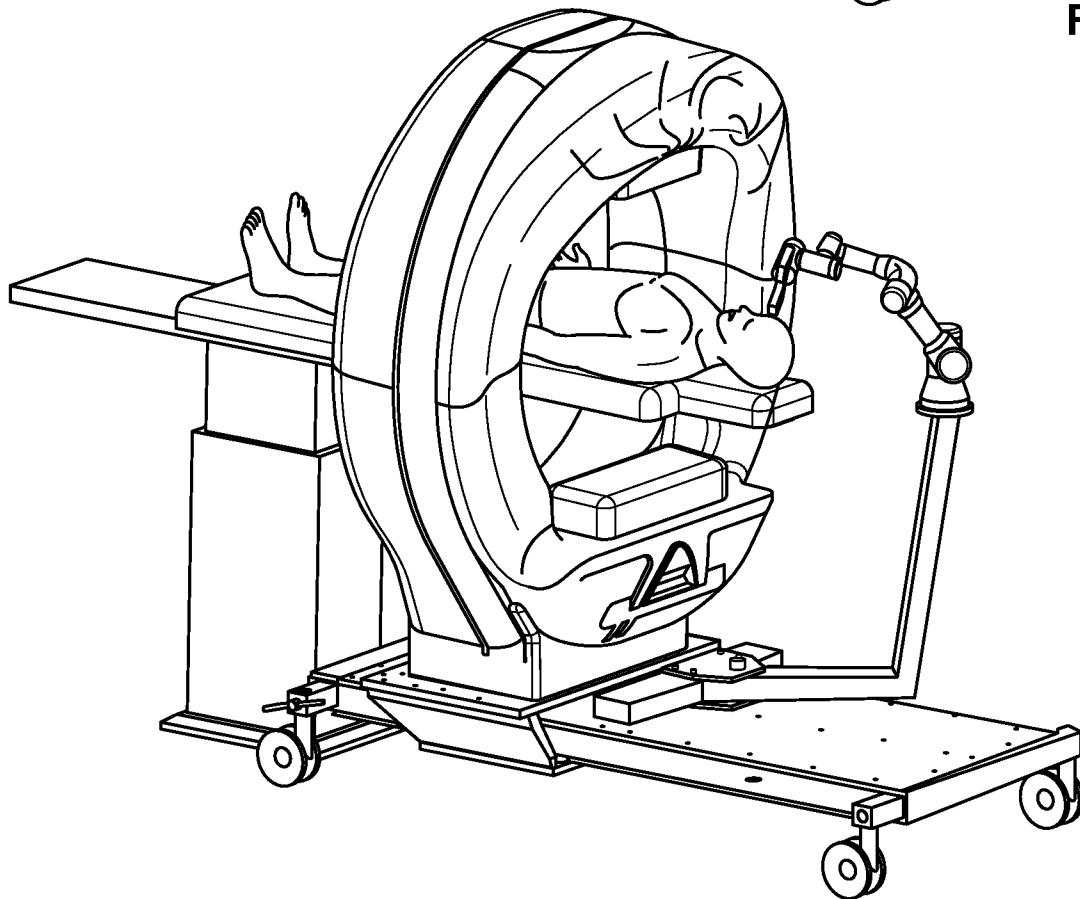


FIG. 4B

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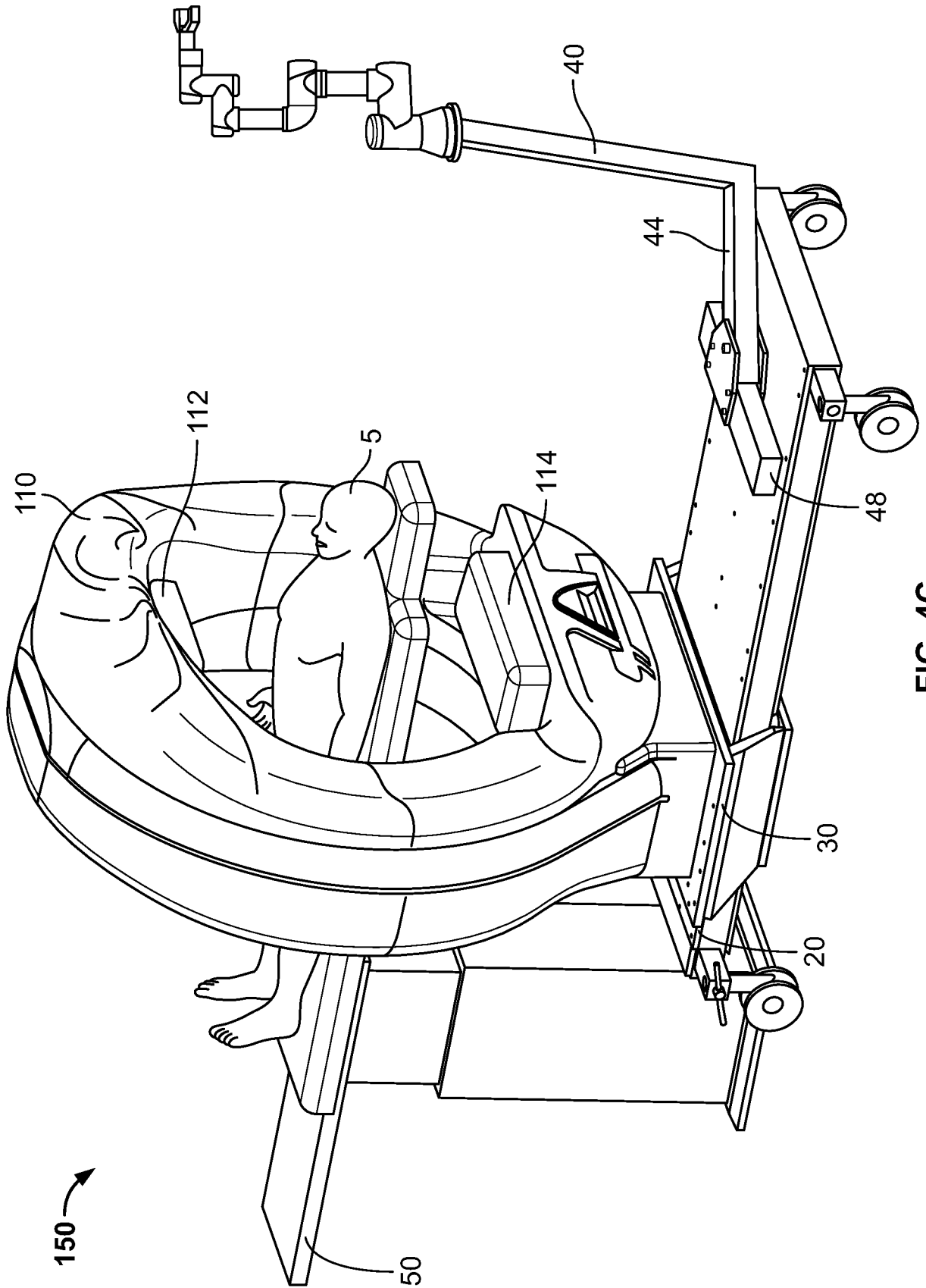


FIG. 4C

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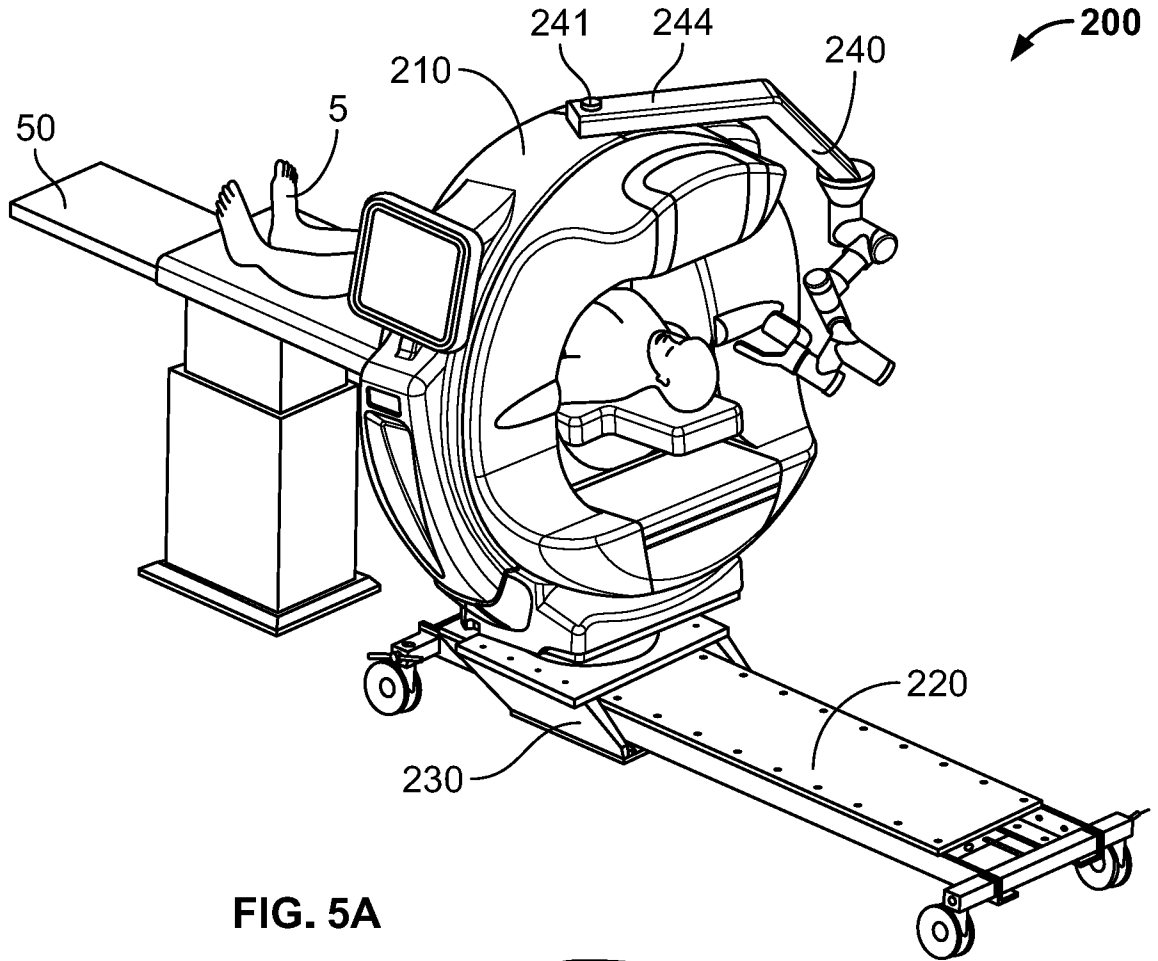


FIG. 5A

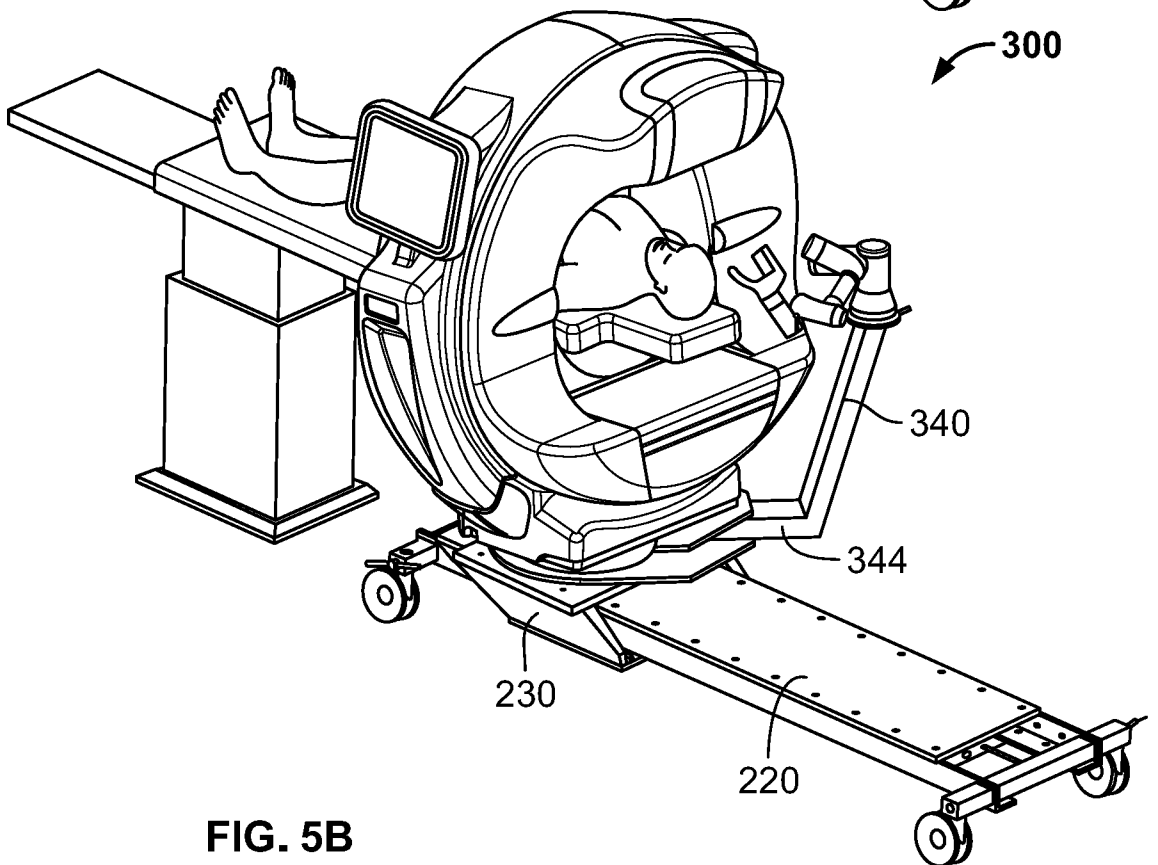


FIG. 5B

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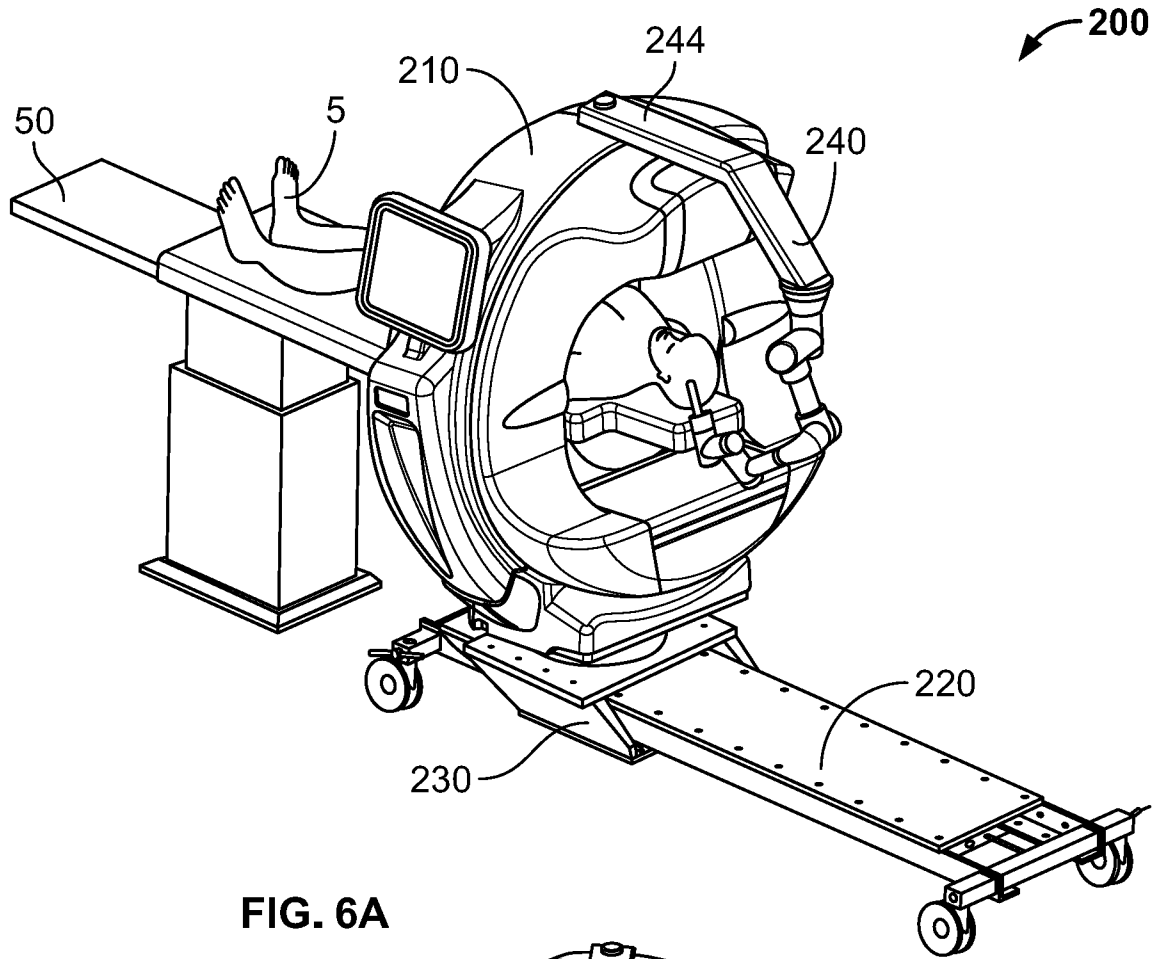


FIG. 6A

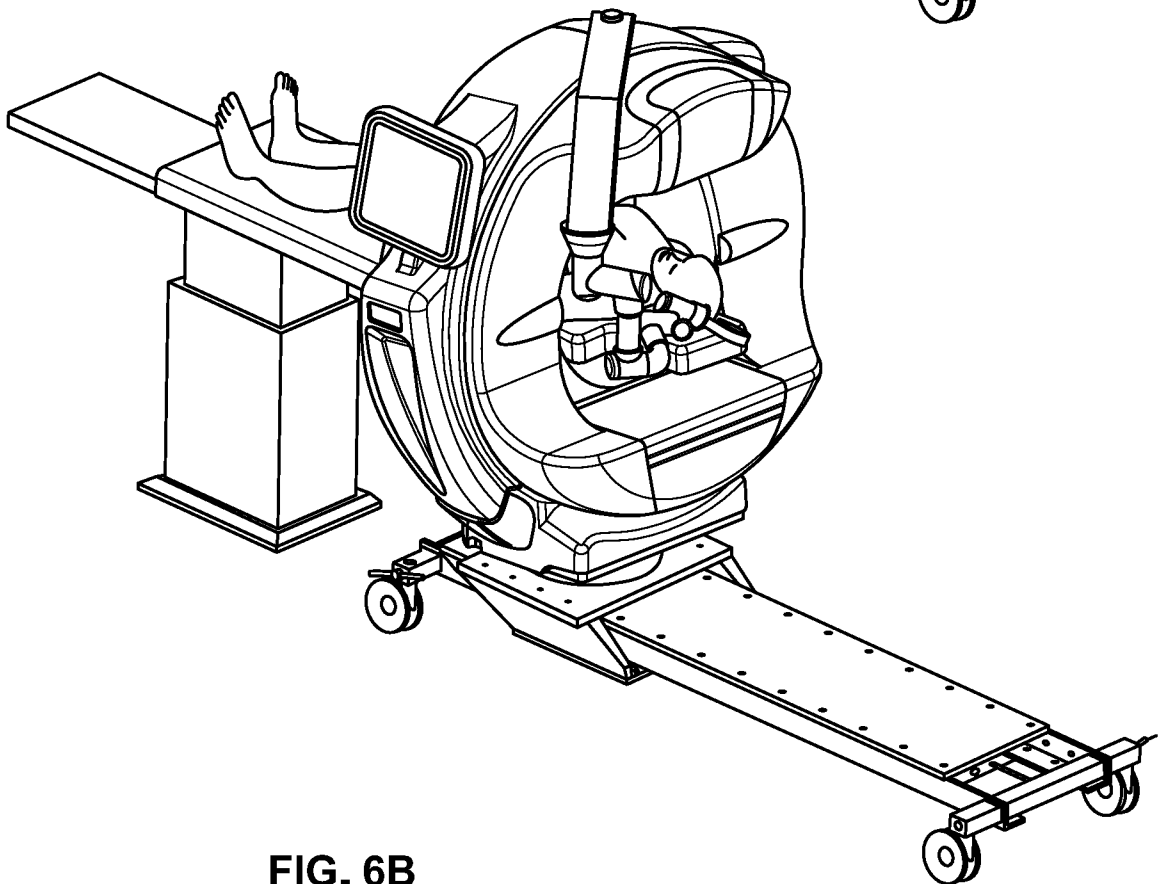


FIG. 6B

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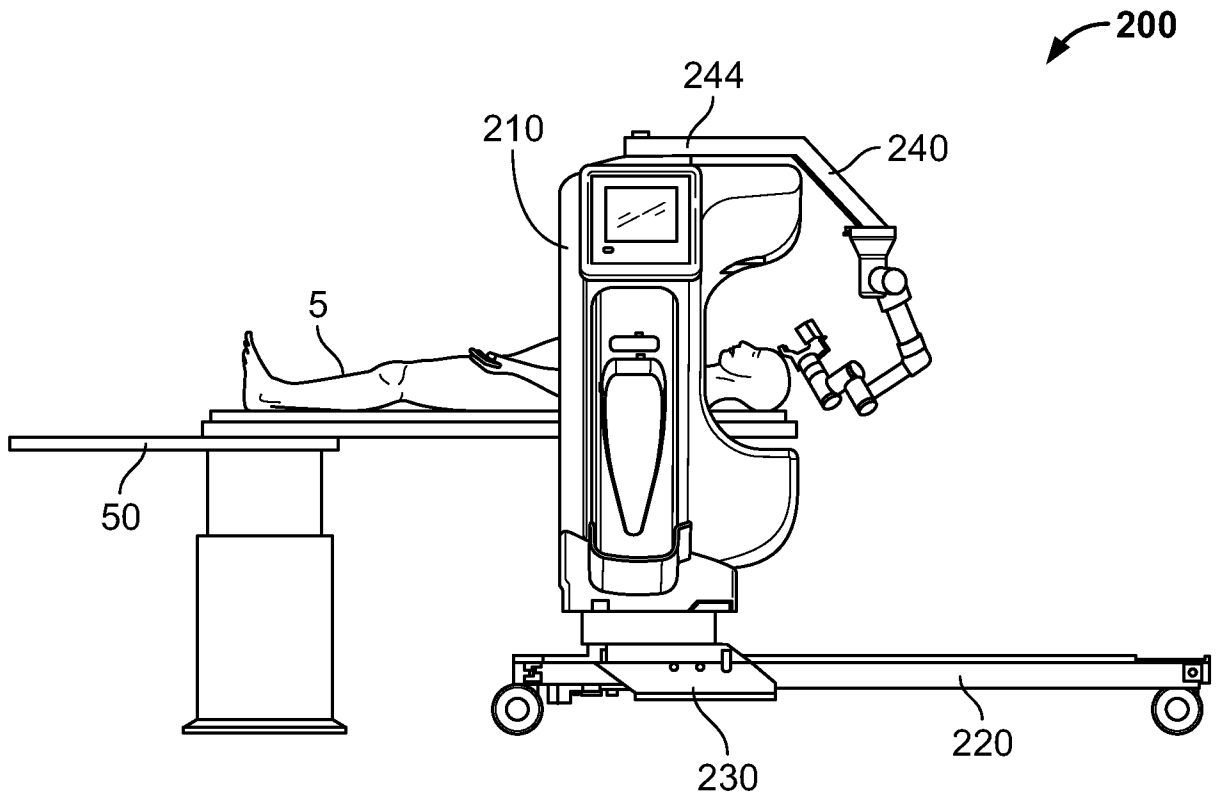


FIG. 6C

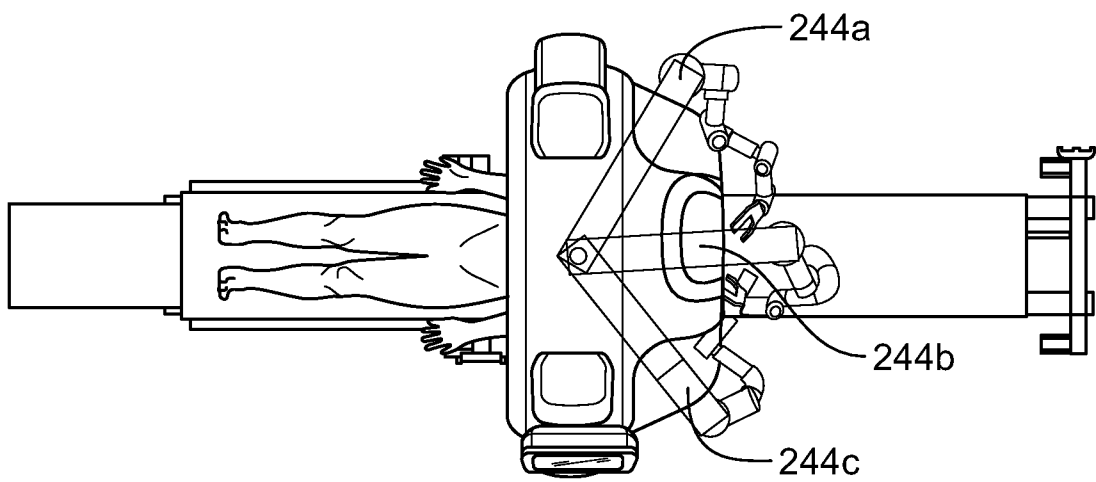


FIG. 6D

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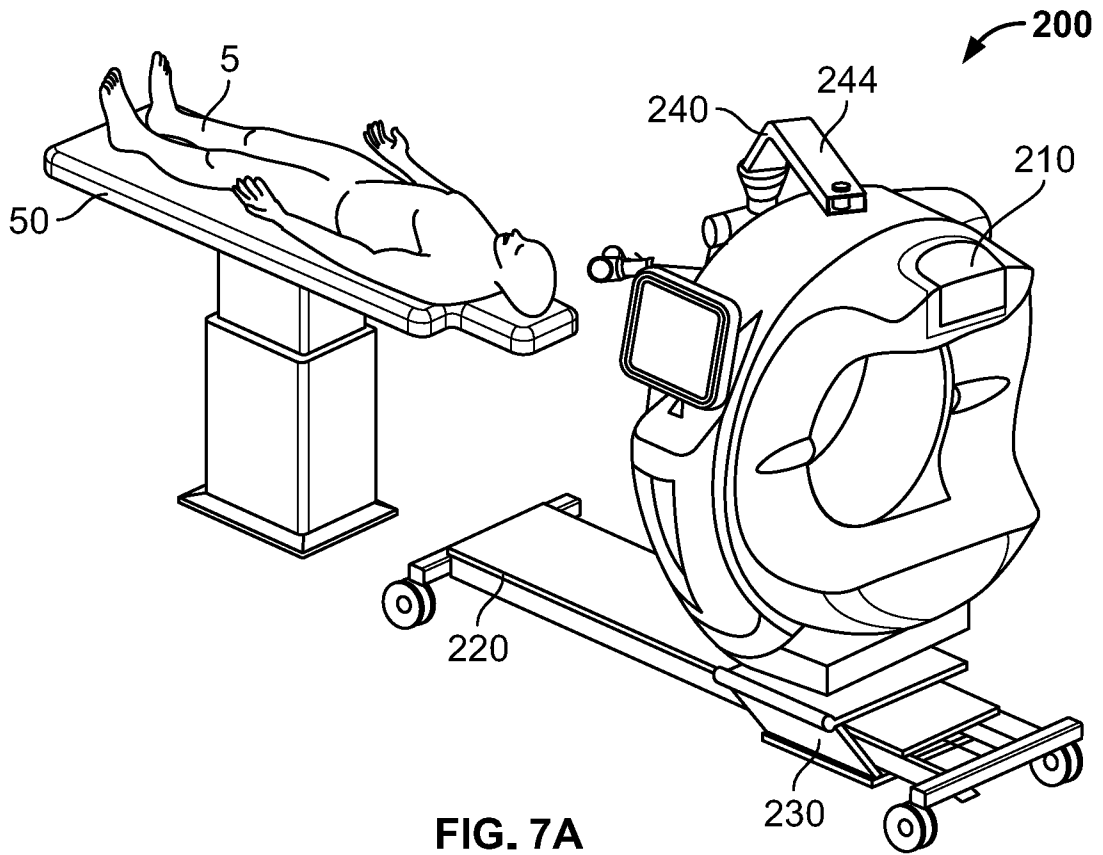


FIG. 7A

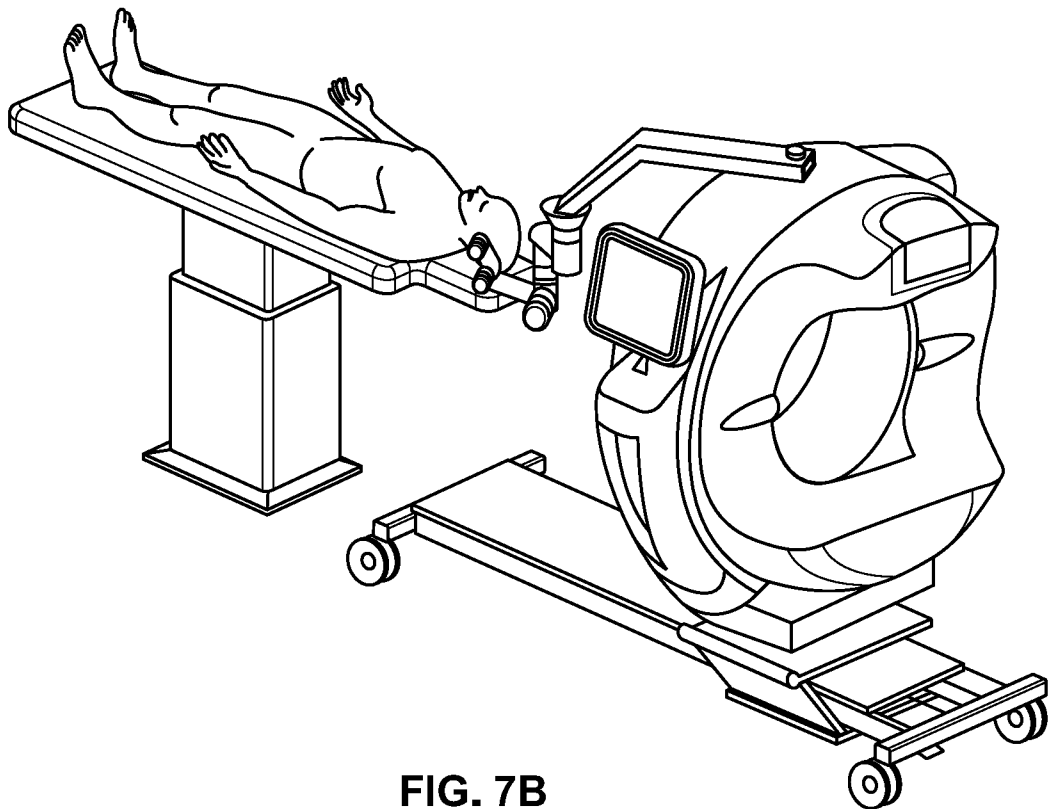


FIG. 7B

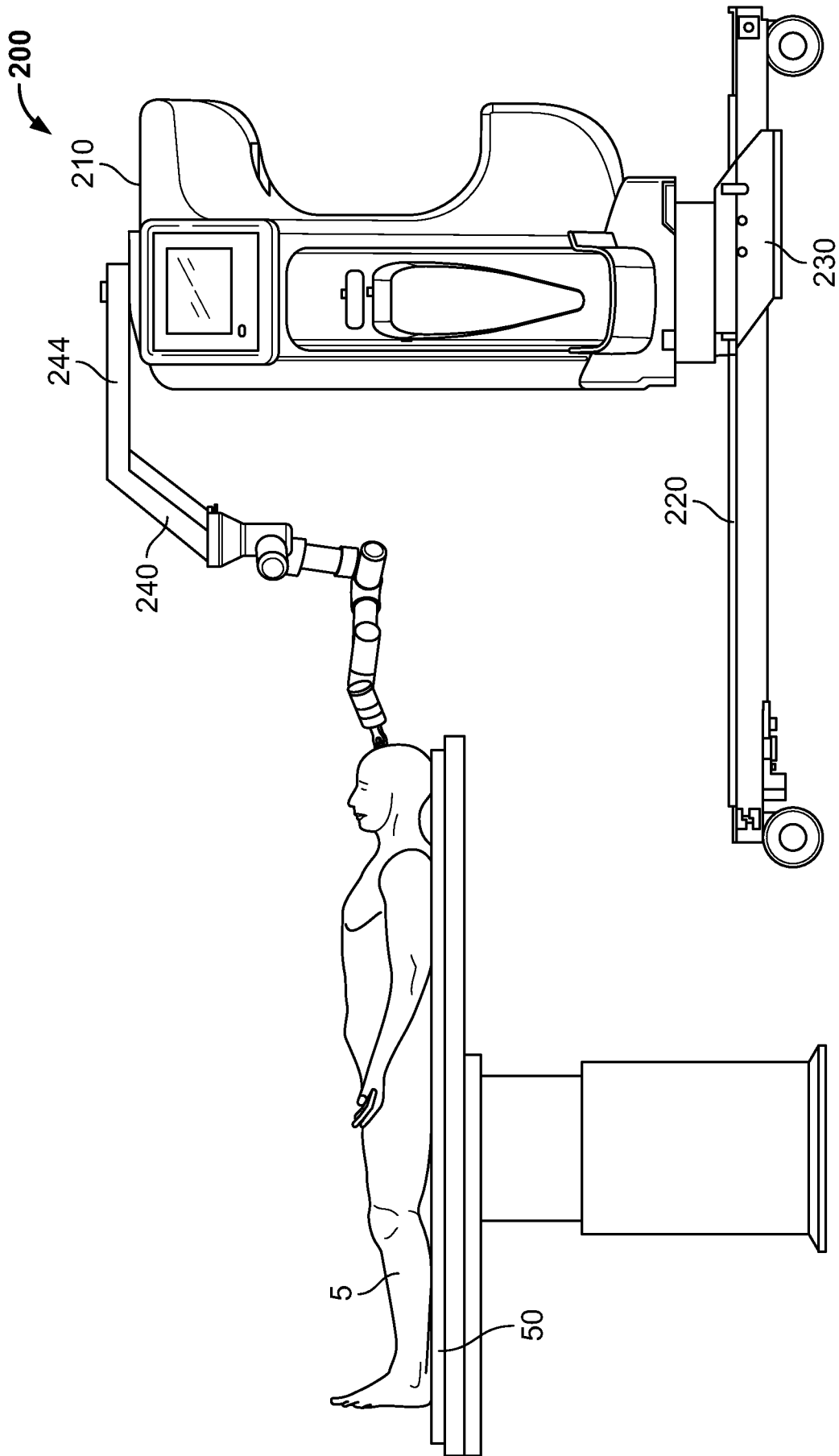


FIG. 7C

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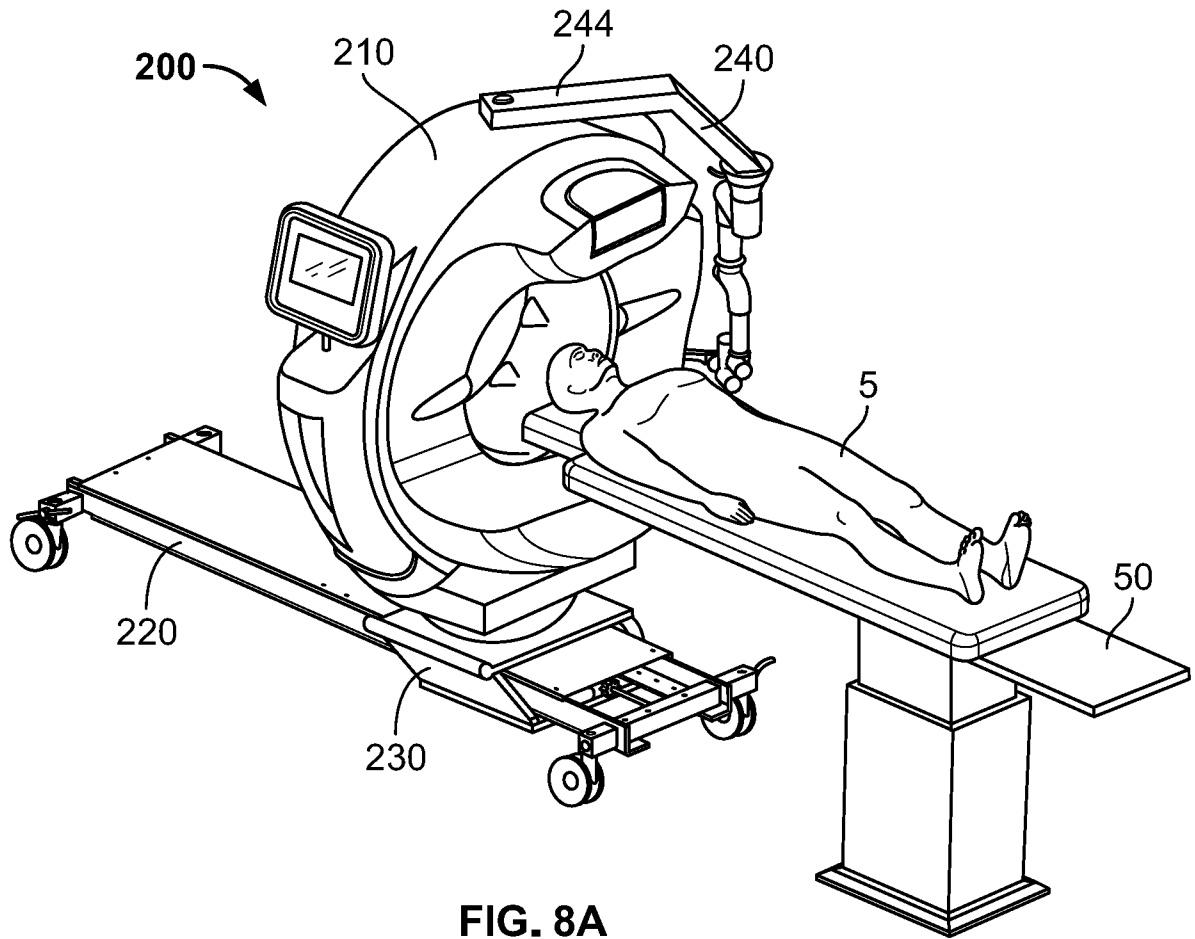


FIG. 8A

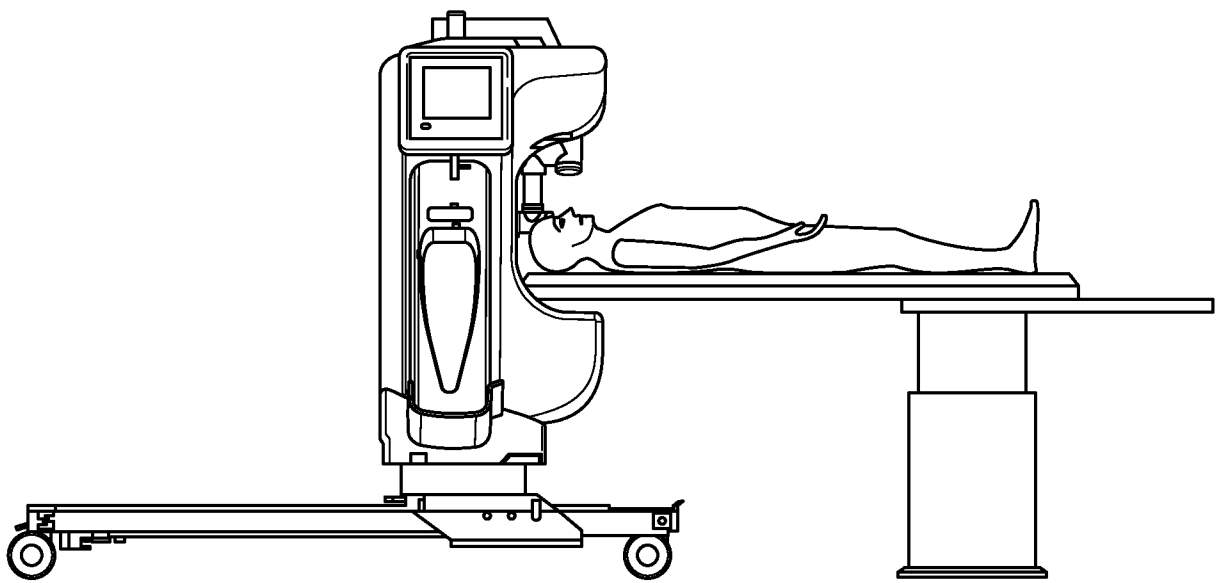


FIG. 8B

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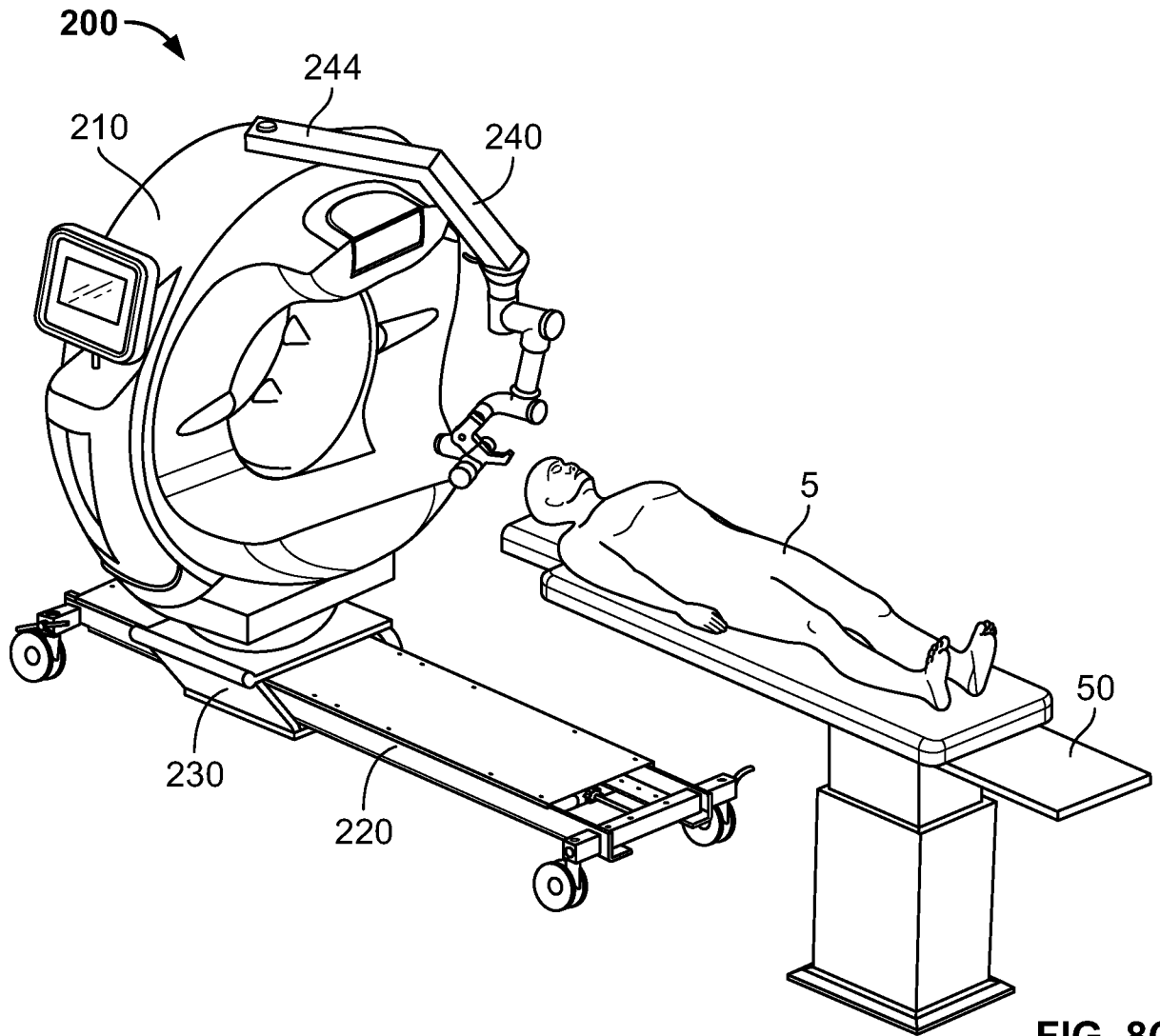


FIG. 8C

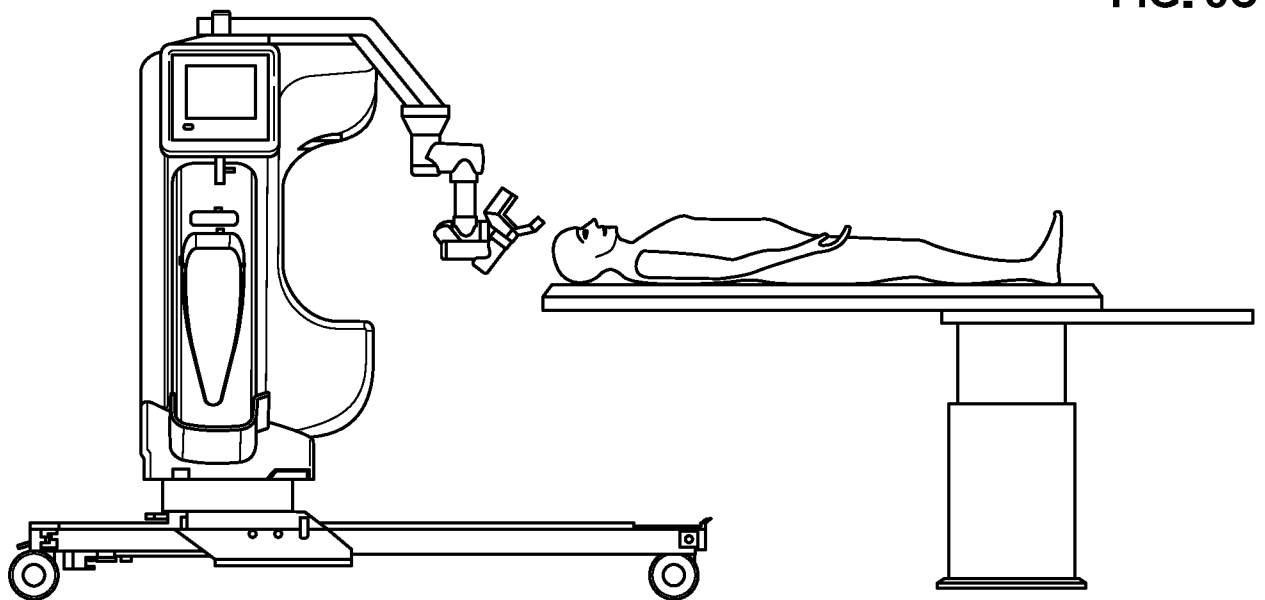


FIG. 8D

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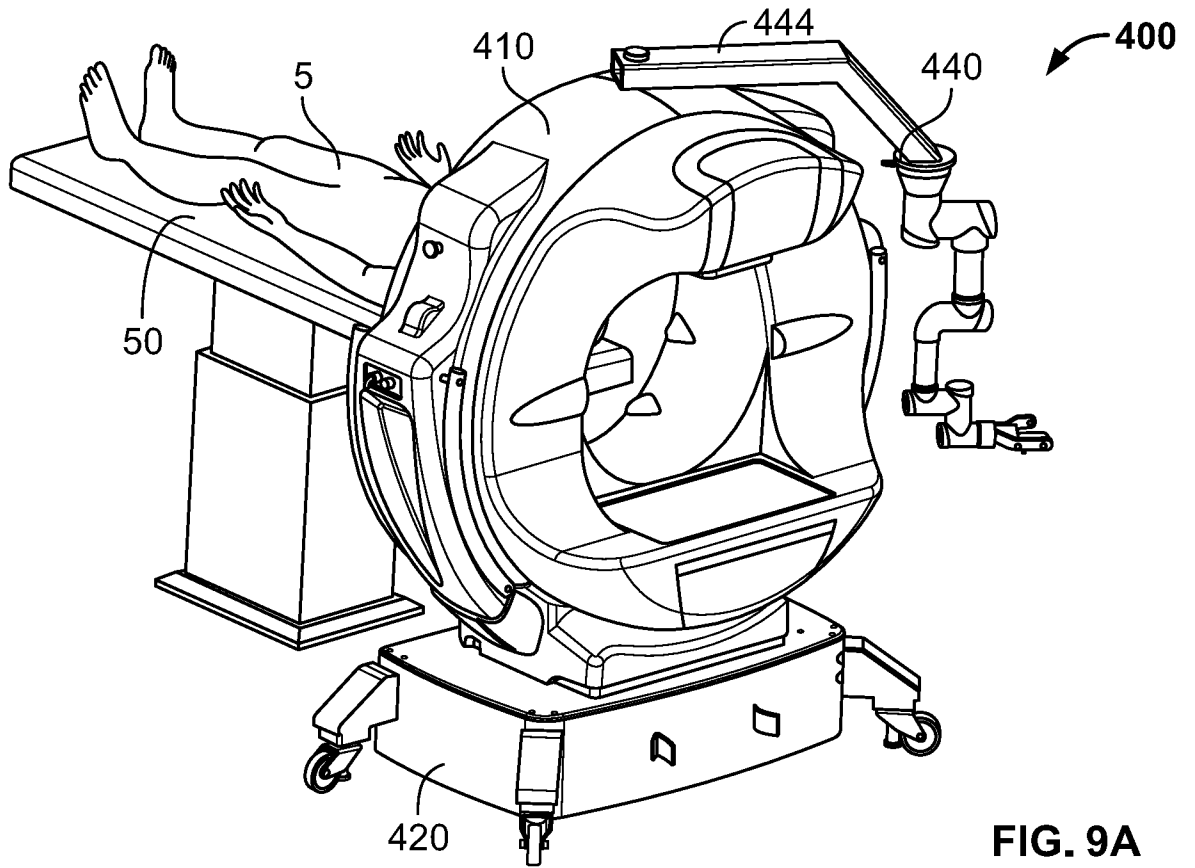


FIG. 9A

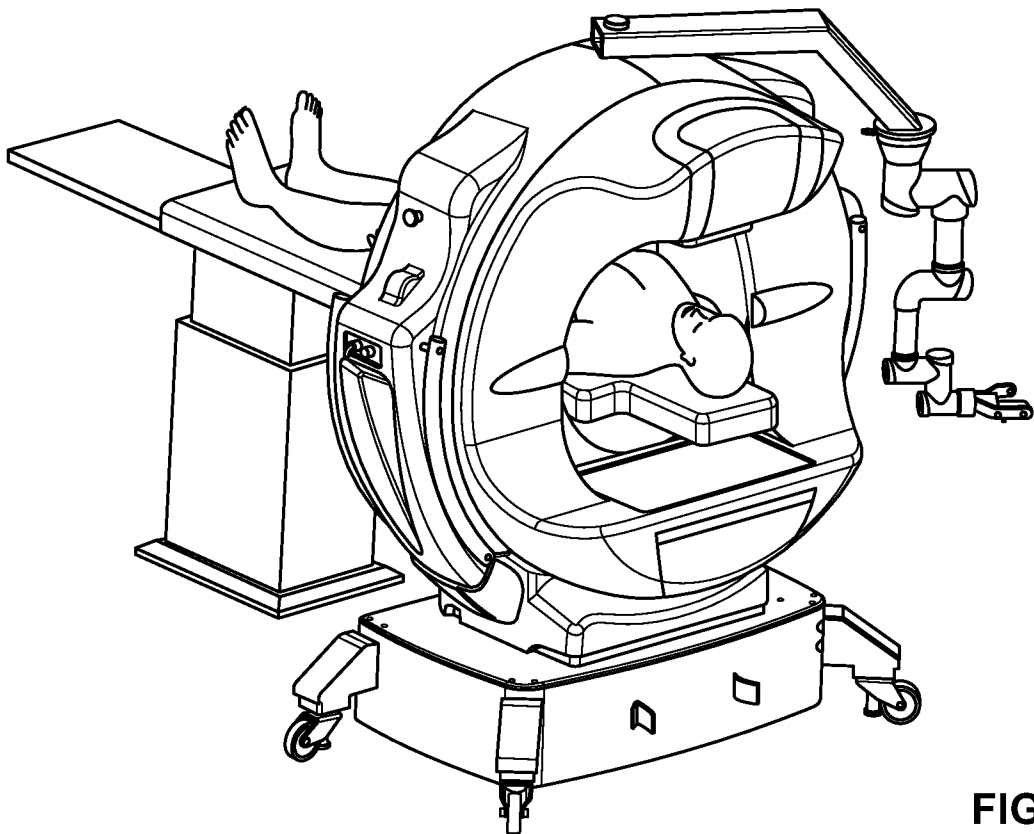
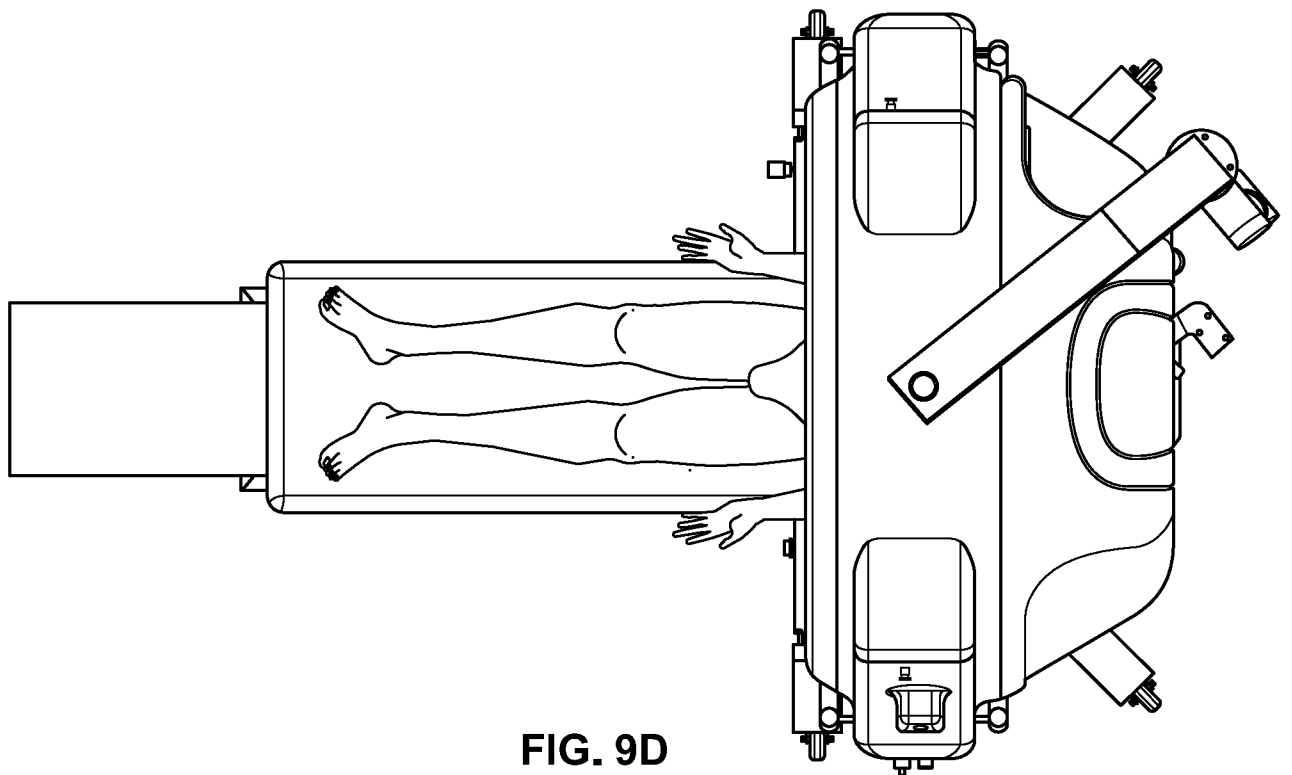
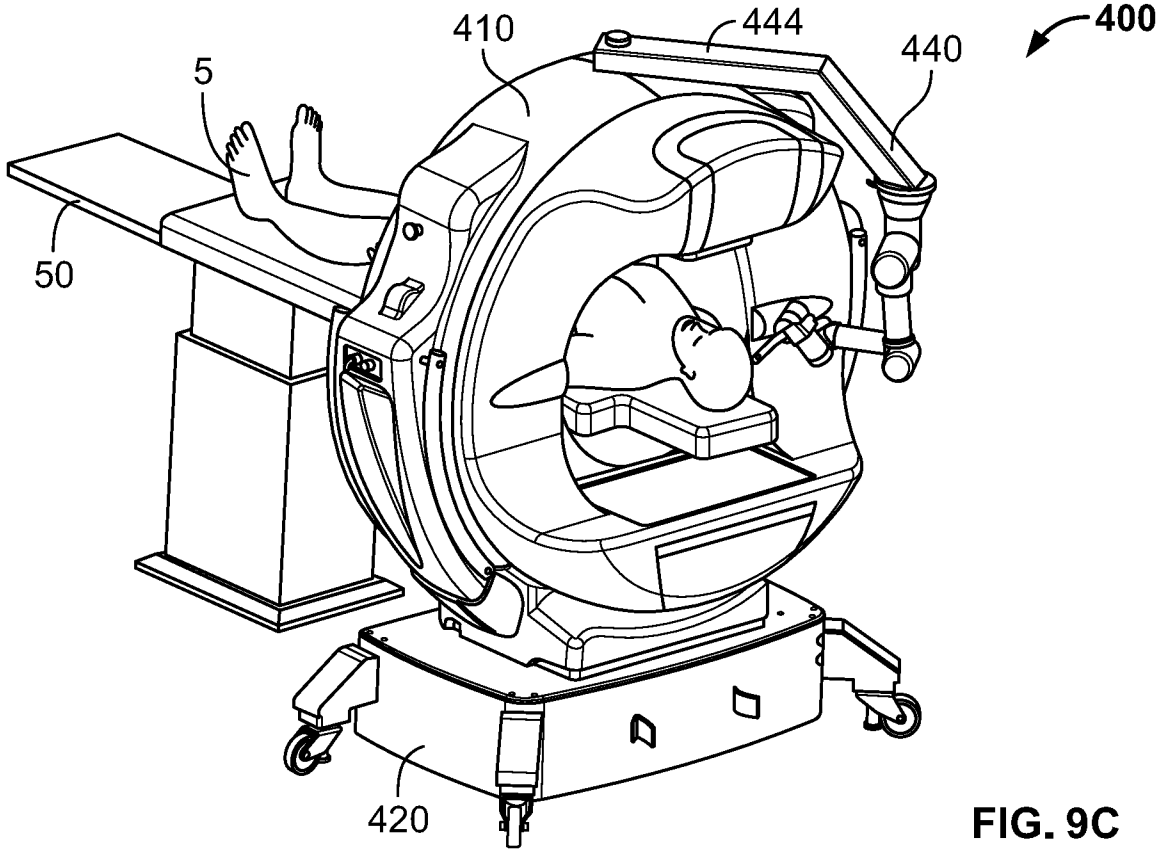
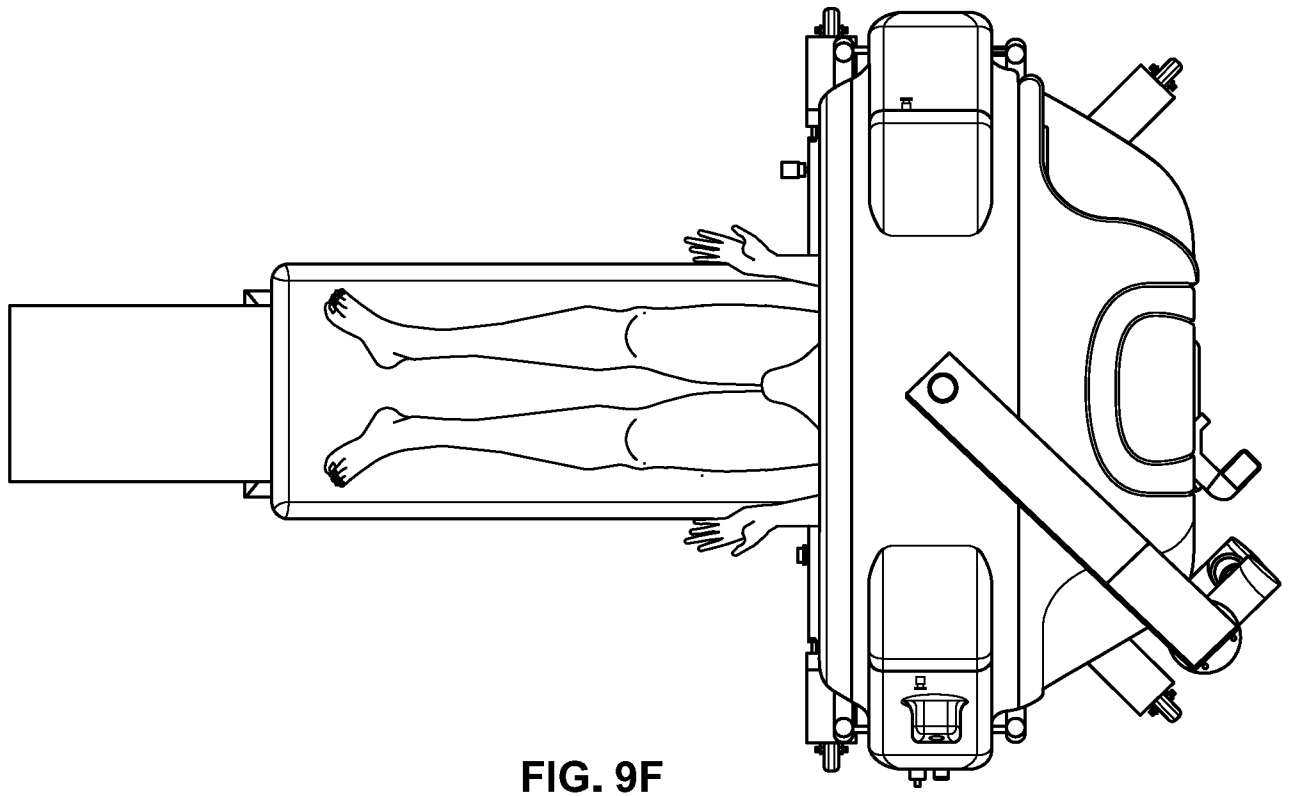
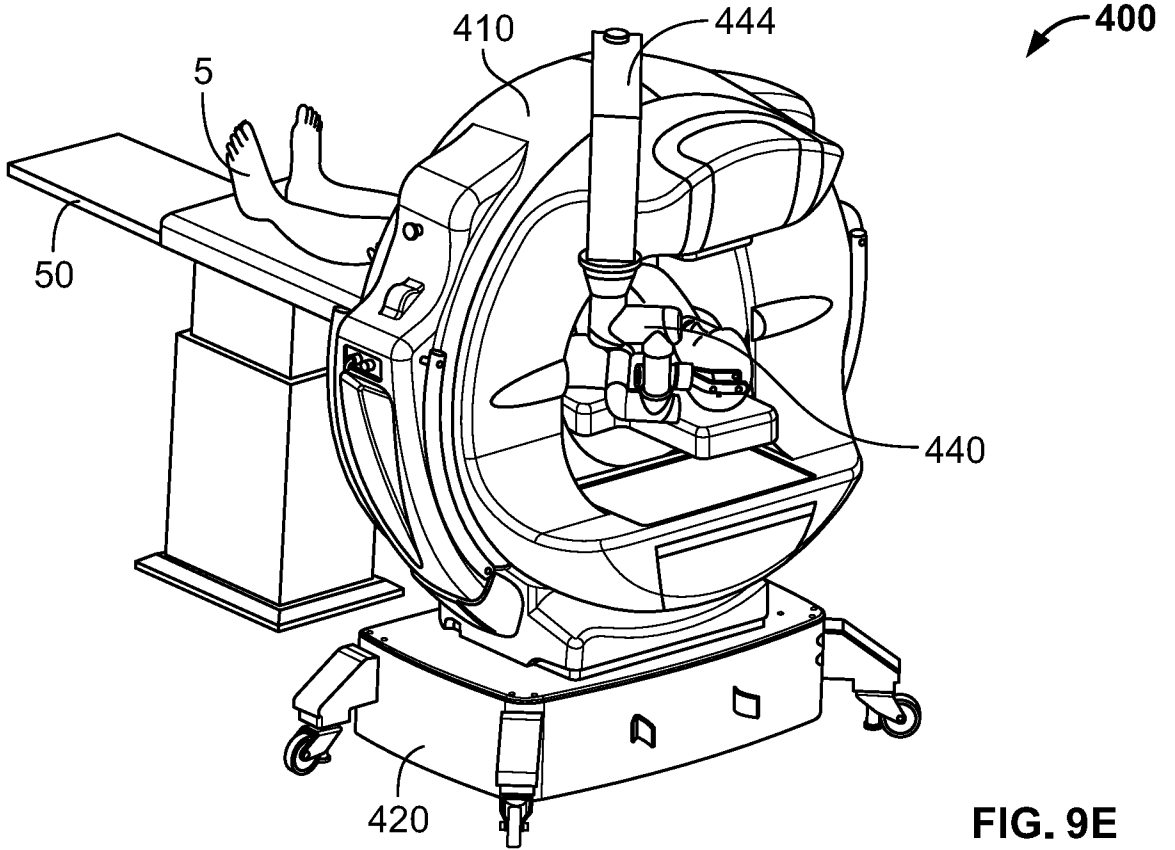


FIG. 9B

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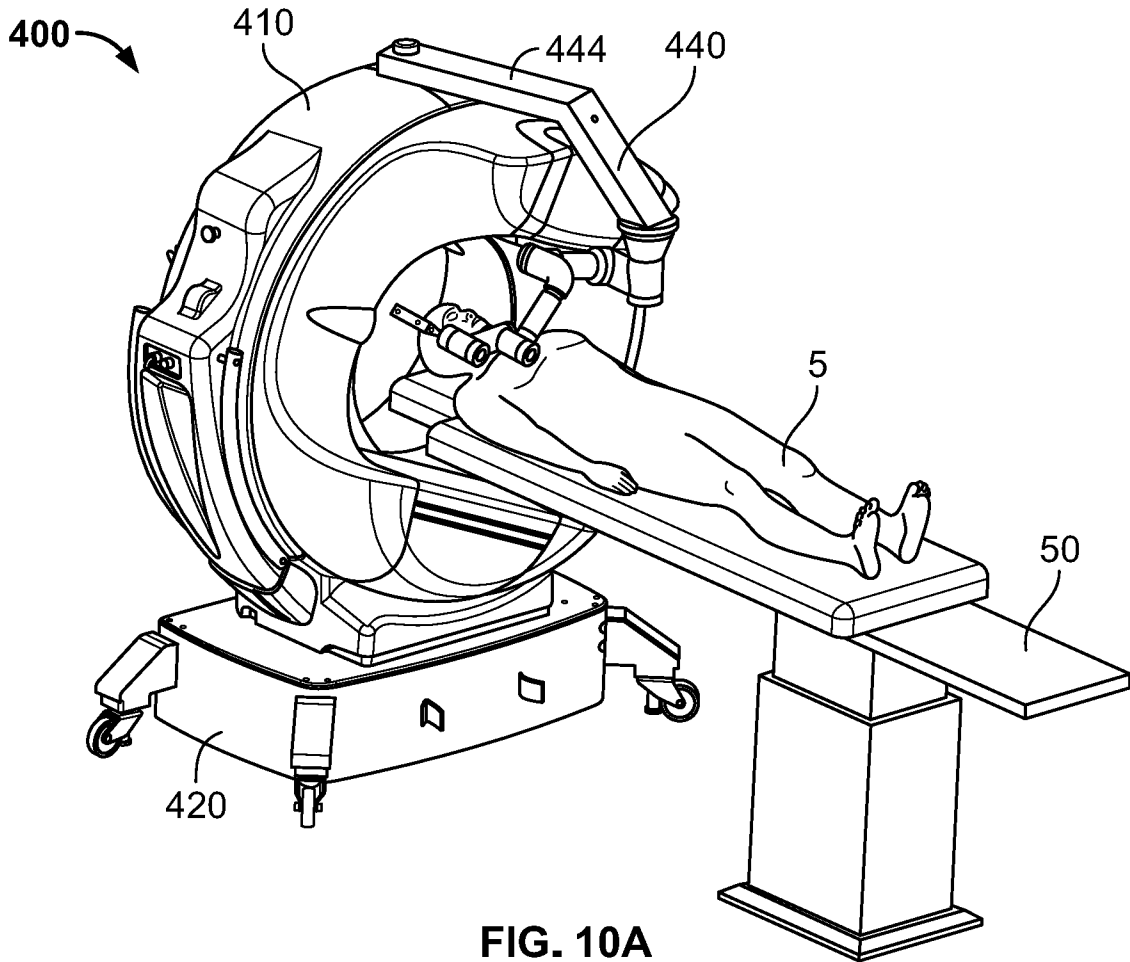


FIG. 10A

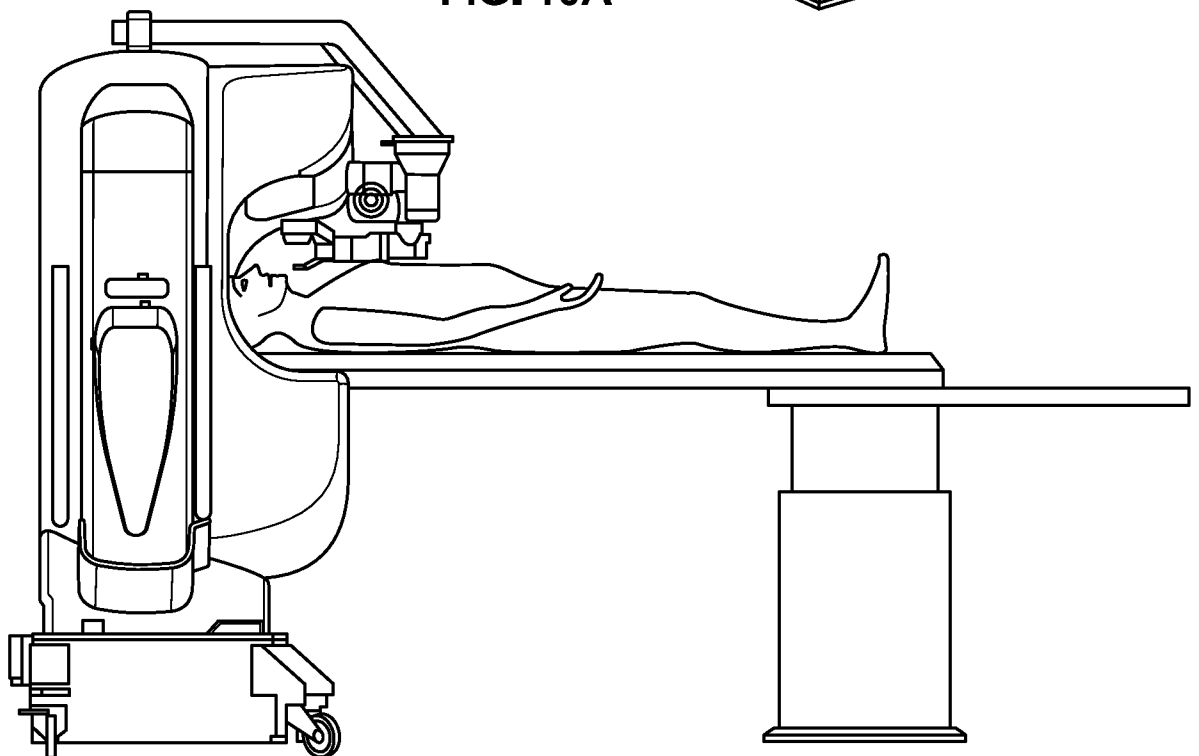


FIG. 10B

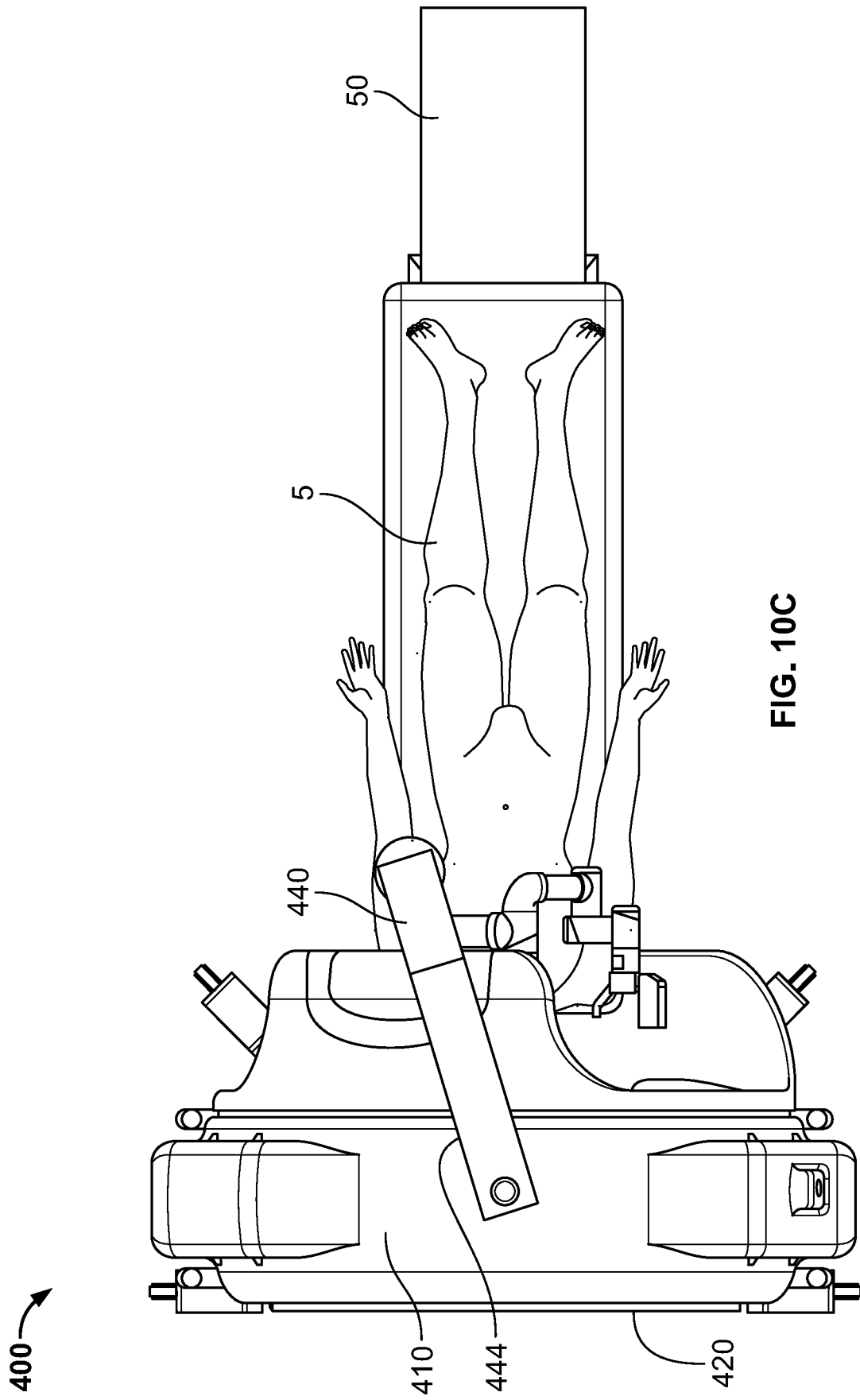


FIG. 10C

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 19/30462

A. CLASSIFICATION OF SUBJECT MATTER
 IPC(8) - A61B 6/03 (2019.01)
 CPC - A61B 6/035, 6/03, 6/032, 6/44, 6/4435, 6/4441

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History Document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History Document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	WO 2017/134546 A2 (IMAGINALIS S.R.L.) 10 August 2017 (10.08.2017) entire document, especially Figs. 3a-b, 4a-b, 6a-b, 9a-b; pg. 5, ln 22-25; pg. 21, ln 4-7; pg. 6, ln 25 - pg. 7, ln 11	1-3, 5-6, 8 ----- 4, 7
Y	US 2016/0302871 A1 (MOBIUS IMAGING, LLC.) 20 October 2016 (20.10.2016) entire document, especially Fig. 13C; para [0026], [0031]	4, 7
A	US 2016/0008078 A1 (INTUITIVE SURGICAL OPERATIONS, INC.) 14 January 2016 (14.01.2016) entire document	1-8
A	US 2016/0302871 A1 (MOBIUS IMAGING, LLC.) 20 October 2016 (20.10.2016) entire document	1-8
A	WO 2018/049196 A1 (GYS TECH, I.I.C D/B/A CARDAN ROBOTICS) 15 March 2010 (15.03.2010) entire document	1-8

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
 3 July 2019

Date of mailing of the international search report
 02 OCT 2019

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