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CA 2500973 C 2012/05/15

(11)(21) 2 500 973

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 2003/09/29
(87) Date publication PCT/PCT Publication Date: 2004/04/08
(45) Date de délivrance/Issue Date: 2012/05/15
(85) Entrée phase nationale/National Entry: 2005/03/22
(86) N° demande PCT/PCT Application No.: US 2003/030906
(87) N° publication PCT/PCT Publication No.: 2004/028351
(30) Priorité/Priority: 2002/09/27 (US60/414,690)

(51) Cl.Int./Int.Cl. *A61B 17/32* (2006.01),
A61B 1/00 (2006.01)

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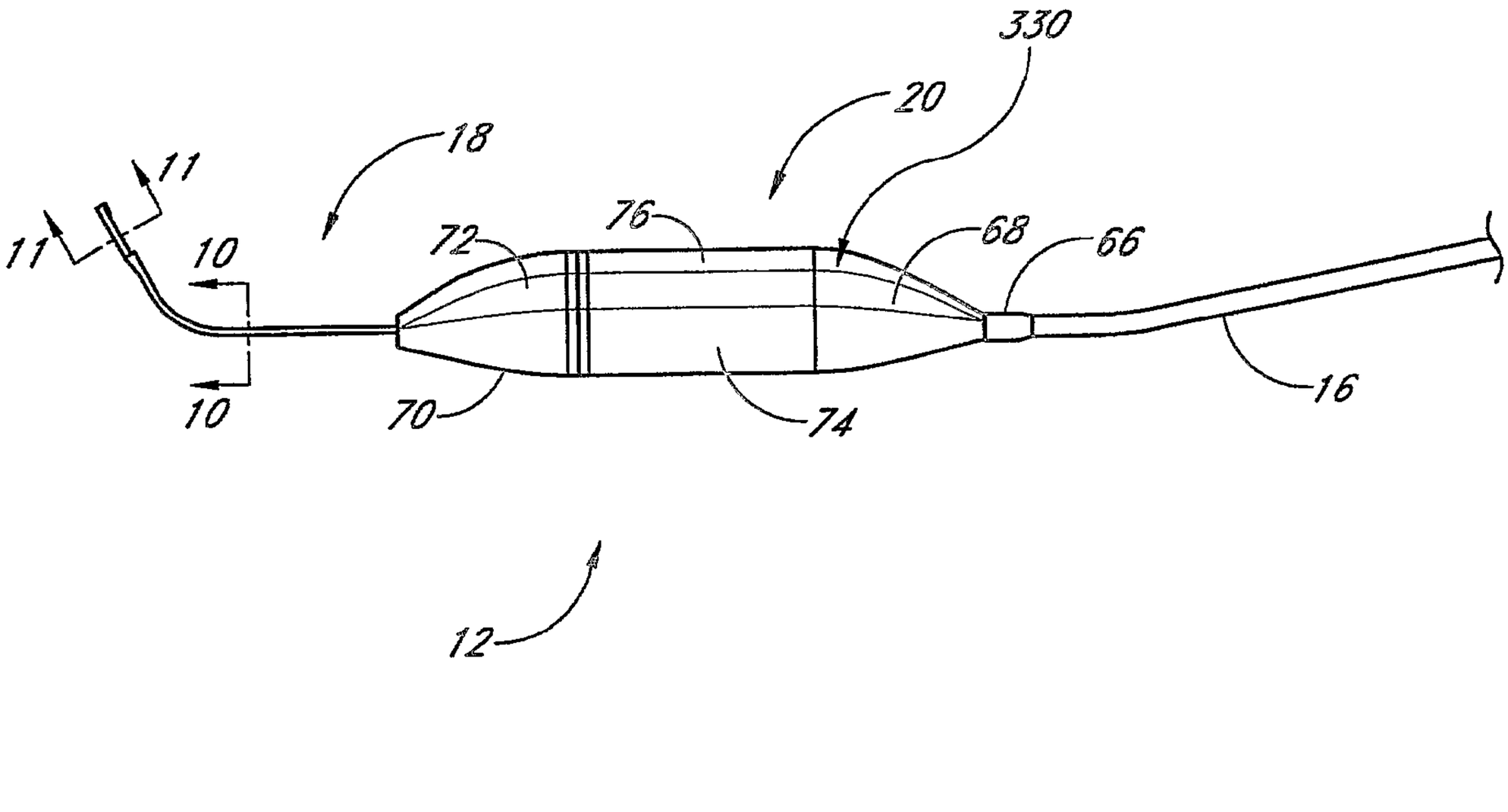
(54) Titre : LIME DE CHIRURGIEN BLINDEE A MOUVEMENT ALTERNATIF
(54) Title: SHIELDED RECIPROCATING SURGICAL FILE



(57) Abrégé/Abstract:
A shielded reciprocating surgical file system (10) is used for precisely removing bone or tissue material. The system allows a user to maneuver the system and navigate into hard to access sites under a direct vision mechanism (32) included in the system. A transmission mechanism (80) converts rotary motion from a motor into reciprocating motion and provides it to the surgical file for precision bone and/or tissue removal. A pulsatile pump (290) is operatively coupled with the transmission mechanism and provides irrigating fluid to the surgical site.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

CORRECTED VERSION

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
8 April 2004 (08.04.2004)

PCT

(10) International Publication Number
WO 2004/028351 A3

(51) International Patent Classification[7]: A61B 17/32

(21) International Application Number:
PCT/US2003/030906

(22) International Filing Date:
29 September 2003 (29.09.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/414,690 27 September 2002 (27.09.2002) US

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(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ (utility model), CZ, DE (utility model), DE, DK (utility model), DK, DM, DZ, EC, EE (utility model), EE, EG, ES, FI (utility model), FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK (utility model), SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

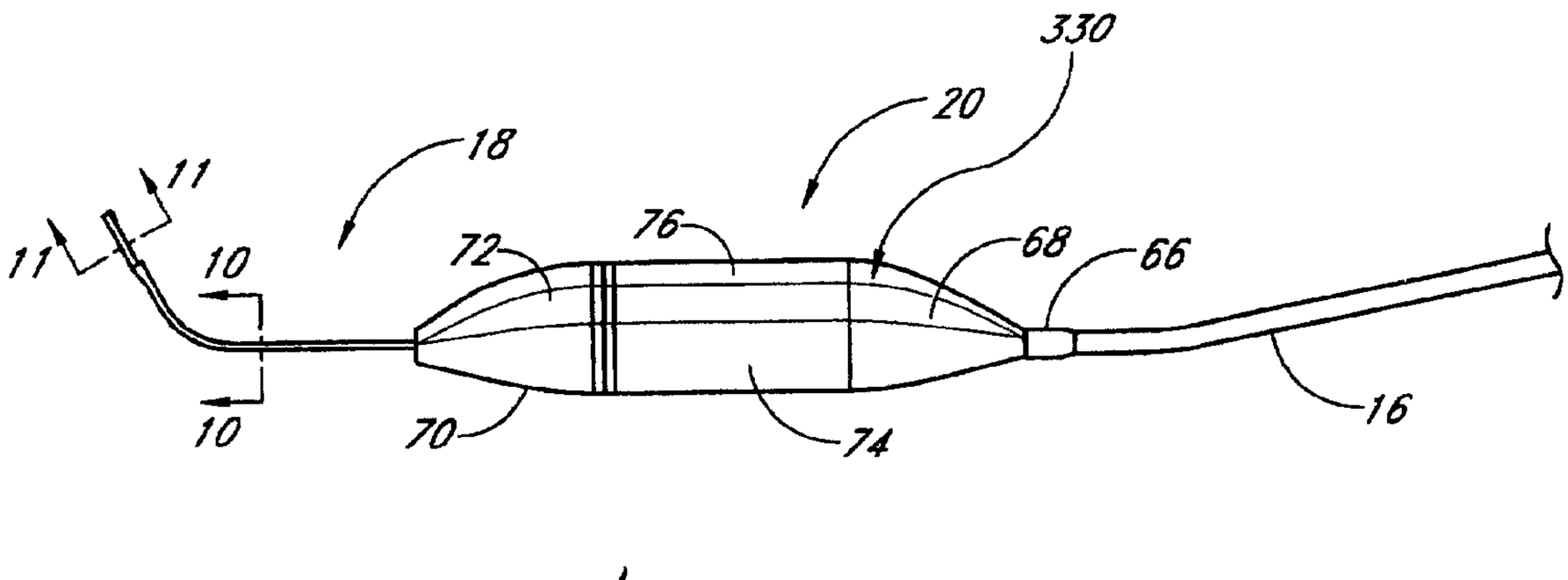
Declaration under Rule 4.17:
— *of inventorship (Rule 4.17(iv)) for US only*

Published:
— *with international search report*

(88) Date of publication of the international search report:
29 July 2004

[Continued on next page]

(54) Title: SHIELDED RECIPROCATING SURGICAL FILE



(57) Abstract: A shielded reciprocating surgical file system (10) is used for precisely removing bone or tissue material. The system allows a user to maneuver the system and navigate into hard to access sites under a direct vision mechanism (32) included in the system. A transmission mechanism (80) converts rotary motion from a motor into reciprocating motion and provides it to the surgical file for precision bone and/or tissue removal. A pulsatile pump (290) is operatively coupled with the transmission mechanism and provides irrigating fluid to the surgical site.

WO 2004/028351 A3

WO 2004/028351 A3

(48) Date of publication of this corrected version:
23 September 2004

(15) Information about Correction:
see PCT Gazette No. 39/2004 of 23 September 2004, Section II

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

SHIELDED RECIPROCATING SURGICAL FILE

Background of the Invention

Field of the Invention

The invention relates generally to systems and methods for tissue cutting and removal. More particularly, the invention relates to a shielded reciprocating surgical file system for cutting, removing, grinding, shaping and sculpturing bone and/or tissue material under direct vision.

Description of the Related Art

Adjacent spinal vertebrae are spaced by intervertebral discs that are tough and semi-elastic. The discs act as a flexible spacer between the vertebrae that makeup the backbone. Vertebrae are shaped to provide a bony tubular shaped tunnel between upper and lower pairs of vertebrae and this tunnel is made-up in part by the spacing disc. These tubular shaped tunnels are called neuroforamen and serve as a passageway for nerve roots. The size of the neuroforamen tubular shaped tunnels is a close fit for the nerve roots that pass through these tunnels on their way from the spinal cord to the arms, legs and other muscles.

Each year millions of people encounter neck and back injuries. Many million suffer from truly problematic back pain that either keeps them out of work or debilitates them in some way. Many vertebral and disc injuries result in pain from nerve irritation and compression.

When an intervertebral disc is damaged, often it is because of a physical overrotation between two vertebrae and normal wear and tear. When a vertebra is overrotated, small facet joints called the zygapophyseal capsules that are located to the left and right sides of the disc are damaged. When the body incurs damage to these small joints, unwanted osteophytes and bony overgrowths frequently occur at the edges of these tiny joints. The unwanted bony overgrowth restricts the neuroforamen and pinches the delicate and sensitive nerve roots.

Also, with age, for many people, the sensation of thirst is somewhat reduced. As a result, sometimes less water is consumed than needed by the body. The intervertebral discs depend on water as well as other materials to maintain a healthy function. When a disc looses a part of its fluid mass it is said to desiccate. When a disc is desiccated it reduces in

height and reduces the space between the two vertebras it is connected to, that is, the neuroforamen becomes constricted and pinches nerve roots.

Pinched nerves that are constrained in between vertebras can cause neck and back pain. The bony overgrowth and a reduction in the space between vertebras pinch the nerves causing irritation, pain and numbness. The pinching can potentially result in a loss of use of the limbs controlled by the affected nerve.

Thus, when intervertebral discs are damaged from accident, age and/or general wear and tear the intervertebral nerve roots in the neuroforamen are irritated and pinched and can cause unwanted involuntary muscular contractions. The muscle contractions can come in the form of a continuous low-grade ache or become more severe as a spasm. The muscle contractions can act to further compress the space between the vertebras, which further pinches the nerve. This becomes a severely painful, self-destructive and self-feeding problem.

One current technology to treat a patient with nerve compression that causes pain and numbness involves the removal of the disc and fusion of the vertebra below with the vertebra above it. Vertebral fusion removes a disc that was flexible and fuses one vertebra together with the adjacent vertebra resulting in a rigid joint between two vertebrae. This causes added strain on the disc above and below the now rigid bone fusion. Sometimes the attempted fusion of one vertebra onto another vertebra is unsuccessful and does not provide the intended fusion.

Disadvantageously, the intervertebral fusion is an invasive and relatively complicated procedure. In addition, and undesirably, the fusion process can result in a long hospital stay for the patient, a long recuperation and rehabilitation period and high costs for both the patient and care providers.

Summary of the Invention

Embodiments of the invention overcome some or all of the above disadvantages by providing systems and methods for tissue cutting and removal including a shielded reciprocating surgical file and a direct vision apparatus. Some embodiments provide surgical instrumentation that allows a surgeon to navigate into the tiny neuroforamen next to delicate nerves under direct vision, and locate and remove obstructions of tissue that can cause nerve compression and irritation. Advantageously, this offers many patients a minimally invasive surgical option that can result in shorter hospital stays and lower cost.

Embodiments of the invention can desirably be adapted and tailored to serve at least three surgical fields. These include, but are not limited to, neurosurgery, orthopaedic surgery and plastic surgery. The neurosurgical embodiments enable surgeons to safely enlarge the constricted neuroforamen and provide more space for the nerve roots to pass through the rigid bony vertebral structure, thereby relieving the nerve pinching and compression.

The orthopaedic embodiments provide improved bone and/or tissue removal instrumentation and methodology, for example, for orthopaedic surgical procedures such as knee surgery. The plastic surgery embodiments provide improved bone and/or tissue sculpturing instrumentation and methodology, for example, for cosmetic surgical procedures such as nose reshaping or rhinoplasty.

Some embodiments include a surgical instrument comprising a blade; a housing in which the blade moves, the housing having a long axis; a transmission that converts rotary motion to reciprocating, linear motion, wherein the transmission is coupled to the blade such that the blade moves reciprocally in the housing; a first opening in the housing through which a portion of the blade is exposed; and a cutting surface on the exposed portion of the blade, the surface configured to perform at least one of grinding, filing, and cutting of tissue, the transmission comprises: two surfaces that are a substantially fixed distance apart; a cam that rotates about a central axis, the central axis being at an angle to a plane extending between the two surfaces; and the cam having a curvilinear body, the body having a nonuniform thickness, wherein the body continuously contacts the two surfaces as the cam rotates about the central axis, such that the two surfaces remain at the substantially fixed distance apart as they move linearly in response to the cam's rotation about the central axis.

In some embodiments the housing is concave about at least a portion of its long axis, such as at least a distal portion of its long axis. In some embodiments the housing is convex about at least a portion of its long axis, such as at least a distal portion of its long

axis. In some embodiments the first opening is in an opening surface on the housing. In some embodiments the housing is curved along its long axis, to assist in placing the surgical instrument in the body of a patient. In some embodiments the blade is substantially flat.

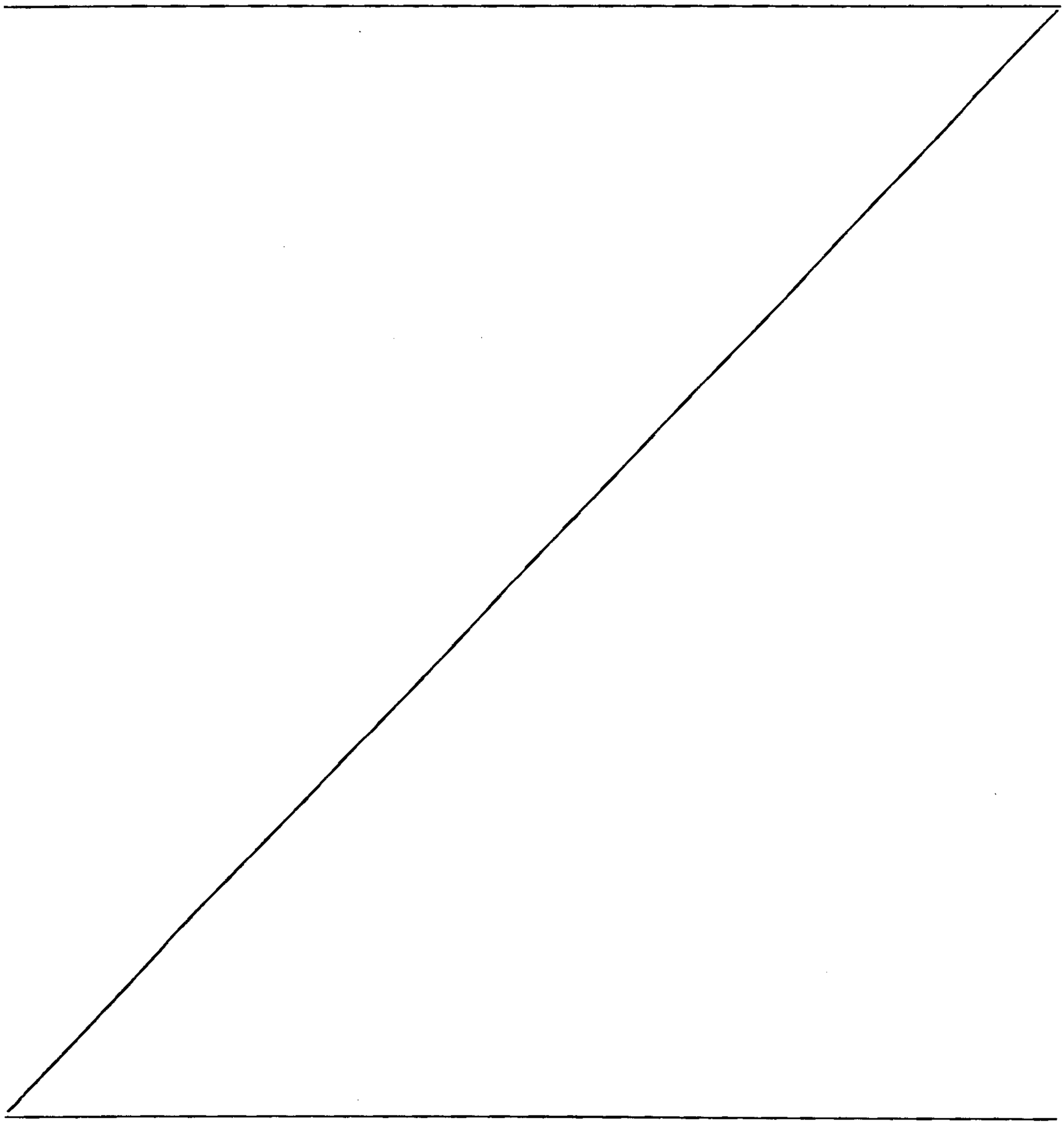
In some embodiments the housing is curved along its long axis in a direction toward the opening surface. Some embodiments further comprise at least one bearing retainer for reducing friction. In some embodiments the at least one bearing retainer has at least one slot configured to transmit fluid toward a distal end of the instrument. Some embodiments further comprise at least one fiberoptic in or on the housing, for transmission of at least one of a video signal and illumination light. In some embodiments the housing has at least a second opening at a distal end of the housing.

Some embodiments further comprise at least two lenses coupled to the at least one fiberoptic. In some embodiments, at least one of the at least two lenses is disposed at a distal end of the housing, and another of the at least two lenses is disposed in proximity to the first opening in the housing. Some embodiments further comprise a pump for pumping fluid through the surgical instrument. In some embodiments the pump is mechanically coupled to the transmission.

In some embodiments, the cam's central axis is substantially parallel to a direction of the linear motion of the two surfaces. In some embodiments, the central axis is substantially perpendicular to the plane extending between the two surfaces. In some embodiments the two surfaces move linearly back and forth in reciprocating motion in response to the cam's rotation about the central axis. In some embodiments the curvilinear body has a shape comprising at least two toruses, the at least two toruses being partially superimposed, and each of the at least two toruses has a central axis, wherein the central axes of the at least two toruses are at an angle to each other. In some embodiments at least one bearing comprises the two surfaces. In some embodiments two bearings respectively comprise the two surfaces.

In some embodiments the curvilinear body is disposed at an angle to the central axis of the cam. Some embodiments include an apparatus for translating a rotary motion to a linear motion, the apparatus comprising: two surfaces that are a substantially fixed distance

apart; and a cam that rotates about a central axis, the central axis being at an angle to a plane extending between the two surfaces; the cam having a curvilinear body, the body having a nonuniform thickness, wherein the body continuously contacts the two surfaces as the cam rotates about the central axis, such that the two surfaces remain at the substantially fixed distance apart as they move linearly in response to the cam's rotation about the central axis.



In some embodiments the cam's central axis is substantially parallel to a direction of the linear motion of the two surfaces. In some embodiments the central axis is substantially perpendicular to the plane extending between the two surfaces. In some embodiments the two surfaces move linearly back and forth in reciprocating motion in response to the cam's rotation about the central axis. In some embodiments the curvilinear body has a shape comprising at least two toruses, the at least two toruses being partially superimposed, and each of the at least two toruses has a central axis, wherein the central axes of the at least two toruses are at an angle to each other.

In some embodiments at least one bearing comprises the two surfaces. In some embodiments two bearings respectively comprise the two surfaces. In some embodiments the curvilinear body is disposed at an angle to the central axis of the cam. Some embodiments include a pump comprising: a fluid path; two plungers configured to at least partially occlude the fluid path; a cam configured to cause the two plungers to at least partially occlude the fluid path alternatingly; and at least one check valve along the fluid path for reducing backflow of fluid within the fluid path.

In some embodiments the cam translates in a direction that is substantially perpendicular to a long axis of at least one of the two plungers. In some embodiments the cam translates in a direction that is substantially perpendicular to a long axis of each of the two plungers. In some embodiments the pump comprises: a fluid path; two plungers configured to at least partially occlude the fluid path; a cam configured to cause the two plungers to at least partially occlude the fluid path alternatingly; and at least one check valve along the fluid path for reducing backflow of fluid within the fluid path.

In some embodiments the cam translates in a direction that is substantially perpendicular to a long axis of at least one of the two plungers. In some embodiments the cam translates in a direction that is substantially perpendicular to a long axis of each of the two plungers. Some embodiments of the instrument further comprise at least one opening in the exposed portion of the blade, for transmitting fluid. In some embodiments the cutting surface comprises an abrasive material. In some embodiments the cutting surfaces comprises diamond. In some embodiments the blade comprises stainless steel.

Some embodiments further comprise a handpiece coupled to the housing. Some embodiments further comprise a video camera. In some embodiments the camera is configured to couple with a fiberoptic that extends to a distal end of the housing. In some

embodiments a video camera is located in the handpiece. Some embodiments further comprise a watertight seal in the handpiece. In some embodiments the handpiece is configured to contain the video camera in a chamber such that the watertight seal reduces or prevents ingress of at least one of water and bacteria from outside the handpiece into the chamber containing the video camera in the handpiece.

Some embodiments further comprise a motor in the handpiece, the motor configured to power the rotary motion. In some embodiments the motor comprises a gas turbine. Some embodiments further comprise a cord configured to couple to a proximal end of the surgical instrument, the cord comprising at least one of a fiberoptic, an electrical line, an irrigation channel, a suction line, and a gas tube for powering a gas turbine motor in the surgical instrument.

The present invention further concerns a surgical instrument, comprising:

a blade;

a housing in which the blade moves, the housing having a long axis;

a transmission that converts rotary motion to reciprocating, linear motion, wherein the transmission is coupled to the blade such that the blade moves reciprocally in the housing;

a first opening in the housing through which a portion of the blade is exposed; and

a cutting surface on said exposed portion of the blade, said surface configured to perform at least one of grinding, filing, and cutting of tissue; and

a pump for pumping fluid through the surgical instrument, wherein the pump comprises:

a fluid path;

two plungers configured to at least partially occlude said fluid path;

a cam configured to cause said two plungers to at least partially occlude said fluid path alternatingly; and

at least one check valve along said fluid path for reducing backflow of fluid within said fluid path.

The present invention also concerns a surgical instrument, comprising:

a blade;

a housing in which the blade moves, the housing having a long axis;

a transmission that converts rotary motion to reciprocating, linear motion, wherein the transmission is coupled to the blade such that the blade moves reciprocally in the housing;

a first opening in the housing through which a portion of the blade is exposed;

a cutting surface on said exposed portion of the blade, said surface configured to perform at least one of grinding, filing, and cutting of tissue;

a handpiece coupled to the housing;

a video camera located in the handpiece; and

a watertight seal in the handpiece;

wherein the handpiece is configured to contain the video camera in a chamber such that the watertight seal reduces or prevents ingress of at least one of water and bacteria from outside the handpiece into the chamber containing the video camera in the handpiece.

The present invention further concerns a surgical instrument, comprising:

a housing having a longitudinal axis;

a blade assembly configured to oscillate linearly relative to the housing in a direction generally parallel to the longitudinal axis, the blade assembly comprising a blade having a cutting surface;

a rotary shaft; and

a transmission configured to convert rotation of the rotary shaft into oscillating linear movement of the blade assembly;

wherein the transmission comprises a torus-like shape disposed on the rotary shaft, the torus-like shape having a central axis that is angled relative to an axis of the rotary shaft.

FIG. 3 is a simplified perspective view of a surgical file device with a curved distal tip configuration illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 4 is a simplified perspective view of a surgical file device with a straight distal tip configuration illustrating features and advantages in accordance with another embodiment of the invention.

FIG. 5 is a simplified side view of a surgical file device illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 6 is a simplified partially exploded view of the surgical file device of **FIG. 5**.

FIG. 7 is a simplified perspective view of the surgical file device of **FIG. 5** with the distal cover removed illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 8 is a simplified perspective view of a distal tip assembly of the surgical file device of **FIG. 5**.

FIG. 9 is a simplified exploded perspective view of the distal tip assembly of **FIG. 8** illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 10 is a sectional view along line **10-10** of **FIG. 5** illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 11 is a sectional view along line **11-11** of **FIG. 5** illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 12 is a simplified perspective view of a surgical cutting blade illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 13 is a simplified schematic cross-section view of a convex surgical file cutting surface illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 14 is a simplified schematic cross-section view of a concave surgical file cutting surface illustrating features and advantages in accordance with another embodiment of the invention.

FIG. 15 is a simplified schematic side view sectional view of surgical file distal tip with a top cutting surface illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 16 is a simplified schematic side sectional view of a surgical file distal tip with a top cutting surface illustrating features and advantages in accordance with another embodiment of the invention.

FIG. 17 is a simplified perspective view of a surgical file cutting surface with abrasives illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 18 is a simplified perspective view of a surgical file cutting surface with irrigation fluid openings illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 19 is a simplified schematic view of a surgical file cutting blade with irrigation fluid flow therethrough illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 20 is a simplified schematic cross-section view of a surgical file distal cutting tip with irrigation fluid passageways illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 21 is a simplified side sectional view of a surgical file distal cutting tip with a linear reciprocation stroke illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 22 is a simplified side sectional view of a surgical file distal cutting tip with fiber optic probes illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 23 is a simplified sectional view along line **23-23** of **FIG. 22** illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 24 is a simplified side sectional view of a surgical file distal cutting tip with an illumination and vision system illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 25 is a simplified schematic view of an arrangement of lenses of a surgical file illumination and vision system illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 26 is a simplified schematic view of display images provided by a surgical file illumination and vision system illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 27 is a simplified perspective view of a dual torus and drive shaft illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 28 is a simplified side view of the dual torus and drive shaft of **FIG. 27**.

FIG. 29 is a simplified schematic view of a dual torus partial superposition illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 30 is a simplified schematic graphical representation of variation in outer rim thickness of a dual torus or toroid illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 31A is a simplified sectional view along line **31-31** of **FIG. 28** illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 31B is a simplified sectional view along line **31-31** of **FIG. 28** illustrating features and advantages in accordance with another embodiment of the invention.

FIG. 31C is a simplified sectional view along line **31-31** of **FIG. 28** illustrating features and advantages in accordance with yet another embodiment of the invention.

FIG. 32 is a simplified perspective view of a distal cutting blade and a reciprocating slide plate that connects to the blade illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 33 is a simplified schematic side view of a distal cutting blade connected to a slide blade illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 34 is a simplified schematic view of toroid drive and associated bearings illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 35 is a simplified schematic view of toroid drive and associated bearings illustrating features and advantages in accordance with another embodiment of the invention.

FIG. 36 is a simplified perspective view of a surgical file transmission system in a test set-up illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 37 is a simplified side cross-sectional view of a surgical file pulsatile pump system illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 38 is a simplified side cross-sectional view of a surgical file pulsatile pump system illustrating features and advantages in accordance with another embodiment of the invention.

FIG. 39 is a simplified exploded perspective view of a surgical file powered handpiece illustrating features and advantages in accordance with another embodiment of the invention.

FIG. 40A is a simplified sectional view along line **40-40** of **FIG. 39** illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 40B is a simplified sectional view along line **40-40** of **FIG. 39** illustrating features and advantages in accordance with another embodiment of the invention.

FIG. 40C is a simplified sectional view along line **40-40** of **FIG. 39** illustrating features and advantages in accordance with yet another embodiment of the invention.

FIG. 41 is a simplified schematic view of a bone and/or tissue removal procedure illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 42 is a simplified perspective view of a bone and/or tissue removal procedure on a plastic anatomical model of the human spine illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 43 simplified side view of a orthopaedic surgical file instrument illustrating features and advantages in accordance with an embodiment of the invention.

FIG. 44 is a simplified front view of a distal cutting assembly of the surgical file instrument of **FIG. 43**.

FIG. 45 is a simplified bottom view of the distal cutting assembly of **FIG. 44**.

Detailed Description of the Preferred Embodiments

The preferred embodiments of the invention described herein relate generally to systems and methods for tissue cutting and removal and, in particular, to a shielded reciprocating surgical file system for cutting, removing, shaping and sculpturing bone and/or tissue material under direct vision.

While the description sets forth various embodiment specific details, it will be appreciated that the description is illustrative only and should not be construed in any way as limiting the invention. Furthermore, various applications of the invention, and modifications thereto, which may occur to those who are skilled in the art, are also encompassed by the general concepts described herein.

FIGS. 1 and **2** show a surgical file system **10** generally comprising a motorized reciprocating shielded surgical file instrument, apparatus, assembly or device **12** and a mobile portable control system **14** connected via a flexible umbilical cable **16**. The surgical file device **12** generally comprises a distal tip assembly **18** and a powered handpiece **20**. Reciprocating as used herein generally includes back and forth motion and to and from motion.

The system **14** generally comprises a mobile portable stand, cabinet or trolley **22** that supports a controller or control unit or box **24** and a computer system **26**. In on embodiment, the system **14** has a footprint of about 0.2 m^2 (2 square feet (ft^2)) and a height of about 1.8 m (6 feet (ft)). In modified embodiments, other suitable dimensions may be efficaciously used, as needed or desired. The system **14** may also utilize wireless communication.

The cabinet **22** has a plurality of drawers or compartments **28** to store system parts, including spare parts, such as cables, connection lines, powered hand piece **20** and an array of various disposable distal cutting tip assemblies, for example, for neurosurgery, orthopaedic surgery and plastic surgery. The storage drawers **28** also serve to store instructions.

The cabinet **22** has a plurality of wheels **30** such as caster wheels to enable movement of the system **14**. In the illustrated embodiment, the cabinet **22** has four wheels **30**. The caster wheels **30** have wheel locks or other suitable fastening mechanisms to enable stationarily locking the unit at the desired position in the operating room or other area.

The computer system **26** comprises a central processing unit (CPU) **32**, a monitor **34**, a keyboard **36** including a mouse and a color printer to produce color pictures. The CPU **32** may be supported on (see, for example, **FIG. 1**) or within (see, for example, **FIG. 2**) the movable cabinet **22**. The CPU **32** includes a video processing system, such as but not limited to a data acquisition board and the like, to process video signals from the surgical file device **12** and supply the signals to the monitor or video display **34**. The CPU **32** has a printer port to interface it with the color printer.

The display monitor **34** can comprise any one of a number of suitable commercially available monitors. In one embodiment, the display **34** is a 17-inch (43 cm) liquid crystal display (LCD) monitor.

The storage cabinet **22** includes a substantially vertical pole or rod **38** to support the monitor **34**. The height and tilt angle of the display **34** is adjustable to allow suitable viewing for the operating surgeons. In one embodiment, the monitor **34** is positioned at a height of about 1.5 meters (5 feet). As discussed further below, the monitor **34** can display a magnified visual picture of the view from the distal end of the cutting tip assembly **18**.

The cabinet **22** includes one or more hooks or supports **42** for mounting of an irrigation fluid bag, container or pouch **44**. The hooks **42** can be positioned at a suitable position, for example, on the pole **38**. The irrigation bag **44** is provided sterile irrigation water from a source **46** through a feedline **48**. The sterile water is transported to the distal cutting tip assembly **18** during device operation through feed line **50**.

In one embodiment, sterile water is provided to the distal cutting tip assembly **18** through the control unit **24** via feedline **50a**. In a modified embodiment, the sterile water is provided directly to the distal cutting tip assembly **18** via feedline **50b**.

The control unit **24** is supported at a suitable working height by the cabinet structure **22**. The control unit **24** is operatively interfaced or connected the cable **16** at its proximal end **40**. In the illustrated embodiment, the cable **16** connects to a front face **52** of the control box **24**. The control box **24** and the CPU **32** can be housed in a single unit.

The control unit **24** and the computer system **26** are powered by a conventional 115-Volt AC electrical power supply **54**, for example, by connecting a male plug to a wall receptacle. In modified embodiments, the system may be powered by a portable power supply such as a generator and the like.

In one embodiment, the control unit **24** connects to a pressurized gas or air source supply **56** via feedline **58**. As discussed further below, the pressurized gas is used to power an air turbine motor of the powered handpiece **20**. The pressurized gas is supplied by the hospital or house supply. In modified embodiments, a portable pressurized gas source such a cylinder may be efficaciously used, as needed or desired.

In one embodiment, the pressurized gas and the irrigation water are supplied from the control unit **24** and through the umbilical cable **16** to the surgical file device **12**. In addition, the cable **16** provides video signals from the surgical file device **12** to the control unit **24** and computer system **26**. The umbilical cable **16** provides a mechanical and waterproof connection for electrical, video, pressurized gas and irrigation water supply. In

modified embodiments, one or more of the electrical and video signals, gas and water may be transmitted through separate cables with efficacy, as needed or desired.

The cable **16** can be any suitable length, for example, about 16 feet long. The cable **16** is sterilizable. The cable **16** may also be used to provide a suction line, as needed or desired.

The control box **24** houses switches and valves to control the flow of the pressurized gas and irrigation water. The control unit **24** has electrical controls for the handpiece **20** and video signals for the computer system **26**. The control unit **24** may also include sensors such as pressure sensors, flow rate sensors and the like to monitor the flow of the pressurized gas and irrigation water.

Software is provided that interfaces with the control unit **24** to monitor and control system operation and perform various other related functions. For example, the software allows the operating room personnel to enter the patient identification and date and other pertinent data into the computer for record reference.

The software also allows operating room personnel to change video picture zoom ratios and to control and modify details of the picture for clarity. The computer based system enables the operating personnel to save pictures of the patient's anatomy, including before and after pictures, to a computer file and to print out color pictures in seconds.

The software is used to control the pressurized gas and irrigation liquid flow to the surgical file device **12**. The software can also be used to turn the device **12** on and off and control the frequency of cutting blade reciprocation during filing procedures.

The control unit **24** accommodates connection to existing cauterizing equipment. As discussed further below, and as shown in phantom in **FIG. 1**, the control unit **24** can be connected to a cauterizing system **60** through connection line **61** to stop or prevent undesirable bleeding during surgery.

In brief, to enable the surgeon to stop the bleeding of freshly cut bone tissue, the cutting blade surface can feature an electrically conductive surface that is operatively connected to an electric circuit, for example, **60**. This allows a controlled pulse of electricity to generate a small amount of heat applied directly onto the bone surface to coagulate the blood and stop the bleeding at the freshly cut bone surface only, while insulating delicate nerve roots from unwanted heat damage. The irrigation water also

works in conjunction to assist in keeping heat precisely localized and preventing heat injury to the nearby delicate nerve roots and spinal cord.

FIG. 3 shows the surgical file device **12** with a distal tip assembly **18** having a generally curved and/or angled configuration. **FIG. 4** shows the surgical file device **12** with a distal tip assembly **18'** having a generally straight configuration. The powered handpiece **20** has at its proximal end **62** a quick connect docking feature **64** to enable connection to the umbilical cable **16** that provides a mechanical and waterproof connection for electrical, pressurized gas and irrigation water supply.

FIG. 5 shows the surgical file device **12** connected to the umbilical cable **16** at its distal end **66**. The interface or connection between a proximal end **330** of the powered handpiece **18** and the cable **16** includes a cover or housing **68**. In the illustrated embodiment, the cover **68** is generally frusto-conical in shape, though in modified embodiments other suitable shapes such as cylindrical and the like may be efficaciously utilized, as needed or desired.

The distal tip assembly **18** at its proximal portion or end **70** includes a cover or housing **72**. In the illustrated embodiment, the cover **72** is generally frusto-conical in shape, though in modified embodiments other suitable shapes such as cylindrical and the like may be efficaciously utilized, as needed or desired.

The powered handpiece **20** includes a cover **74** intermediate the front and back covers **68** and **72**. In the illustrated embodiment, the cover **74** is generally cylindrical in shape and can include a longitudinally extending bulging portion **76** for housing a video camera. In other embodiments, the cover **74** may be efficaciously contoured in suitable ergonomic shapes that facilitate operation by a surgeon or other operator.

The covers **68**, **72**, **74** can be formed from a number of suitably durable materials. In one embodiment, the covers **68**, **72**, **74** are formed from a suitable plastic such as a thermoplastic. In another embodiment, the covers **68**, **72**, **74** are formed from a suitable metal such as stainless steel. In modified embodiments, other suitable plastics, metals, alloys, ceramics, combinations thereof, among others, may be efficaciously utilized, as needed or desired. Suitable surface coatings or finishes may be applied, as required or desired.

The covers **68**, **72**, **74** can be fabricated by using a number of manufacturing techniques. These include, but are not limited to, molding, machining, casting, forging,

laser cutting and/or processing, laminating, adhesively fixing, welding, combinations thereof, among others, with efficacy, as needed or desired.

FIG. 6 shows a partially exploded view of the surgical file device **12**. As discussed further below, the powered handpiece **20** includes a video camera **78** and a micro-motor **80** that provides rotary motion which is converted to linear reciprocating motion within the distal tip assembly **18**. **FIG. 7** shows another perspective view of the surgical file device **12** with the distal cover **72** removed illustrating some of the features of the distal tip assembly.

Distal Tip Assembly

FIGS. 8 and **9** show the distal tip assembly **18** in greater detail. In one embodiment, the composite tip **18** has a length of about 10 cm (4 inches) to about 15cm (6 inches), including all values and sub-ranges therebetween. In one embodiment, the composite tip **18** has a length of about 5 cm (2 inches) to about 30cm (12 inches), including all values and sub-ranges therebetween. In modified embodiments, other suitable lengths may be efficaciously utilized, as needed or desired.

The distal tip assembly **18** is sterile to maintain appropriate surgical standards and is provided in a sterile packaging. In one embodiment, the distal tip assembly **18** is for one time use and is disposable thereafter. As described further below, embodiments of the distal tip assembly **18** include a cartilage or other tissue and bone removal file with vision, illumination, irrigation and cauterization features.

The distal tip assembly **18** generally comprises a distal tip portion **92** that has a distal-most end **94** and a proximal portion extending into the cover **72** that encloses a housing **96** that receives a toroidal power converter system **98** and a water pump system. The distal tip assembly **18** further includes an interface member **102** and a coupling **104** that facilitate connection between the distal tip assembly **18** and the powered handpiece **20**.

The distal tip portion **92** generally comprises a reciprocating cutting or filing blade **106** that is enclosed in a protective case or shield **108**. The shield **108** has an aperture, window, opening **112** to expose a cutting surface **114** of the filing blade **106** proximate the distal end **94**. Desirably, the shielded blade **106** permits surgical bone and/or tissue removal substantially without risk of damage to nearby delicate tissues such as nerve tissue.

The distal tip portion **92** can be configured to be small and thin so it is minimally intrusive and can go around corners and into any small inaccessible blind channels where nerves are located. The distal tip portion **92** can be configured to fit any desired cavity or

contoured shape. The tip portion **92** can be supplied in a variety of sizes and shapes to suit a particular application such as, but not limited to, neurosurgery, orthopaedic surgery and plastic surgery.

The blade cutting surface **114** can be located on the end of an extension with a bend **116** of any desired angle. In the illustrated embodiment of **FIGS. 8** and **9**, the tip portion **92** has a curved, angled or bent configuration with the bend **116**. In another embodiment, the distal tip portion **92** has a substantially straight and/or planar (flat) configuration.

The tip portion **92** further includes a linear bearing retainer **118** within the shield **108**. The reciprocating blade **106** is precision fitted within the bearing retainer **118** that allows free linear motion of the reciprocation blade stroke. Advantageously, the bearing retainer **118** provides low friction bearing surfaces for the reciprocating motion of the blade **106**.

The bearing retainer **118** comprises a plurality of stationary linear bearings **120** which are positioned on the top, bottom and both sides of the reciprocation blade. The top linear bearing **120** has an aperture, opening or window **122** that is substantially aligned with the shield aperture **112** to expose the blade cutting surface **114**. In one embodiment, the tip portion **92** (and hence the lengths of the blade cutting surface **114** and the apertures **112, 122**) are configured so that substantially the entire blade cutting surface **114** is exposed during the full blade reciprocation cycle.

The bearing retainer **118** can be formed from a number of suitably durable materials. In one embodiment, the bearing retainer **118** is formed from a suitable plastic such as a thermoplastic. In modified embodiments, other suitable plastics, metals, alloys, ceramics, combinations thereof, among others, may be efficaciously utilized, as needed or desired. Suitable surface coatings or finishes may be applied, as required or desired.

The bearing retainer **118** can be fabricated by using a number of manufacturing techniques. These include, but are not limited to, molding, machining, casting, forging, laser cutting and/or processing, laminating, adhesively fixing, welding, combinations thereof, among others, with efficacy, as needed or desired.

As described in more detail below, the distal tip portion **92** further includes a pair of fiber optic probes **124, 126** that are part of an on-board optical illumination and vision system. The fiber optic probes **124, 126** optically connect or interface at their proximal ends to the video camera **78**.

The bottom or lower fiber optic probe **124** is below the lower bearing **120**. The fiber optic probe **124** may be housed within the shield **108** or it may have its independent protective jacket below the shield **108**. The fiber optic probe **124** has a distal end **128** at about the distal-most end **94** of the tip portion **92**.

The top or lower fiber optic probe **126** is above the upper bearing **120**. The fiber optic probe **126** may be housed within the shield **108** or it may have its independent protective jacket above the shield **108**. The fiber optic probe **126** has a distal end **130** proximal to a proximal end **132** of the aperture **112** and/or the cutting surface **114**.

The shield **108** can include the aperture **112** on any one of its sides depending on the positioning of the cutting surface **114**. This includes the top (as shown in, for example, **FIGS. 8** and **9**), the bottom and the sides of the shield **108** and even its distal end **134**. The shield **108** has a longitudinally extending cavity that houses the blade **106**, the bearing retainer **118** and in some embodiments the fiber optic probes **124, 126**. In the illustrated embodiment, the distal end **134** closes the longitudinal shield cavity.

In one embodiment, the shield **108** is capable of deflecting and bends at predetermined and/or low loads (for example about 2 lbs.) in order to prevent injury or damage to tissue, such as nerve tissue, engaged by the shield **108**. The shield **108** has a predetermined stress-strain curve and spring constant to provide the desired deflection and can comprise, for example, a suitable polymer and the like. The shield **108** may bend at the bend location **116** or at a location proximate to the contact with the tissue. One or more of the associated tip portion **92** components such as the blade **106**, bearings **120** and the fiber optic probes **124, 126** can also bend with the shield **108**, as needed or desired.

The shield **108** can be formed from a number of suitably durable materials. In one embodiment, the shield **108** is formed from a suitable plastic such as a thermoplastic. In another embodiment, the shield **108** is formed from a polymer that is flexible or can bend under a predetermined load. In modified embodiments, other suitable plastics, metals, alloys, ceramics, combinations thereof, among others, may be efficaciously utilized, as needed or desired. Suitable surface coatings or finishes may be applied, as required or desired.

The shield **108** can be fabricated by using a number of manufacturing techniques. These include, but are not limited to, molding, machining, casting, forging, laser cutting

and/or processing, laminating, adhesively fixing, welding, combinations thereof, among others, with efficacy, as needed or desired.

The shield **108**, the bearing retainer **118** and the fiber optic probes **124**, **126** generally conform in shape to the longitudinal profile of the blade **106**. In the illustrated embodiment of **FIGS. 8** and **9**, this is a curved, angled or bent profile with a bend at around **116**.

FIG. 10 shows a cross-sectional view of the distal tip portion **92** at a location proximal to the aperture **112** and the bend **116**. The blade **106** is substantially centrally located within the shield or outer jacket **108**. The blade **106** is precision fitted within the bearing retainer **118** including the linear bearings **120**. The respective lower and upper fiber optic probes **124**, **126** are buffered from the blade **106** by the stationary bearings **120**.

The cutting blade linear bearing **120** has a series of shallow slots **190** running substantially longitudinally in line with the proximal to distal axis. The slots **190** serve as water passageways to enable irrigation water to be transported from a proximal to a distal location. The irrigation water serves several functions and provides several advantages.

The water is a lubricant for the interface between the moving blade **106** and the stationary linear bearings **120**, which in one embodiment are positioned on the top and bottom and both sides of the reciprocation blade **106**. The water cools the blade and bearing material, and in the embodiment the bearing material is plastic, prevents the plastic bearing material from getting hot and softening. The water also serves to wet the cutting blade surface. The water is also used to clean tissue and transport the cut tissue away from the cutting blade **106**. Additionally, water transported across the linear blade **106** intimately irrigates the volume of water in the distal blade area to clear the optical vision field for clear viewing.

FIG. 11 shows a cross-sectional view of the distal tip portion **92** at the shield aperture **112**. The cutting surface **114** of the blade **106** is exposed and is above the lower bearing **120**, the lower fiber optic probe **124** and a lower portion **192** of the shield **108**. The drawing also shows portions of the shield **108** and the upper bearing **120** at the tip distal end **94**. In this embodiment, the cross-sectional profile of the cutting surface **114** is convex and the associated portions of the shield **108**, bearings **120** and lower fiber optic probe **124** generally conform to this shape.

In one embodiment, and as described further below, the toroidal drive system **98** is substantially mounted within the housing **96** and generally comprises a rotatable toroid drive **136** and a drive slide **138**. A drive shaft **140** is connected to the handpiece motor **80** and transfers rotary motion to the toroid drive **136** which engages the linear slider **138** to convert rotary motion into reciprocating motion that is provided to the blade **106** for performing bone and/or tissue removal operations. In modified embodiments, other suitable rotary to reciprocating motion mechanisms or devices may be used, as needed or desired, to reciprocatingly drive the blade **106**.

As discussed further below, the drive shaft **140** is connected to the toroid drive **136** and has a specially designed female receptor hole. The receptor hole allows the drive shaft **140** to substantially irrotationally mate with a power drive shaft of the motor **80**.

The housing **96** has a distal end **142** and a proximal end **144** and a generally flat recessed surface **146** extending from the distal end **142** towards the proximal end **144**. The linear slide **138** is reciprocatingly seated on or within the recessed surface **146**. The housing **96** includes a cavity **148** intermediate the recessed surface **146** and the housing proximal end **144** that receives the rotatable toroid drive **136**. The housing proximal end **144** has an opening **149** that receives a power shaft of the handpiece motor **80** that connects to the drive shaft **140**.

The housing **96** can be formed from a number of suitably durable materials. In one embodiment, the housing **96** is formed from a suitable plastic such as a thermoplastic. In modified embodiments, other suitable plastics, metals, alloys, ceramics, combinations thereof, among others, may be efficaciously utilized, as needed or desired. Suitable surface coatings or finishes may be applied, as required or desired.

The housing **96** can be fabricated by using a number of manufacturing techniques. These include, but are not limited to, molding, machining, casting, forging, laser cutting and/or processing, laminating, adhesively fixing, welding, combinations thereof, among others, with efficacy, as needed or desired. The housing **96** and bearing retainer **118** may comprise an integral unit, for example, they may be formed by molding and the like.

The toroid drive **136** is connected with the drive shaft **140**. The toroid drive **136** has an outer rim **150** that is engaged with the slider **138** and transmits rotary motion that is converted into reciprocating motion by the slider **138**.

The slide plate **138** has a distal end **152**, a proximal end **154** and a specially contoured slot **156** proximate to the proximal end **152** with a pair of generally opposed bearing surfaces **164, 166**. As described in greater detail below, the slot **156** receives the rotating outer rim **150** of the toroid drive **136**.

The blade **106** is connected to the slide **138**. As described in greater detail below, this connection utilizes shear pins to provide a safety mechanism against blade buckling.

The slide **138** can be formed from a number of suitably durable materials. In one embodiment, the slide **138** is formed from a suitable plastic such as a thermoplastic. In modified embodiments, other suitable plastics, metals, alloys, ceramics, combinations thereof, among others, may be efficaciously utilized, as needed or desired. Suitable surface coatings or finishes may be applied, as required or desired.

The slide **138** can be fabricated by using a number of manufacturing techniques. These include, but are not limited to, molding, machining, casting, forging, laser cutting and/or processing, laminating, adhesively fixing, welding, combinations thereof, among others, with efficacy, as needed or desired.

The interface member **102** has an opening **158** which allows passage of the fiber optic probes **124, 126** for connection to the camera **78**. The interface member **102** has an opening **160** that receives that receives a power shaft of the handpiece motor **80** that connects to the drive shaft **140**.

The coupling **104** has an opening **162** that receives that receives a power shaft of the handpiece motor **80** that connects to the drive shaft **140**. The openings **149, 160** and **162** are substantially aligned with one another.

The interface member **102** and coupling **104** can be formed from a number of suitably durable materials. In one embodiment, the interface member **102** and coupling **104** are formed from a suitable plastic such as a thermoplastic. In modified embodiments, other suitable plastics, metals, alloys, ceramics, combinations thereof, among others, may be efficaciously utilized, as needed or desired. Suitable surface coatings or finishes may be applied, as required or desired.

The interface member **102** and coupling **104** can be fabricated by using a number of manufacturing techniques. These include, but are not limited to, molding, machining, casting, forging, laser cutting and/or processing, laminating, adhesively fixing, welding, combinations thereof, among others, with efficacy, as needed or desired.

Blade Embodiments

Embodiments of the invention provide reciprocating cutting blade for precision bone and/or tissue removal. In one embodiment, the reciprocating cutting blade is shielded or covered or guarded on five sides to provide a shielded surgical file.

The shielded file can be flat, planar, convex or concave in its cross-section. The shielded file can extend generally straight or be curved, angled or bent along its longitudinal axis. Advantageously, the angled configuration allows the cutting surface to travel around a corner to reach into usually inaccessible body cavities. Desirably, this provides the ability to remove unwanted tissue in a blind tunnel or body cavity while enabling direct vision through the illumination and vision probes.

The shielded file can be dimensioned in a number of manners. The shielded file can be any length or width suitable for the human or mammalian anatomy proportions. For other non-medical applications, the shielded file can be of any length or width to suit the material removal application.

The thickness of the shielded file can be varied to be very thin. In one embodiment, the thickness can be of the order of $1/10^{th}$ of an inch. Advantageously, this enables the shielded file to fit into small spaces such as between a nerve and the foramen opening that it is passing through. In other embodiments, the thickness of the shielded file can be greater, as needed or desired.

The cutting blade can be shaped and contoured in several configurations. In one embodiment, the reciprocating cutting blade is straight and planer (in one flat plane). In another embodiment. the reciprocating cutting blade that is curved convex or concave in its cross sectional shape. In yet another embodiment, the reciprocating cutting blade that is substantially straight in its longitudinal axis. In still another embodiment, the reciprocating cutting blade is curved in its longitudinal axis.

The thickness of the cutting blade drive **106** can be varied. In one embodiment, the cutting blade thickness is in the range from about 100 microns or μm (0.004 inches) to about 300 μm (0.012 inches). In another embodiment, the cutting blade thickness is in the range from about 50 μm (0.002 inches) to about 600 μm (0.024 inches). In yet another embodiment, the cutting blade thickness is in the range from about 25 μm (0.001 inches) to about 2.5 mm (0.1 inches). In modified embodiments, other suitable dimensions may be efficaciously utilized, as needed or desired.

The cutting blade **106** can be formed from a number of suitably durable materials. In one embodiment, the cutting blade **106** is formed from steel. In another embodiment, the cutting blade **106** comprises spring stainless steel. In modified embodiments, other suitable metals, alloys, plastics, ceramics, combinations thereof, among others, may be efficaciously utilized, as needed or desired. Suitable surface coatings or finishes may be applied, as required or desired.

The cutting blade **106** can be fabricated by using a number of manufacturing techniques. These include, but are not limited to, molding, machining, casting, forging, laser cutting and/or processing, laminating, adhesively fixing, welding, combinations thereof, among others, with efficacy, as needed or desired.

In one embodiment, the cutting blade **106** is flexible. Advantageously, this allows the cutting blade to be easily bent, angled or curved along its length as it is enclosed in a bent, angled or curved outer shield **108**. In another embodiment, the cutting blade is substantially rigid. This can be suitable for blade configurations that are generally straight. The rigid blade may also be bent by suitable techniques, as needed or desired. In modified embodiments, the cutting blade **106** may efficaciously comprise one or more flexible portions and one or more rigid portions, as needed or desired.

FIG. 12 shows an embodiment of the cutting blade **106**. The blade **106** comprises a thin flexible material that is capable of bending along its length. The blade **106** includes a distal section or portion **194** with the cutting surface **114**, a medial section or portion **196** and a proximal section or portion **198**. When enclosed within the curved, angled or bent shield **108** the blade **106** flexes like a thin spring to conform to the shape of the shield or guide cover **108**. Thus, the medial section **196** is curved, angled or bent while the respective distal and proximal sections **194**, **198** extend generally straight.

FIG. 13 shows a cross-section of a cutting surface **114a** and an associated portion **202a** of the shield **108a** having a generally convex configuration suited for some particular bone and/or tissue removal applications. The convex curvature of the cutting surface **114a** can also be advantageous in providing enhanced rigidity to the thin cutting surface **114a** and/or the associated blade **106**.

FIG. 14 shows a cross-section of a cutting surface **114b** and an associated portion **202b** of the shield **108b** having a generally concave configuration suited for particular bone and/or tissue removal applications. The concave curvature of the cutting surface **114b** can

also be advantageous in providing enhanced rigidity to the thin cutting surface **114b** and/or the associated blade **106**.

FIG. 15 shows a lengthwise-section of the distal tip portion **92** having a cutting surface **114c** on the top or upper side of the reciprocating blade **106** within the non-moving shield **108**. This configuration is suited for some particular bone and/or tissue removal applications. The bend **116** allows the cutting surface **114c** to pass into a cavity that involves traveling around a corner. The direction of blade travel is generally denoted by arrows **204**.

FIG. 16 shows a lengthwise-section of the distal tip portion **92** having a cutting surface **114d** on the bottom or lower side of the reciprocating blade **106** within the non-moving shield **108**. This configuration is suited for some particular bone and/or tissue removal applications. The bend **116** allows the cutting surface **114d** to pass into a cavity that involves traveling around a corner. The direction of blade travel is generally denoted by arrows **204**.

FIG. 17 shows the cutting surface **114** including an abrasive material or abrasives **206** for cutting, removing, filing or grinding bone and/or tissue materials. For clarity, one side of the shield **108** has been removed in the drawing. Any one of a number of suitable abrasives may be used that are safe to use within a patient's body or are biocompatible and hard. In one embodiment, the abrasives **206** comprise embedded diamonds or diamond particles.

Also shown in **FIG. 17** is a lateral slot or opening at the tip portion distal end **94**. Advantageously, the distal opening **208** allows the removal of any bone and/or tissue debris that may collect within the distal and provides for flushing out of the debris as the blade cutting surface **114** reciprocates and the irrigation fluid flows out of the instrument.

FIG. 18 shows the blade cutting surface **114** including a plurality of micro holes or openings **212** for the flow of irrigation fluid therethrough. For clarity the abrasives are not shown in the drawing. The holes **212** are in fluid, liquid or hydraulic communication with the longitudinal slots **190** of the lower linear bearing **120**. The slots **190** of the upper linear bearing **120** also provide irrigation water to the cutting area.

FIG. 19 schematically depicts the fluid, liquid or hydraulic communication between the bearing slot(s) **190** and the cutting surface holes **212**. The flow of water from the bearing slots(s) **190** and the micro hole openings **212** is generally indicated by arrows **214**.

The water is forced to flow up, down or out through the openings **212** in the cutting blade surface **114** and away from the blade cutting surface **114**. The water washes away cut material and keeps debris from clogging the cutting surface **114** to maintain optimum cutting and material removal performance, and to keep the cutting area cool to prevent tissue necrosis damage.

The water also flows over the moving (reciprocating) cutting blade **106** and drive mechanism or bearings **120** to provide cooling and lubrication. The water can be forced into the cutting cavity **112** to flush away micro cutting debris and maintain a clear field of view for video navigation and visualization. The water can be forced into the cutting area cavity **112** to clean and remove freshly cut bone cells and bone fragments to prevent repopulation and unwanted bone growth in the area.

FIG. 20 is another schematic depiction showing the fluid, liquid or hydraulic communication between the irrigation fluid holes **212** and the bearing irrigation passageways **190**. The drawing also shows the abrasive material or abrasives **206** of the blade cutting surface **114**.

FIG. 21 shows the reciprocation blade stroke direction as generally indicated by arrows **216**. The free linear motion of the reciprocation blade stroke is a linear stroke. In one embodiment, for applications within the human body, the linear stroke is in the range from about 2.5 mm (0.1 inches) to about 7.6 mm (0.3 inches), including all values and sub-ranges therebetween. In another embodiment, the linear stroke is in the range from about 1.3 mm (0.05 inches) to about 12.7 mm (0.5 inches), including all values and sub-ranges therebetween. In yet another embodiment, the linear stroke is in the range from about 0.25 mm (0.01 inches) to about 25.4 mm (1 inch), including all values and sub-ranges therebetween. In modified embodiments, the linear stroke may efficaciously be lower or higher depending on the particular application, as needed or desired.

Cauterization

In accordance with one embodiment, the surgical file instrument **12** can stop the small amount of bleeding of freshly cut or sculpture shaped bone or other tissue by accommodating connection to existing cauterizing equipment **60**. In this embodiment, the special feature the system has is a non-electrically conductive shield **108**, which is covering an electrically conductive metal file blade **106**.

When bleeding of the freshly cut bone is detected, the file cutting blade **106** can be brought back into contact with the freshly shaped bone that may be bleeding slightly. A pulse of electricity can be momentarily applied that will flow from the metal blade file surface into the bleeding bone or other tissue surfaces. This will heat the bleeding bone or other tissue surfaces, coagulate the blood flow and advantageously stop the bleeding of the bone and/or tissue surface. Desirably, the irrigation flow facilitates localizing the heat and cooling while the shield **108** protects the adjacent nerves and spine from heat.

Illumination and Vision Probes

FIG. 22 shows a fiber optic vision system **218** including the fiber optic probes **124** and **126**. The fiber optic vision system **218**, in some surgical embodiments, enables surgeons to visually see and verify the presence of unwanted bone and cartilage buildup that is causing nerve root compression and damage to normal body functions. This information on the unwanted material can be documented and recorded by saving visual pictures into a computer database and printing color pictures immediately for reference and record.

The lower fiber optic probe **124** includes a plurality of optical fibers **220a** that optically terminates at a distal lens array or arrangement **222a**. The lens array **222a** is positioned at substantially the tip distal end **94**. The fiber optic probe **124** may be placed within the shield **108** or it may have a separate housing. The lower fiber optic probe **124** generally follows the longitudinal profile of the distal tip portion **92**, the blade **106** and/or the shield **108**.

The upper fiber optic probe **126** includes a plurality of optical fibers **220b** that optically terminates at a distal lens array or arrangement **222b**. The lens array **222b** is positioned proximal to the blade cutting surface **114**. The fiber optic probe **126** may be placed within the shield **108** or it may have a separate housing. The upper fiber optic probe **126** generally follows the longitudinal profile of the distal tip portion **92**, the blade **106** and/or the shield **108**.

Advantageously, the fiber optic vision system **218** enables visual viewing of the patients body cavities all during insertion and placement of the cutting blade. This is intended to enable the surgeon to safely navigate the tiny body cavities such as neuro-foramen tubular canal and avoid damage to fragile nerve roots.

FIG. 23 shows the optical fibers **220a** in more detail. The upper optical fibers **220b** (**220b'**, **220b"**) have a similar configuration and functioning though they may have a different curvature or be flat and planar. The optical fibers **220a** comprise a central plurality of optical vision fibers **220a'** flanked by light or illumination fibers **220a"**. The optical vision fibers **220a'** are connected at their proximal end to the video camera **78**.

The fiber optical illumination fibers **220a"** illuminate the body cavity and enable video visualization. An LED located at the proximal end of the fiber optics illumination fibers **220a"** is used transmit light to the distal end of the illumination fibers **220a"** to provide illuminating light. Advantageously, the direct vision optical system **218** enables surgeons to safely navigate into blind cavities of the human body and to illuminate and see specific body anatomy such as nerves and bony buildups that could be irritating and pressing against nerves causing nerve compression.

In the illustrated embodiment, the direct vision optical system **218** desirably provides an integrated illumination and optical vision system. The optics for vision and illumination are included within the distal tip assembly **18** which in some embodiments is a docking sterile one time use assembly.

Referring in particular to **FIG. 24**, the distal optical system lenses arrangements **222a** and **222b** are each arrayed in three segments. The lower optical segments **222a** are arranged with a video imaging lens **222a'** centered medially and with illuminating lenses **222a"** positioned on the right and left lateral sides. The upper optical segments **222b** are arranged with a video imaging lens **222b'** centered medially and with illuminating lenses **222b"** positioned on the right and left lateral sides.

FIG. 25 shows the lens arrays **222a**, **222b** in more detail. The lateral sides of the central lenses **222a'**, **222b'** have a respective semi-arc male shape **224a'**, **224b'** to each of their left and right sides. The illuminating lenses **222a"**, **222b"** are shaped to have mating female semi-arc medial sides **226a"**, **226b"** on there medial sides which mate into the male mating features **224a'**, **224b'** of the central lens sides.

Advantageously, such mating lens arrays **222a**, **222b** can accommodate a wide range of instrument sizes while using substantially the same basic lens assembly design. Different lenses may be used in the design and the curvature of the lens array adjusted and changed to provide the desired illumination and/or field of view. For example, for a particular medial video imaging lens **222a'**, **222b'** the curvature of the side illuminating

lenses **222a"**, **222b"** can be adjusted or changed to illuminate the desired field of view. This desirably saves on cost since micro lenses are very expensive to tool up and make. The distal tip assembly **18** can have numerous sizes with varying cross sections of the distal tip portion **92** depending on the particular application and advantageously substantially the same basic lens assembly design **222a**, **222b** can be utilized with the different sizes.

Additionally the mating lenses **222a'**, **222b'** and **222a"**, **222b"** allow the black out of the respective mating surfaces **224a'**, **224b'** and **226a"** and **226b"** to substantially prevent illumination light from passing laterally into the imaging lens **222a'**, **222b'** and degrading the optical quality of the resulting picture. A lens set comprising the central imaging lens **222a'**, **222b'** and one each right and left illuminating lenses **222a"**, **222b"** can be assembled onto a wide range of instrument disposable cutting tips **18** in an assembly that has an optical distal lens system which is very thin in cross section and that the lenses follow the instrument cross sectional curve. Advantageously, for embodiments of the invention and in particular the neurosurgery embodiments, having a very thin cross section enables the instruments distal tip to fit into the tiny space between a nerve root and its neuroforamen opening.

As shown in **FIG. 26** the images from the direct vision optical system **218** can be viewed on the LCD monitor **34**. The drawing shows an example of the display with a view **228** from the upper fiberoptic **126** looking onto the blade **106** and a view **230** from the lower fiberoptic **124** looking out from the instrument distal end **92**.

Toroidal Transmission System

The toroidal transmission or power conversion system **98** is a mechanical conversion device that converts rotary to reciprocating motion or action. The powered handpiece **20** houses a rotating motor **80** to power the cutting action of the tissue removal instrument or blade **106**. The rotating mechanical action of the motor **80** is converted into reciprocating mechanical motion of a suitable reciprocal stroke length. It is desirable that the mechanical motion conversion device be simple and have few parts.

Having a video camera system mounted directly into a reciprocating motion mechanical device can create a stability problem with respect to inherent vibration that is usually inherent in all reciprocating motion mechanical devices. Advantageously, the toroidal drive system **98** of embodiments of the invention provides a desirable solution for the vibration problem since it has low or minimum levels of associated vibration. This

advantageously provides a stable platform for the capture of high quality pictures by the video system including the camera **78** housed in the handpiece **20**.

The toroidal drive system **98** inherently has few parts and can be built to be very low vibration due to low mass of the reciprocating components. Thus, the toroidal drive system **98** can provide the powered handpiece **20** with a stable platform and a smooth running mechanical action. The transmission system of embodiments of the invention has utility in a number of fields and applications where conversion of rotary motion to reciprocating motion is desired.

FIGS. 27 and **28** show the toroid drive **136** and the female receptor drive shaft **140**. In one embodiment, the toroid drive **136** and the drive shaft **140** comprise an integral unit and are formed as a single piece. In another embodiment, the toroid drive **136** and the drive shaft **140** can be rigidly connected to one another.

The toroid drive **136** and the drive shaft **140** can be formed from a number of suitably durable materials. In one embodiment, the toroid drive **136** and the drive shaft **140** are formed from a suitable plastic by molding. The plastic material may comprise a suitable thermoplastic. In modified embodiments, other suitable plastics, metals, alloys, ceramics, combinations thereof, among others, may be efficaciously utilized, as needed or desired. Suitable surface coatings or finishes may be applied, as required or desired.

The toroid drive **136** and the drive shaft **140** can be fabricated by using a number of manufacturing techniques. These include, but are not limited to, molding, machining, casting, forging, laser cutting and/or processing, laminating, adhesively fixing, welding, combinations thereof, among others, with efficacy, as needed or desired.

The toroid drive **136** and the drive shaft **140** are rotatable about a substantially central rotation axis **232**. The toroid drive **136** has a generally circular or curvilinear cam portion **234** and a generally central shank portion **236**. As discussed further below, the cam **234** has a specially designed generally circular or curvilinear outer rim **150** with a varying or non-uniform thickness.

The cam **234** and/or the outer rim **150** have a substantially central side view plane **238**. The cam **234** and/or the outer rim **150** are tilted relative to a vertical plane or axis **240** by a predetermined angle α and hence to the rotation axis by an angle β where $\beta = 90° - \alpha$. Thus, typically β and α are less than 90°.

In one embodiment, α is about 20° and β is about 70°. In another embodiment, α is in the range from about 10° to about 40°and β is in the range from about 50° to about 80°, including all values and sub-ranges therebetween. In yet another embodiment, α is in the range from about 5° to about 80°and β is in the range from about 10° to about 85°, including all values and sub-ranges therebetween. In modified embodiments, α and β may be lower or higher, as needed or desired.

As schematically illustrated in **FIG. 29**, in one embodiment, the cam **234** and/or the outer rim **150** are designed to provide a variable thickness for the outer rim **150** by the partial superimposition of two toruses or toroids **242, 244** of substantially uniform rim thickness with respective central axes **246, 248**. By controlling the degree of superposition, the rim **150** of variable and controlled thickness is created. Thus, the transmission or power conversion system **98** is also referred to as a "hybrid dual or twin toroid" system.

Advantageously, the outer rim **150** thickness is varied such that the rim **150** substantially continuously contacts the bearing surfaces **164** and **166** as the cam **234** rotates about the central axis **232**. Thus, desirably the two surfaces **164** and **166** can remain at a substantially fixed distance apart as they move linearly back and forth in reciprocating motion in response to the cam's rotation about the central axis **232**.

In the illustrated embodiment, the torus central axes **246, 248** are at an offset angle θ to produce the desired variable thickness rim **150**. The slightly dimpled or grooved surface **250** is indicative of the partial superposition of the two toruses or toroids **242, 244**. In modified embodiments, more than two toruses and/or toruses with variable rim thickness may be utilized to create the desired outer rim profile.

Advantageously, the dual torus or toroid (one toroid partially inside another) configuration provides an elegant solution of for maintaining a uniform distance between the bearing surfaces **164, 166** or driven rollers. The rotation of the toroid or torus cam **234** moves the outer rim **150** in a reciprocating motion with the motion being generally parallel to the rotary axis **232**. The reciprocating motion of the slide plate **138** is also generally parallel to the rotary axis **232** which is then transmitted to the blade **106**.

FIG. 30 shows the thickness profile of the outer rim **150** in accordance with one embodiment. The thickness varies across the rim **150** in a generally offset sinusoidal profile with a minimum thickness T_{min} and a maximum thickness T_{max}. In modified

embodiments, other suitable rim thickness profiles may be efficaciously utilized, as needed or desired.

The disposable cutting blade assembly **18** includes the integrated transmission system **98** within the distal cover **72**. The transmission system **98** converts the rotary motion of the drive motor **80** into the reciprocating motion of the tissue-cutting blade **106**. The transmission system **98** is a sterile assembly of the disposable cutting blade assembly **18** that is sterile packaged.

The transmission system **98** is an internal mechanism and is generally housed within the housing **96**. This is important in that the "one time use disposable" tip assembly **18** embodiments because easy separation from the re-sterilizable motor drive portion of the powered handpiece **20**. In theses embodiments, the powered handpiece **20** with its rotary motor **80** comprises an independent assembly from the disposable distal cutting tip assembly **18**. Numerous sizes and shapes of distal cutting tip portion **92** are available to be connected onto the motor drive powered handpiece **20**.

Since the disposable distal cutting tip assembly **18** has an internal mechanism to convert rotary motion into reciprocating motion, it advantageously enables a simple and cost effective means of disconnecting the two assemblies **18** and **20**. The drive shaft **140** at its proximal end **253** includes a female receptor hole **254** that is configured to substantially irrotationally mate with a matching male distal shaft drive protruding out of the motor drive **80**.

FIG. 31A shows a simple female triangular hole **254a** in the drive shaft **140** that can engage a triangular shaped distal shaft drive protruding out of the motor drive assembly. When the distal tip assembly **18** and the powered handpiece **20** are connected both the female triangular receptor hole **254a** and the motor's male triangular drive shaft can rotate in tandem. The male and female features are free to mesh and align during the axial motion of connecting the disposable cutting tip assembly **18** onto the reusable sterilizable motor handpiece **20**.

A triangular shaped male mating drive is desirable because it facilitates sterilization of the male triangular shaft. The surfaces that are steam sterilized and reused are desirably simple surfaces that are easy to wash and clean. The surfaces should also enable reliable cleaning prior to sterilization. A triangular male shaft has three flat surfaces that are both easy to see and clean.

In modified embodiments, other suitable male-female mating drive polygonal or non-polygonal interlocking configurations may be utilized with efficacy, as needed or desired. For example, **FIG. 31B** shows a generally square or rectangular female receptor hole **254b** and **FIG. 31C** shows a generally hexagonal female receptor hole **254c**.

FIG. 32 and **33** show the cutting blade **106** and the drive slide **138**. The outer rim **150** of the toroid drive **136** engages the slide slot **156** and abuts against the bearing surfaces **164**, **166** as it rotates to reciprocatingly displace the slide **138** connected to the blade **106**. The slide **138** can be generally above the toroid drive **136** or it can be generally below the toroid drive **136**. In modified embodiments, the slide **138** can be to the sides of the toroid drive **136** as long as the outer rim **150** rotates within the slide slot **156** and causes the slide to move in a reciprocating motion.

It is important that the distal filing blade **106** maintain its structural rigidity and not to fail in a buckling mode that would cause the file blade **106** to become bent or distorted into a shape that may result in an undesirable thicker profile. To safeguard against this, in one embodiment, a safety shear system is provided.

The slide **138** includes a pair of posts or pins **260**, **262** that engage respective blade holes **256**, **258**. In one embodiment, the posts **260**, **262** are formed from a molding process in which the slide **138** including the posts **260**, **262** comprises a plastic. The posts **260**, **262** in one embodiment are heat staked and the like to mushroom and form respective heads **264**, **266** to affix the blade **106** and the slide **138**. The mushroomed pins **260**, **262** prevent undesirable blade buckling by being configured to shear at a force much lower than the force that could potentially buckle the file blade **106**.

Thus, advantageously, the file blade **106** is driven by a structure that has an intentional weak point that will shear away the driving reciprocating action of the blade drive **106** to prevent a potential distal blade **106** buckling. The configuration of the shear pins **260**, **262** is tailored to the specific file blade configuration (which varies in width and length and cross sectional curve). Thus, the shear pin connection including the diameter and/or cross-section of the mushroomed heads **264**, **266** and/or the shank portions of the pins **260**, **262** is configured such that the mushroomed pins **260**, **262** shear at a force lower than a force that would buckle the specific distal cutting blade **106** and allow safe disengagement and disconnection of the blade **106** from the slide **138**.

Advantageously, the diameter(s) of the pins **260, 262** provides a desirable shear pin safety mechanism. The pins **260, 262** allow the connection between the drive slide **138** and the blade **106** to shear at a predetermined force. This force can be determined for a particular cutting blade configuration by a number of methods including modeling, numerical analysis, computer simulation, experimental and empirical testing and the like, among others. Accordingly, each differing cutting blade **106** is provided with a shear connection feature to shear and stop the blade driving action before the blade could conceivably buckle. A clearance space **268** in the slide **138**is provided in the proximal direction behind a blade proximal end **270** to allow the blade **106** to move proximally in the slide part **138** when shear disconnection occurs so that the blade **106** is substantially decoupled from the reciprocating motion.

The safety shear force F_{shear} can be calculated as a function of the blade buckling force F_{buckle} in a number of ways to provide suitable protection. In one embodiment, the shear force F_{shear} is about $1/3^{rd}$ of the blade buckle force F_{buckle}. In another embodiment, the shear force F_{shear} is in the range from about $0.25F_{buckle}$ to about $0.75F_{buckle}$, including all values and sub-ranges therebetween. In yet another embodiment, the shear force F_{shear} is in the range from about $0.1F_{buckle}$ to about $0.9F_{buckle}$, including all values and sub-ranges therebetween. In modified embodiments, the shear force F_{shear} may be lower or higher, as needed or desired.

FIGS. 32 and **33** illustrate a connection between the blade **106** and the slide plate **138** in accordance with an embodiment that provides a safety shear decoupling between the **106** and the slide plate **138**. In modified embodiments, as the skilled artisan will appreciate, the blade **106** and the slide **138** may be connected utilizing other suitable techniques, as needed or desired.

FIG. 34 shows the hybrid dual toroid drive **136** with a pair of associated bearings **272, 274** operatively mounted on the slide plate **138**. The bearings **272, 274** and their toroid abutting surfaces **276, 278** are spaced by a predetermined distance that allows the variable thickness cam outer rim **150** to be in substantially continuous contact while rotating. In this embodiment, the rotation axis **232** is substantially perpendicular to a plane **280** between the bearing surfaces **276, 278**.

The specially configured bearing abutting surfaces **282, 284** of the outer rim **150** advantageously provide an increased surface contact area with respective bearing surfaces

276, 278. This desirably decreases the pressure load between driving toroidal surfaces **282, 284** and the driven linear slide follower bearings **272, 274** and their respective surfaces **276, 278**. The bearings **272, 274** also provide for a low friction contact with the driving toroidal surfaces **282, 284** and advantageously improve wear-resistant properties.

FIG. 35 shows a modified embodiment wherein the toroid drive **136** has an outer rim **150a** that substantially contacts the bearing surfaces **276, 278** mounted on the slide **138** in a low surface area or point contact arrangement. In further embodiments, the cam outer rim **150** can directly contact the slide bearing surfaces **164** and **166**, as needed or desired.

FIG. 36 shows the operation of the toroidal transmission and power converter system **98** in a laboratory system set-up. Rotation of the toroid drive **136** is about the central rotary axis **232** is converted into linear reciprocating motion of the slide **138** as generally indicated by arrows **204**. The slide is connected to the cutting blade **106**. Also shown are the slide bearings **272** and **274**.

Irrigation Pump System

A pulsatile water pump system **290** is incorporated into the disposable cutting blade assembly **18** and is housed within the distal cover **72**. The pulsating water pump **290** supplies sterile water into a patient and in one embodiment is disposed after one use to insure no "patient to patient" bio-contamination. The pulsatile pump system of embodiments of the invention has utility in a number of fields and applications where fluid transport is desired. In one embodiment, a pulse of water is provided after each linear motion stroke.

The integrated cutting blade water pump system **290** is advantageously driven by blade motion and insures that the blade **106** will automatically be cooled and lubricated whenever the cutting blade **106** is in reciprocating motion. In modified embodiments, an external pump system may be utilized, as needed or desired.

The water pump system **290** lubricates the reciprocating blade moving parts. The water pump system **290** cools the reciprocating blade moving parts. The water pump system **290** provides clear water for optical vision capability.

The pulsating water pump system **290** more effectively clears debris from the cutting blade surface for better cutting performance by providing pulsed jets of irrigation fluid. The pulsatile water pump system **290** is driven by reciprocating cutting blade motion

pumps water whenever reciprocating blade **106** is driven. In modified embodiments, the system may have a manual override feature for pump operation.

FIG. 37 shows the pulsatile dual direction water pump system **290** in accordance with an embodiment. The pump system **290** has a stationary pump body **292** that includes an inlet **294**, a flow chamber **296** and an outlet **298**. The inlet **294** is fed water from the umbilical cord **16** or through another feedline. The outlet **298** provides water to the bearing retainer **118** within the blade shield **108**. The general direction of flow or the fluid path through the pump **290** is generally indicated by arrows **302**.

The inlet **294** has a one-way or check valve **304** and the outlet **298** has a one-way or check valve **306** to prevent undesired back-flow. Any one of a number of suitable valves may be used such as, but not limited to, pressure relief valves, ball-spring devices and the like.

The pump system **290** includes a pair of spaced spring-biased or -loaded plungers **308, 312**. In modified embodiments, other suitable resilient biasing or loading mechanisms may be efficaciously utilized, as needed or desired. The plungers **308, 312** can move back and forth into the pump chamber **296** to selectively occlude the pump chamber **296** and/or fluid path **302** to displace fluid and pulsatingly pump it to the desired site. Water is drawn in from the inlet **294** through the valve **304** as the plungers **308, 312** move back towards their undepressed position.

The slide **138** has a lower surface **314** with a pair of specially contoured and spaced cam surfaces **316, 318** that operatively couple the slide **138** with the pump plungers **308, 312**. During a forward linear stroke motion the distal cam surface **316** contacts or abuts the distal plunger **308** and depresses it to pump water out of the outlet **298**. During a backward linear stroke motion the proximal cam surface **318** contacts or abuts the proximal plunger **312** and depresses it to pump water out of the outlet **298**.

Thus, the reciprocating linear stroke blade drive motion moves cam surfaces **316, 318** to alternatingly depress pump plungers and thereby pump water in a pulsing modality whenever the driven cutting blade **106** is moved through a linear stroke by the transmission system **98**. Desirably, the transmission system **98** provides the motion, force or energy to substantially simultaneously and synchronously drive the reciprocating blade **106** and the pulsatile pump system **290**.

In embodiments of the invention, the water pump **290** is integrated into the reciprocating blade mechanism. The pulsatile (pulsating with each linear stroke) water pump feature pulses a jet of water out through the cutting blade irrigation holes **212** to keep the cutting surface **114** clean for optimum cutting action. The pulse powered pump **290** is powered by the reciprocating action of the cutting blade **106**. Advantageously, this direct drive eliminates a separate pump drive source. This desirably saves parts and cost by eliminating a separate water pump.

The disposable cutting tip assembly **18** is sterile. It incorporates the water pump **290** which is also sterile. The pump **290** is very close or proximate to the site where the pressurized water is provided. Advantageously, this reduces pressure losses that would be incurred if the pump is at a distance from the point of use. It desirably also solves the problem of sterilizing a far away water pump.

When the reciprocating blade device **106** is cutting it should be provided lubrication and cooling and the cutting surface **114** should desirably also remain clean and clear of tissue debris. The water pump **290** pumps water when the cutting surface **114** is activated as the same drive mechanism drives both. Thus, an operator need not remember to activate the pump **290** since its operation is automatically actuated with cutting blade **106**. Desirably, this provides a safety feature to prevent damage, galling, a freeze up and also prevents cutting debris buildup and thermal glazing.

The pump system **290** can be formed from a number of suitably durable materials. In one embodiment, the pump system **290** is formed from a suitable plastic. The plastic material may comprise a suitable thermoplastic. In modified embodiments, other suitable plastics, metals, alloys, ceramics, combinations thereof, among others, may be efficaciously utilized, as needed or desired. Suitable surface coatings or finishes may be applied, as required or desired.

The pump system **290** can be fabricated by using a number of manufacturing techniques. These include, but are not limited to, molding, machining, casting, forging, laser cutting and/or processing, laminating, adhesively fixing, welding, combinations thereof, among others, with efficacy, as needed or desired.

FIG. 38 shows a pulsatile single direction eater pump system **290a** in accordance with another embodiment. The pump system **290a** includes a plunger **320** connected to the slide **138**. During forward linear stroke motion the plunger **320** occludes the pump cavity

296 to displace water form the outlet 298 to the desired site. During backward linear stroke motion the plunger 320 moves in an outward direction from the pump cavity 296 and water is drawn into the cavity 296 through the inlet 294.

Powered Handpiece

FIG. 39 shows the powered handpiece 20 including the cover or housing 74, the video camera 78, the motor assembly 80 and a distal interface member 322 for connecting to the interface member 102 and coupling 104 of the distal tip assembly 18. The interface member 322 has an opening 324 substantially aligned with the interface opening 158 which allow passage of the fiber optic probes 124, 126 for connection to the camera 78.

The proximal end 70 of the distal tip assembly 18 and the handpiece's distal end or portion 326 are configured and adapted to provide a quick and reliable connection or mating. This includes, but is not limited to, mechanical docking, electrical docking, optical docking and hydraulic docking.

The housing 74 and motor assembly 80 are steam sterilizable. The steam sterilization process involves the application of hot water and steam under pressure to kill germs followed by a partial drying process. The drying process is not always fully complete in that the instruments and parts processed, often come back partially wet. Usually there are small pockets of standing water trapped in small pools created by part shapes with water-titer pockets that end up facing upward due to there placement in the holding trays used to contain the parts and instruments to be steam sterilized.

With the routine use of steam sterilization it is desirable that any optical or electronic parts that are used with the steam sterilized instruments be designed to provide solutions to residual water and the problems it can create with electro-mechanical and opto-mechanical components. As discussed further below, the motor housing also houses the video camera module, which in inserted into the freshly sterilized motor housing. The hermetically sealed video camera module is designed to specifically address the specialized problems of residual water in a freshly steam sterilized surgical instrument in a sterile surgical setup environment.

The handpiece housing 74 has a motor housing 328 that receives the motor assembly 80 and the video housing 76 that receives the video camera 78. The video camera 78 is contained in the video housing 76 which provides a hermetically sealed housing. The video housing 76 desirably provides a water and gas sealed environmentally protective

housing. The video camera **78** optically connects to the proximal end **70** of the distal tip assembly **18** and interfaces with the imaging fiberoptics.

The cable **16**, the cover **68** and the components of the handpiece **20** are sterilizable except for the video camera **78** that is hard to sterilize. During assembly in a sterile field operating room, the non-sterile video camera **78** is inserted into a freshly sterilized handpiece housing **74**. A hermetic (gas and liquid) seal is created by O-ring seals or the like. The O-rings are part of the interface at the handpiece's proximal end **330** and the distal end interface **322**. Advantageously, this hardware and procedure combined together enables a non-sterile delicate electronic video camera to be made bacteriologically safe inside the sterile outer housing **74** of the sterilized handpiece **20**.

The housing **74** also contains an LED illuminator **332** that connects to the illumination fiberoptics of the distal tip assembly **18**. The LED (Light Emitting Diode) **332** is also mounted into the video housing **74** in a waterproof and gas-tight method to prevent intrusion and damage from water or water vapor accumulation. In one embodiment, a distal video imaging lens **334** is recessed to help prevent accidental damage.

The camera **78** can be provided in a mount **336** with an outer shape that is designed to prevent the incorrect insertion into the housing **74**. The mount **336** has a male structure **338** that is received within a mating female receptor opening **340** within the housing **74**. The male structure **338** provides the mount **336** with an asymmetrical cross sectional shape that is intended to create a visually obvious shape that can be readily inserted into its mating female receptor opening **340** in the correct or desired orientation.

In one embodiment, the camera **78** and the mount **336** comprise a video module **342** with the camera **78** housed in a waterproof and air-tight manner as discussed above in connection with the video housing **74**. The hermetically sealed video module **342** can then be fitted within in the housing **74**. The LED **332** can also be hermetically sealed within the module **342**, for example, in an opening **344**.

The camera **78** can comprise any one of a number of suitable video or digital devices. In one embodiment, the video camera **78** comprises a device as available from Toshiba. Advantageously, the integration of the video camera **78** within the handpiece **20** greatly enhances the capability, compactness, utility and versatility of the system.

As discussed above, the sterilizable powered handpiece **20** contains a non-sterile non-sterilizable video camera **78** contained inside the sterile hand piece assembly.

Advantageously, the sterile powered handpiece **20** hermetically seals the non-sterile video camera **78** in a sterile housing **74** or **336**, which permits safely using the sealed assembly in the sterile field and inside a patients body.

The handpiece **20** can include one or more switches or buttons that allows the user to operably control the surgical file operation. Alternatively, or in addition, the controls can be provided on a separate platform and/or on the control system **14**.

The precision motor **80** can comprise any one of a number of suitable rotary motion creating devices such as, but not limited to, gas turbines and electric motors and the like. In one embodiment, the motor **80** comprises a gas or air turbine rotary motor that is fed pressurized air or gas through the umbilical cord **16**.

In one embodiment, the gas turbine motor **80** is provided air or gas at about 80 psi to run the device. In another embodiment, air or gas is provided at a pressure in the range from about 50 psi to about 100 psi, including all values and sub-ranges therebetween. In modified embodiments, the pressure can be lower or higher, as needed or desired.

The motor assembly **80** at its distal end or portion **342** includes a rotatable power shaft **344** connected to a rotatable drive shaft **346**. The motor distal end **342** docks with the proximal end **70** of the distal tip assembly **18**. The power shaft **344** is generally received in the distal tip assembly holes **162**, **160** and **149**.

The motor **80** powers the reciprocating blade **106**. The male drive shaft **346** is substantially irrotationally received within the matching female receptor hole of the drive shaft **140** to provide rotary motion to the transmission system **98** that converts it into linear reciprocating motion.

FIG. 40A shows a simple triangular shaft **346a** that can engage the triangular receptor hole **254a**. When the distal tip assembly **18** and the powered handpiece **20** are connected both the female triangular receptor hole **254a** and the motor's male triangular drive shaft **346a** can rotate in tandem. The male and female features are free to mesh and align during the axial motion of connecting the disposable cutting tip assembly **18** onto the reusable sterilizable motor handpiece **20**. This docking feature has a simplified rotary triangular shaped drive shaft, even though it drives a reciprocating (push-pull) motion-cutting blade.

A triangular shaped male mating drive **346a** is desirable because it facilitates sterilization of the male triangular shaft **346a**. The surfaces that are steam sterilized and

reused are desirably simple surfaces that are easy to wash and clean. The surfaces should also enable reliable cleaning prior to sterilization. The triangular male shaft **346a** has three flat surfaces that are both easy to see and clean.

In modified embodiments, other suitable male-female mating drive polygonal or non-polygonal interlocking configurations may be utilized with efficacy, as needed or desired. For example, **FIG. 40B** shows a generally square or rectangular male shaft **346b** and **FIG. 31C** shows a generally hexagonal male shaft **346c**.

Surgical Methods

The methods which are described and illustrated herein are not limited to the sequence of acts described, nor are they necessarily limited to the practice of all of the acts set forth. Other sequences of acts, or less than all of the acts, or simultaneous occurrence of the acts, may be utilized in practicing embodiments of the invention.

The surgical instrument of embodiments of the invention enable the removal of obstructions in the tubular spaces (neuroforamen) between the vertebras of the neck and back. Desirably, this allows surgeons to navigate into the tiny (neuroforamen) canals between delicate nerve roots and remove small amounts of bony overgrowth (osteophytes) under direct vision.

Embodiments of the invention allow a surgeon to safely navigate down into the neuroforamen canal next to the nerve roots and see and remove obstructions that cause nerve compression with direct vision. The surgeons can perform a new surgical procedure, a "micro foramentomy" through as small as about a ½ inch to about 1 inch incision. This advantageously represents a truly minimally invasive surgical procedure which would serve to benefit patients and surgeons.

FIGS. 41 and **42** show a bone and/or tissue cutting procedure using the surgical instrument **12**. The shielded cutting blade **106** is inserted into a neuroforamen **348** between a vertebra **350**, unwanted bone and/or tissue **352** and a nerve root **354**. The shield **108** protects the nerve root **354** while the blade cutting surface **114** removes the bone and/or tissue **354** to relieve nerve compression by enlarging the neuroforamen **348**.

Advantageously, embodiments of the invention provide a high level of cutting blade control and enable surgeons to reach into previously inaccessible areas to remove unwanted bone with precision, sensitivity and complete safety and confidence. The shielded cross

sectional profile of embodiments of the cutting tip permit protection of delicate nerves during the neuroforamen enlargement process to relieve nerve compression.

As seen in **FIG. 42**, the shielded portion **108** of the file is facing the delicate nerve **354** and the opposite cutting surface **114** is facing the bone that is to be removed **352** to enlargen the bony and cartilage structural opening. Advantageously, the surgical instrument of embodiments of the invention has a cutting surface **114** that can travel around corners. A direct vision system allows surgeons to safely navigate into blind cavities of the patient's body and also assists visualization of the actual tissue cutting action and its results.

In the embodiments of a sterile disposable (one time use) cutting tip assembly **18**, the cutting tip assembly **18** is used typically, in one embodiment, for about three minutes in a two-hour surgical procedure. The tip of the distal assembly **18** can provide the surgeon with a picture of the area, and enable the doctor to see the cavity and its anatomical features.

The view is magnified so the user sees a full screen image of the small tunnel, which is typically, in one embodiment, about one quarter of an inch in diameter. The enlarged view of the area allows surgeons to inspect and find the exact location and size of nerve irritation and compression, and determine where and how much bone and cartilage to remove to eliminate the nerve compression and relieve the pain.

Orthopaedic File Embodiment

FIGS. 43-43 show different views of an orthopaedic shielded reciprocating surgical file instrument or apparatus **12a**. The surgical file instrument **12a** generally comprises a distal tip assembly **18a** docked to and powered by a handpiece **20a**.

The distal blade assembly **18a** generally comprises a reciprocating blade **106a** with a cutting surface **114a** and a shield or guard **108a**. The cutting surface **114** has an abrasive material or abrasives **206a**.

The distal blade assembly **18a** further includes a handle **356** above the blade **106a**. The handle **356** is used by a surgeon to press against or down on the bone and/or tissue material to be removed. The handle **356** is shaped to facilitate manipulation and has a suitable ergonomic shape or the like. The handle **356** further includes an opening **358** to facilitate operation.

From the foregoing description, it will be appreciated that a novel approach for precision bone and/or tissue removal surgery has been disclosed. While the components, techniques and aspects of the invention have been described with a certain degree of particularity, it is manifest that many changes may be made in the specific designs, constructions and methodology herein above described without departing from the spirit and scope of this disclosure.

Various modifications and applications of the invention may occur to those who are skilled in the art, without departing from the true spirit or scope of the invention. It should be understood that the invention is not limited to the embodiments set forth herein for purposes of exemplification, but is to be defined only by a fair reading of the appended claims, including the full range of equivalency to which each element thereof is entitled.

WHAT IS CLAIMED IS:

1. A surgical instrument comprising:

a blade;

a housing in which the blade moves, the housing having a long axis;

a transmission that converts rotary motion to reciprocating, linear motion, wherein the transmission is coupled to the blade such that the blade moves reciprocally in the housing;

a first opening in the housing through which a portion of the blade is exposed; and

a cutting surface on said exposed portion of the blade, said surface configured to perform at least one of grinding, filing, and cutting of tissues, wherein the transmission comprises:

two surfaces that are a substantially fixed distance apart;

a cam that rotates about a central axis, said central axis being at an angle to a plane extending between the two surfaces; and

the cam having a curvilinear body, the body having a nonuniform thickness, wherein the body continuously contacts the two surfaces as the cam rotates about the central axis, such that the two surfaces remain at the substantially fixed distance apart as they move linearly in response to the cam's rotation about the central axis.

2. The surgical instrument of claim 1, wherein the housing is concave about at least a portion of its long axis.

3. The surgical instrument of claim 2, wherein the housing is concave about at least a distal portion of its long axis.

4. The surgical instrument of claim 1, wherein the housing is convex about at least a portion of its long axis.

5. The surgical instrument of claim 4, wherein the housing is convex about at least a distal portion of its long axis.

6. The surgical instrument of claim 1, wherein the first opening is in an opening surface on the housing.

7. The surgical instrument of claim 1, wherein the housing is curved along its long axis, to assist in placing the surgical instrument in the body of a patient.

8. The surgical instrument of claim 1, wherein the blade is substantially flat.

9. The surgical instrument of claim 6, wherein the housing is curved along its long axis in a direction toward the opening surface.

10. The surgical instrument of claim 1, further comprising at least one bearing retainer for reducing friction.

11. The surgical instrument of claim 10, wherein said at least one bearing retainer has at least one slot configured to transmit fluid toward a distal end of the instrument.

12. The surgical instrument of claim 1, further comprising at least one fiberoptic in or on the housing, for transmission of at least one of a video signal and illumination light.

13. The surgical instrument of claim 1, wherein the housing has at least a second opening at a distal end of the housing.

14. The surgical instrument of claim 12, further comprising at least two lenses coupled to the at least one fiberoptic.

15. The surgical instrument of claim 14, wherein at least one of the at least two lenses is disposed at a distal end of the housing, and another of the at least two lenses is disposed in proximity to the first opening in the housing.

16. The surgical instrument of claim 1, further comprising a pump for pumping fluid through the surgical instrument.

17. The surgical instrument of claim 16, wherein the pump is mechanically coupled to the transmission.

18. The surgical instrument of claim 1, wherein said cam's central axis is substantially parallel to a direction of the linear motion of the two surfaces.

19. The surgical instrument of claim 1, wherein said central axis is substantially perpendicular to the plane extending between the two surfaces.

20. The surgical instrument of claim 1, wherein the two surfaces move linearly back and forth in reciprocating motion in response to the cam's rotation about the central axis.

21. The surgical instrument of claim 1, wherein the curvilinear body has a shape comprising at least two toruses, the at least two toruses being partially superimposed, and each of said at least two toruses has a central axis, wherein the central axes of the at least two toruses are at an angle to each other.

22. The surgical instrument of claim 1, wherein at least one bearing comprises the two surfaces.

23. The surgical instrument of claim 22, wherein two bearings respectively comprise the two surfaces.

24. The surgical instrument of claim 1, wherein the curvilinear body is disposed at an angle to the central axis of the cam.

25. The surgical instrument of claim 16, wherein the pump comprises:

a fluid path;

two plungers configured to at least partially occlude said fluid path;

a second cam configured to cause said two plungers to at least partially occlude said fluid path alternatingly; and

at least one check valve along said fluid path for reducing backflow of fluid within said fluid path.

26. The surgical instrument of claim 25, wherein the second cam translates in a direction that is substantially perpendicular to a long axis of at least one of said two plungers.

27. The surgical instrument of claim 26, wherein the second cam translates in a direction that is substantially perpendicular to a long axis of each of said two plungers.

28. The surgical instrument of claim 17, wherein the pump comprises:

a fluid path;

two plungers configured to at least partially occlude said fluid path;

a second cam configured to cause said two plungers to at least partially occlude said fluid path alternatingly; and

at least one check valve along said fluid path for reducing backflow of fluid within said fluid path.

29. The surgical instrument of claim 28, wherein the second cam translates in a direction that is substantially perpendicular to a long axis of each of said two plungers.

30. The surgical instrument of claim 1, further comprising at least one opening in the exposed portion of the blade, for transmitting fluid.

31. The surgical instrument of claim 1, wherein the cutting surface comprises an abrasive material.

32. The surgical instrument of claim 1, wherein the cutting surfaces comprises diamond.

33. The surgical instrument of claim 1, wherein the blade comprises stainless steel.

34. The surgical instrument of claim 1, further comprising a handpiece coupled to the housing.

35. The surgical instrument of claim 1, further comprising a video camera.

36. The surgical instrument of claim 35, wherein the camera is configured to couple with a fiberoptic that extends to a distal end of the housing.

37. The surgical instrument of claim 34, wherein a video camera is located in the handpiece.

38. The surgical instrument of claim 37, further comprising a watertight seal in the handpiece.

39. The surgical instrument of claim 38, wherein the handpiece is configured to contain the video camera in a chamber such that the watertight seal reduces or prevents ingress of at least one of water and bacteria from outside the handpiece into the chamber containing the video camera in the handpiece.

40. The surgical instrument of claim 34, further comprising a motor in the handpiece, said motor configured to power the rotary motion.

41. The surgical instrument of claim 40, wherein said motor comprises a gas turbine.

42. The surgical instrument of claim 1, further comprising a cord configured to couple to a proximal end of the surgical instrument, said cord comprising at least one of a fiberoptic, an electrical line, an irrigation channel, a suction line, and a gas tube for powering a gas turbine motor in the surgical instrument.

43. A surgical instrument, comprising:

a blade;

a housing in which the blade moves, the housing having a long axis;

a transmission that converts rotary motion to reciprocating, linear motion, wherein the transmission is coupled to the blade such that the blade moves reciprocally in the housing;

a first opening in the housing through which a portion of the blade is exposed; and

a cutting surface on said exposed portion of the blade, said surface configured to perform at least one of grinding, filing, and cutting of tissue; and

a pump for pumping fluid through the surgical instrument, wherein the pump comprises:

a fluid path;

two plungers configured to at least partially occlude said fluid path;

a cam configured to cause said two plungers to at least partially occlude said fluid path alternatingly; and

at least one check valve along said fluid path for reducing backflow of fluid within said fluid path.

44. The surgical instrument of claim 43, wherein the cam translates in a direction that is substantially perpendicular to a long axis of at least one of said two plungers.

45. The surgical instrument of claim 44, wherein the cam translates in a direction that is substantially perpendicular to a long axis of each of said two plungers.

46. The surgical instrument of claim 43, wherein the pump is mechanically coupled to the transmission.

47. The surgical instrument of claim 46, wherein the cam translates in a direction that is substantially perpendicular to a long axis of at least one of said two plungers.

48. A surgical instrument, comprising:

a blade;

a housing in which the blade moves, the housing having a long axis;

a transmission that converts rotary motion to reciprocating, linear motion, wherein the transmission is coupled to the blade such that the blade moves reciprocally in the housing;

a first opening in the housing through which a portion of the blade is exposed;

a cutting surface on said exposed portion of the blade, said surface configured to perform at least one of grinding, filing, and cutting of tissue;

a handpiece coupled to the housing;

a video camera located in the handpiece; and

a watertight seal in the handpiece;

wherein the handpiece is configured to contain the video camera in a chamber such that the watertight seal reduces or prevents ingress of at least

one of water and bacteria from outside the handpiece into the chamber containing the video camera in the handpiece.

49. A surgical instrument, comprising:

a housing having a longitudinal axis;

a blade assembly configured to oscillate linearly relative to the housing in a direction generally parallel to the longitudinal axis, the blade assembly comprising a blade having a cutting surface;

a rotary shaft; and

a transmission configured to convert rotation of the rotary shaft into oscillating linear movement of the blade assembly;

wherein the transmission comprises a torus-like shape disposed on the rotary shaft, the torus-like shape having a central axis that is angled relative to an axis of the rotary shaft.

50. The surgical instrument of claim 49, wherein the transmission further comprises opposed bearing surfaces that are a substantially fixed distance apart.

51. The surgical instrument of claim 50, wherein the torus-like shape has a circumferential portion that fits between the opposed bearing surfaces.

52. The surgical instrument of claim 51, wherein a thickness of the circumferential portion varies about the circumference.

53. The surgical instrument of claim 49, wherein the torus-like shape comprises at least two toruses that are partially superimposed, the at least two toruses having central axes that are angled relative to one another.

54. The surgical instrument of claim 53, wherein the torus-like shape has a circumferential portion, and a thickness of the circumferential portion varies about the circumference.

55. The surgical instrument of claim 49, wherein the housing has an opening through which a portion of the blade is exposed.

56. The surgical instrument of claim 55, wherein the housing shields the blade from access except at the opening.

57. The surgical instrument of claim 55, further comprising at least one opening in the exposed portion of the blade, for transmitting fluid.

58. The surgical instrument of claim 57, further comprising a pump for pumping fluid through the surgical instrument.

59. The surgical instrument of claim 55, wherein the blade is substantially flat.

60. The surgical instrument of claim 49, further comprising a pump for pumping fluid through the surgical instrument.

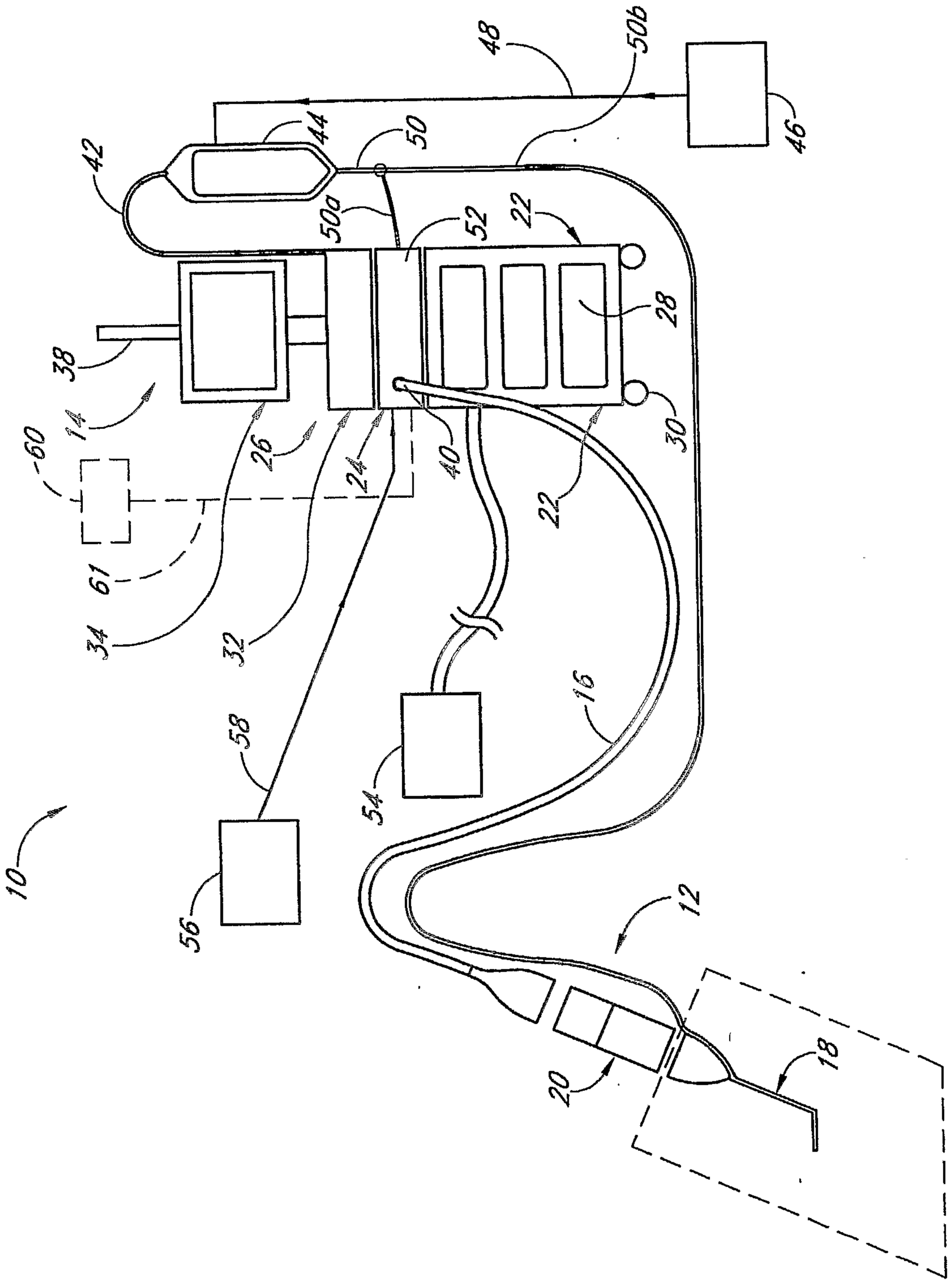

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FIG. 1

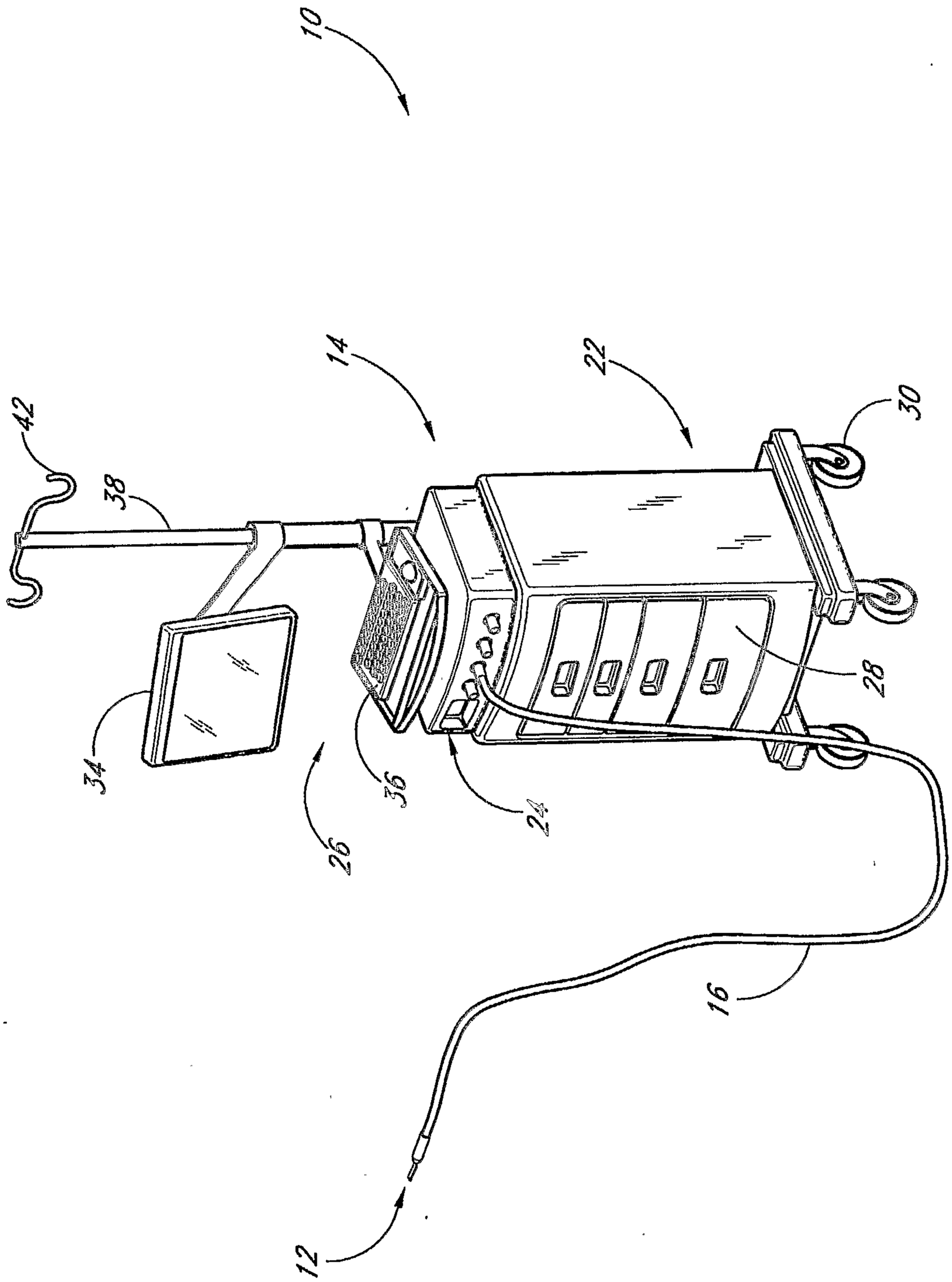

FIG. 2

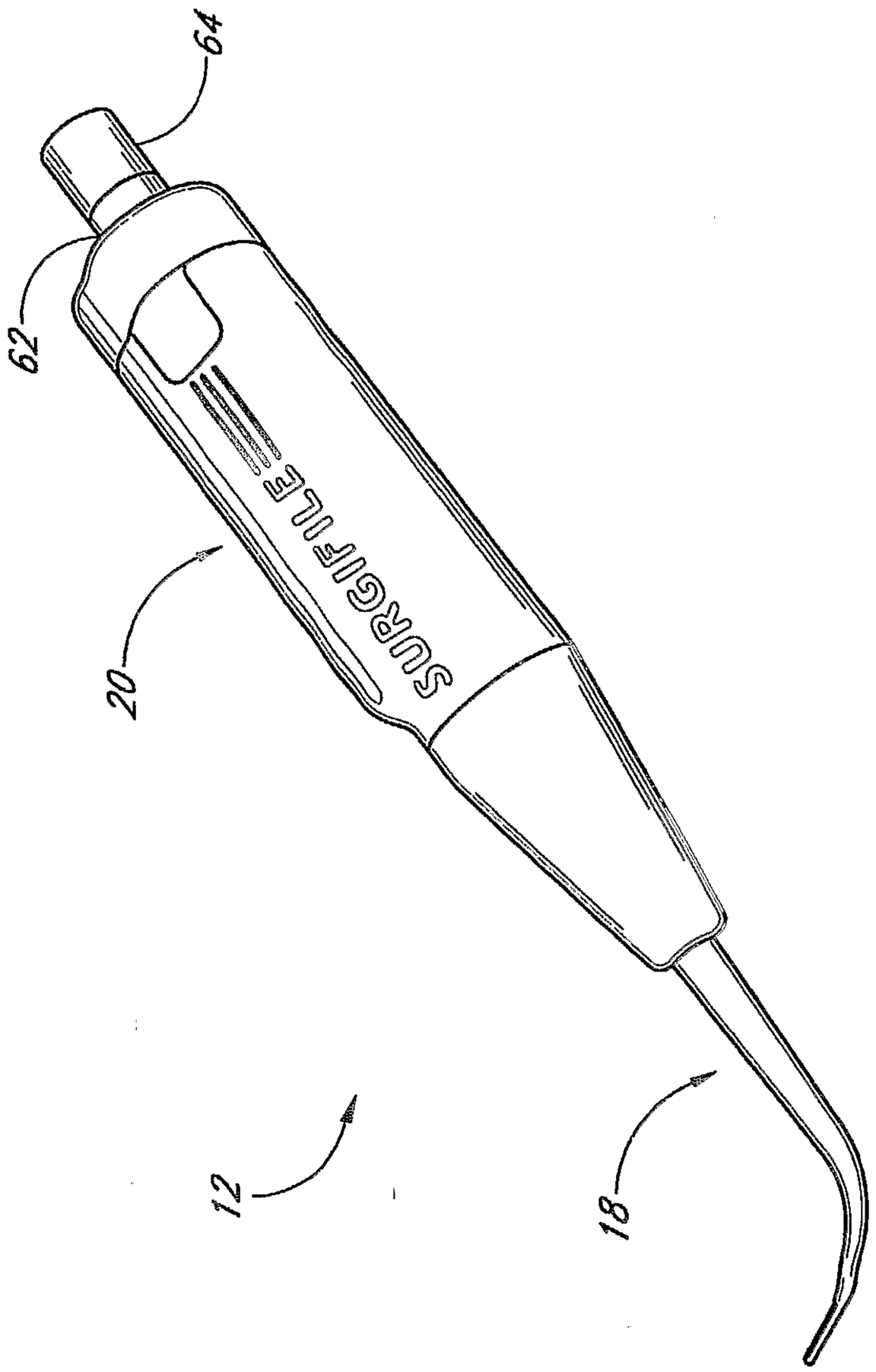

FIG. 3

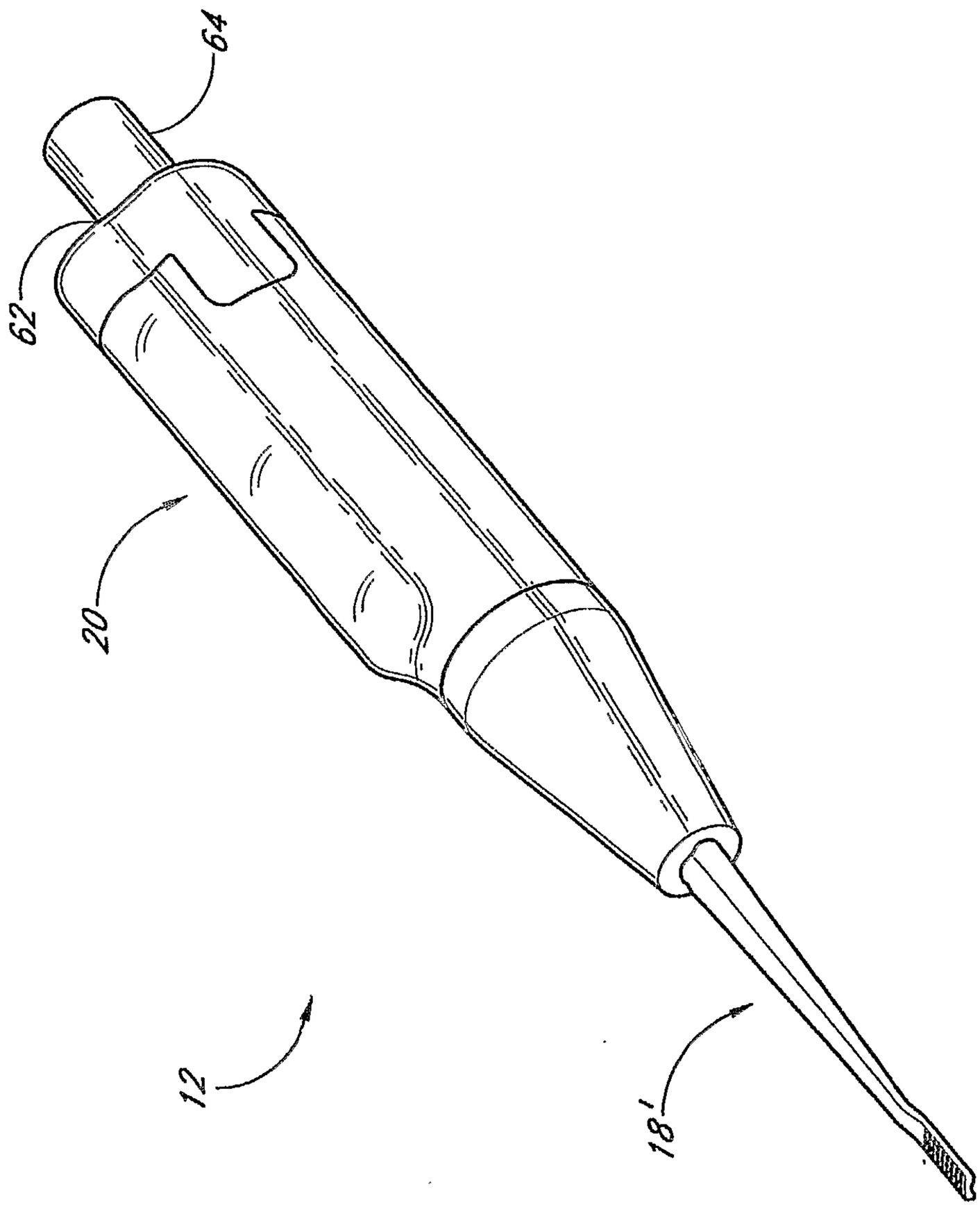

FIG. 4

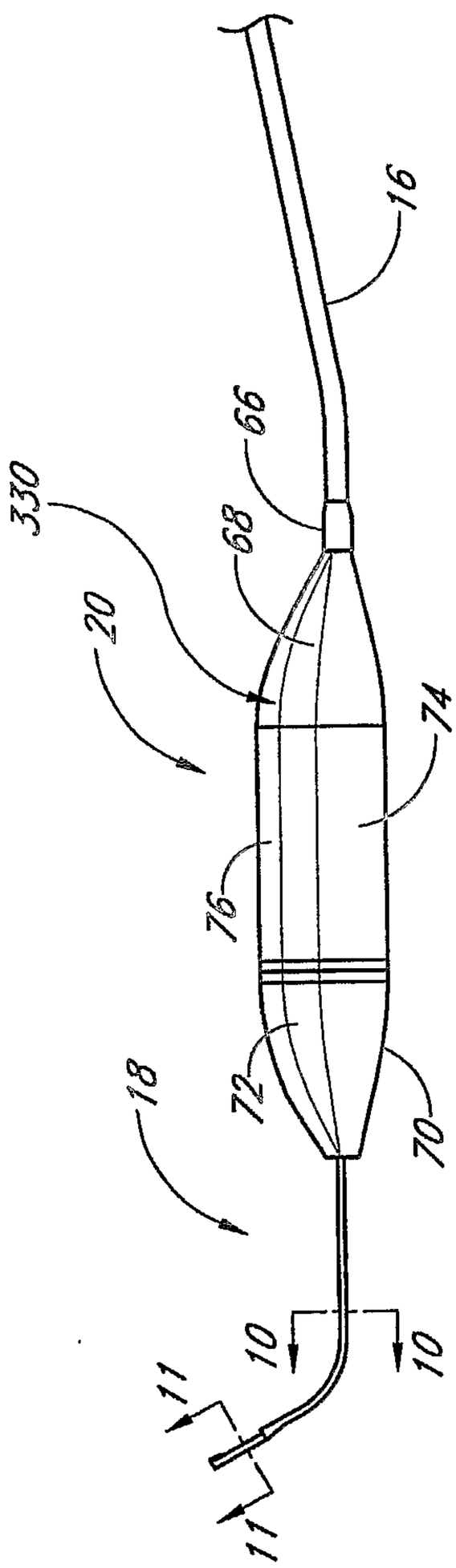

FIG. 5

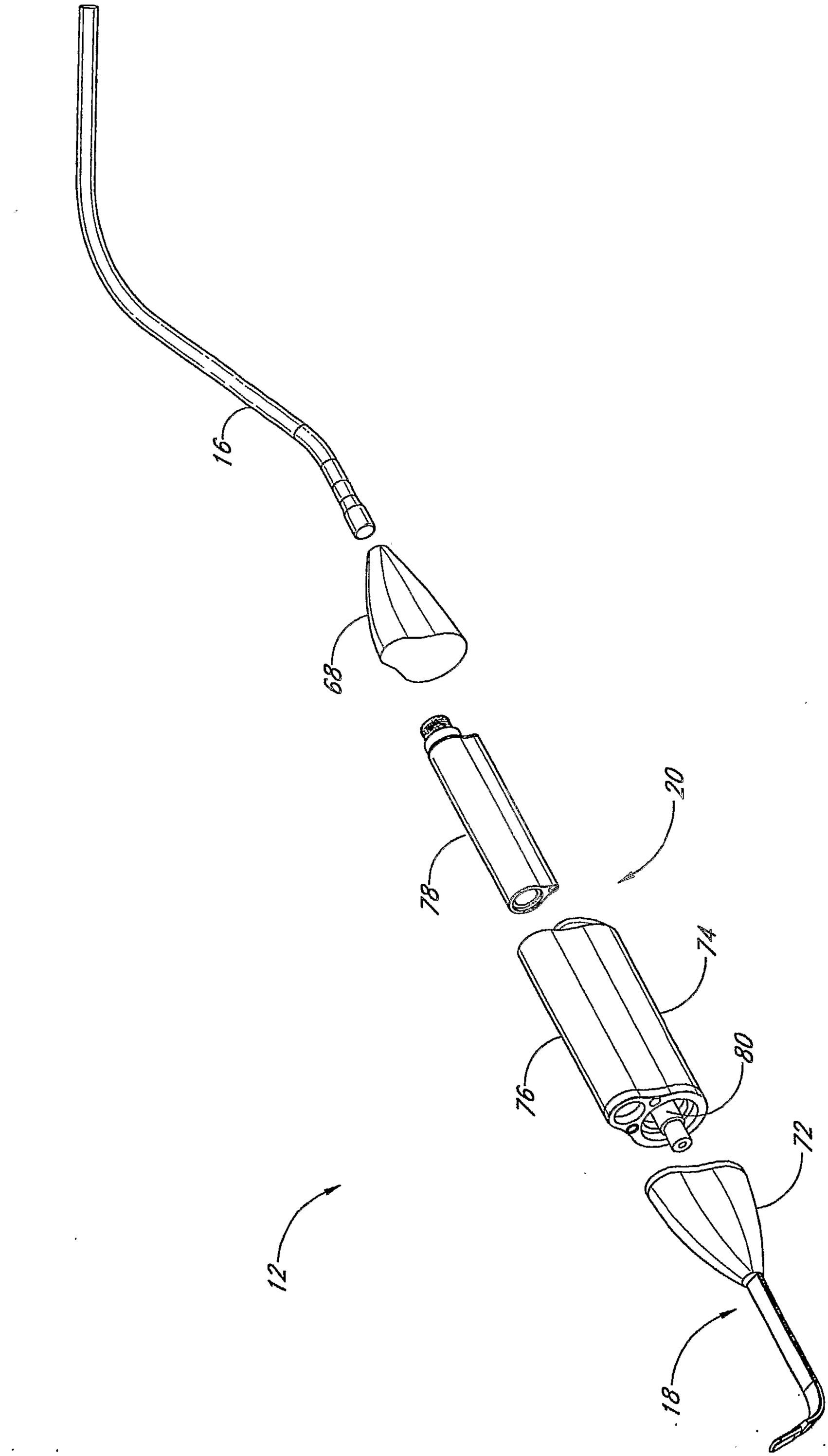

FIG. 6

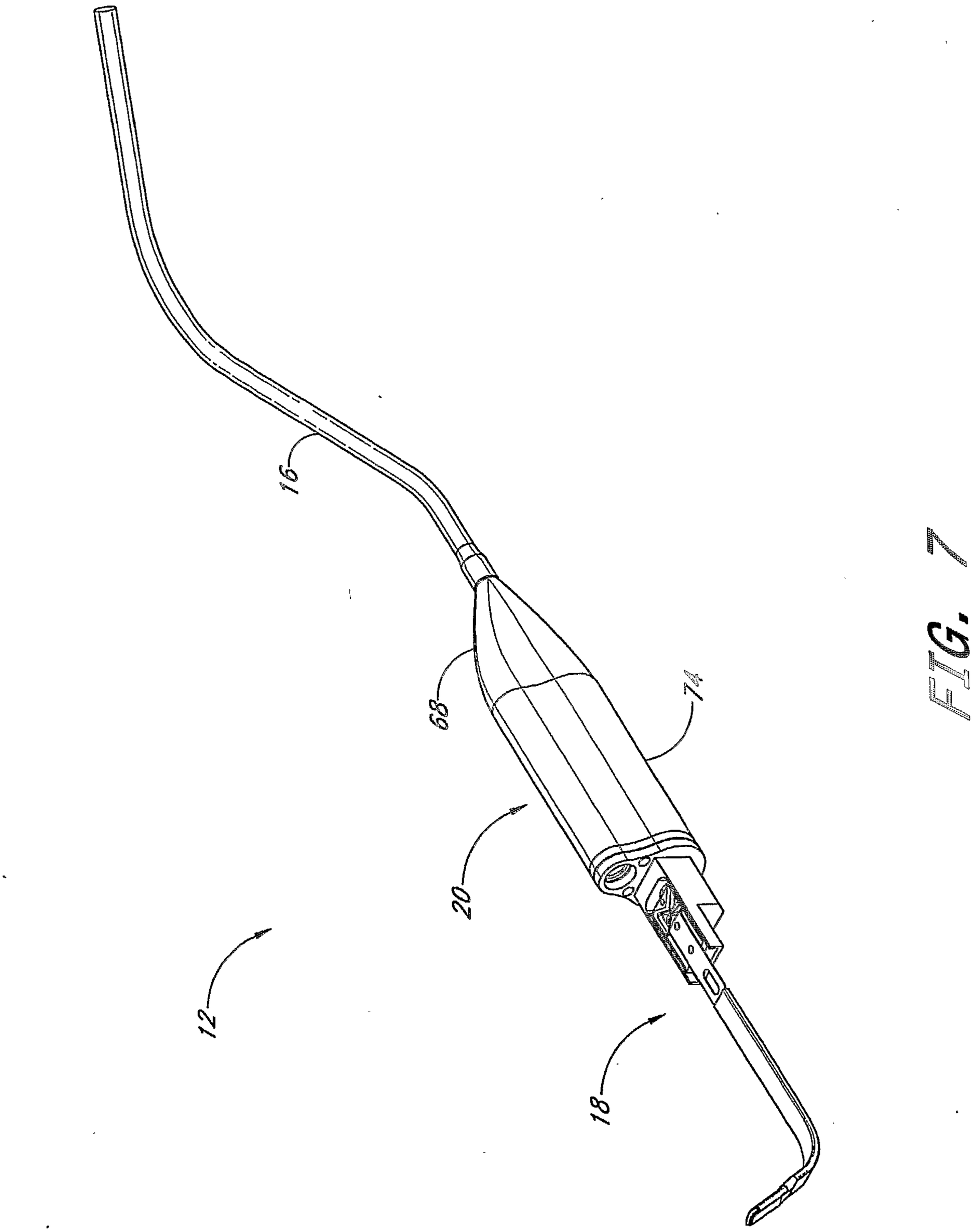

FIG. 7

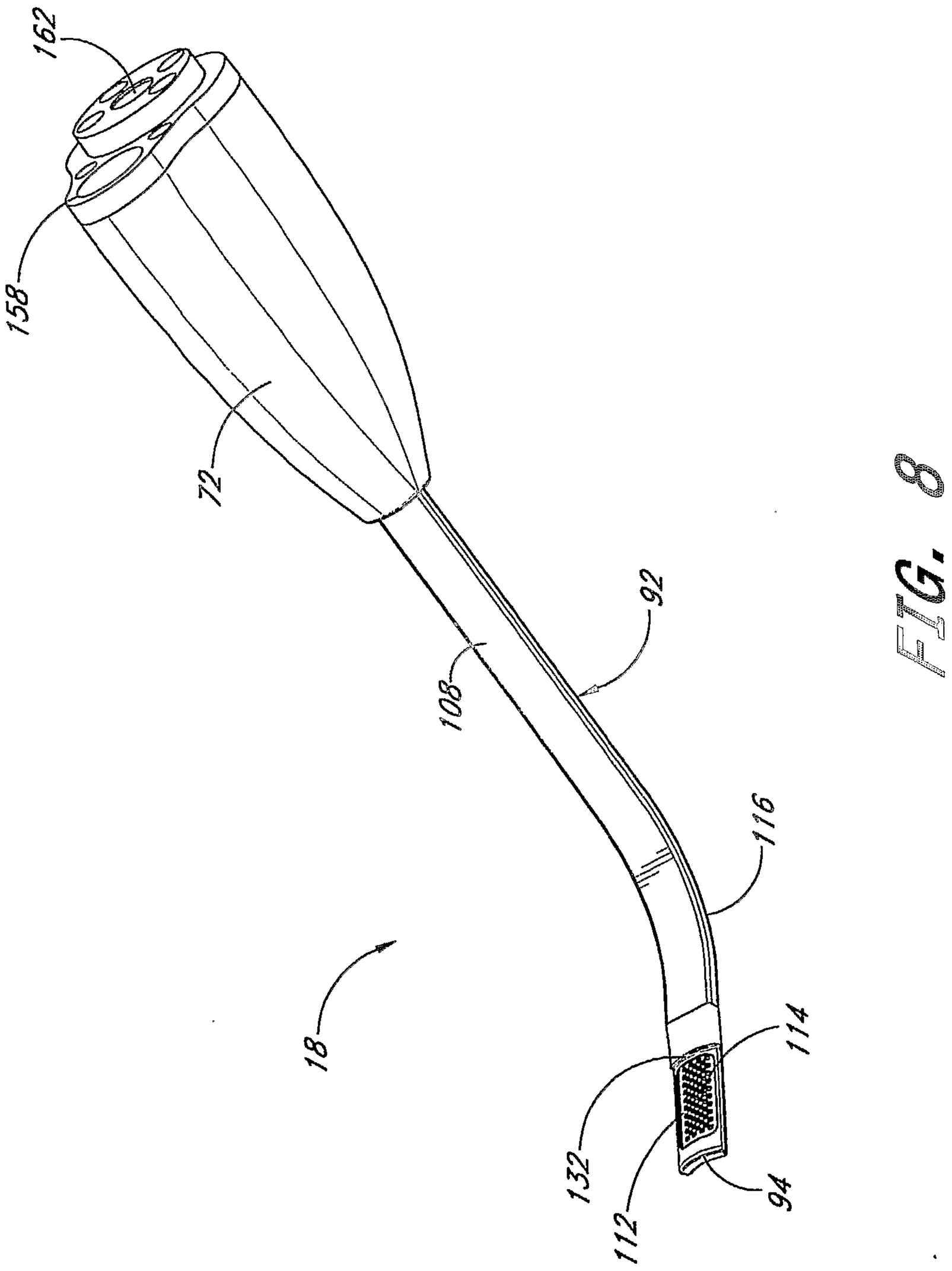

FIG. 8

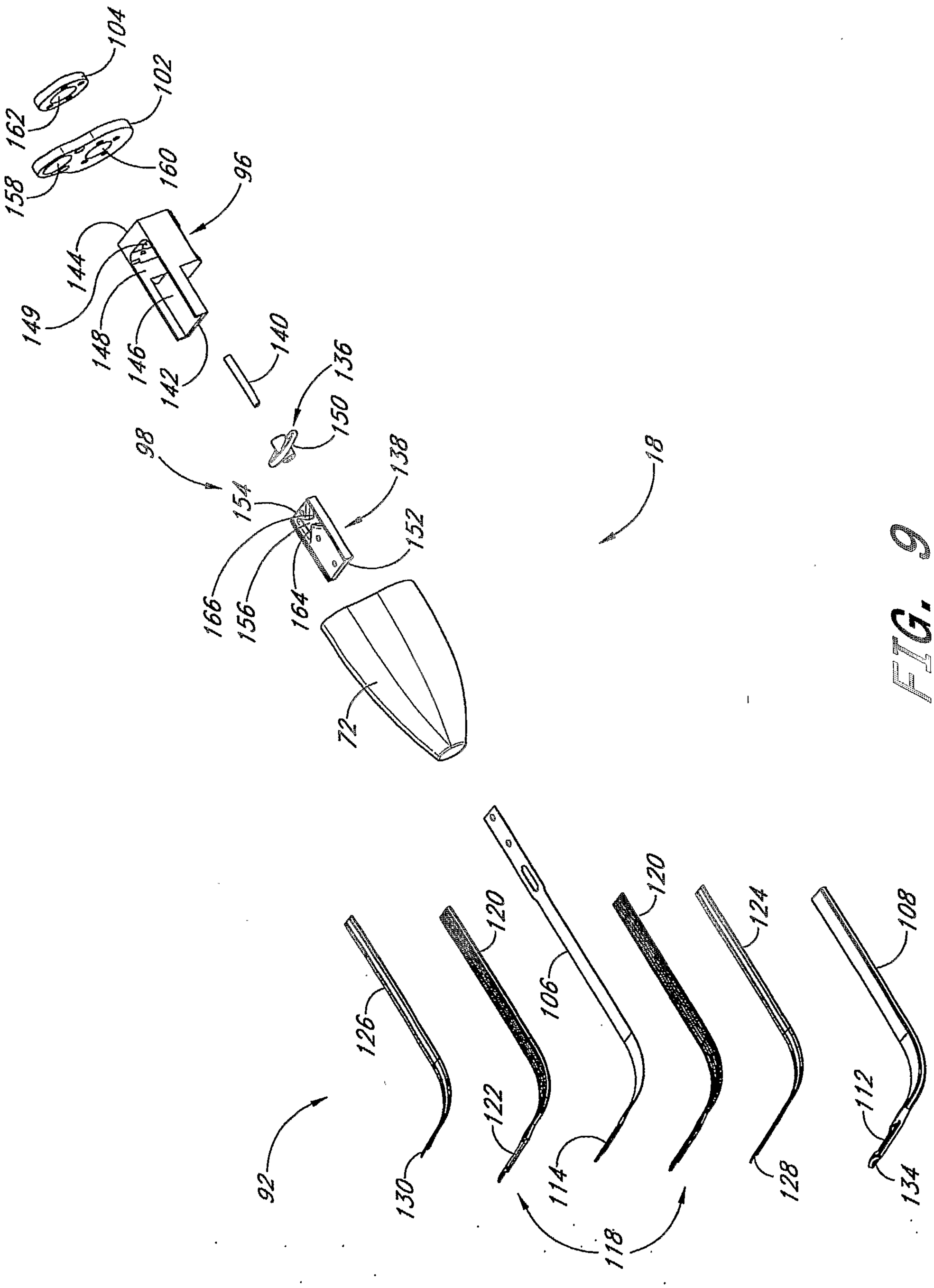
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FIG. 9

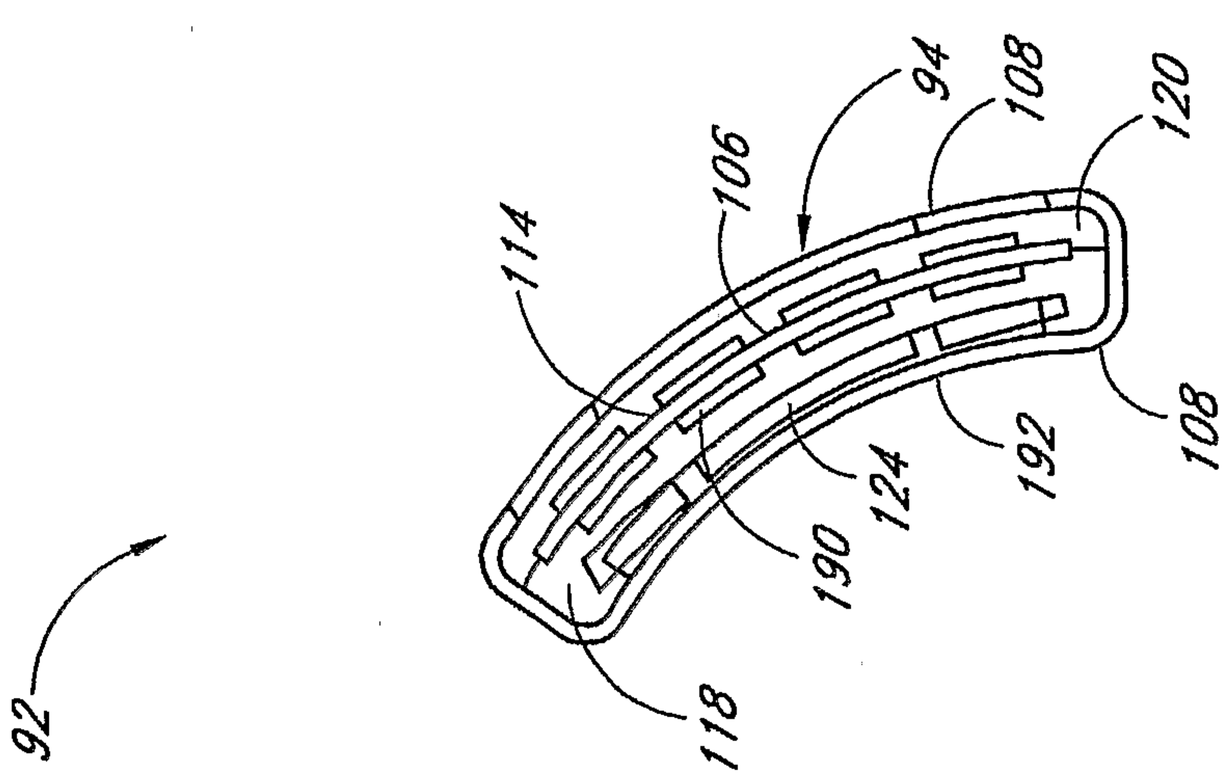
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FIG. 11

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FIG. 10

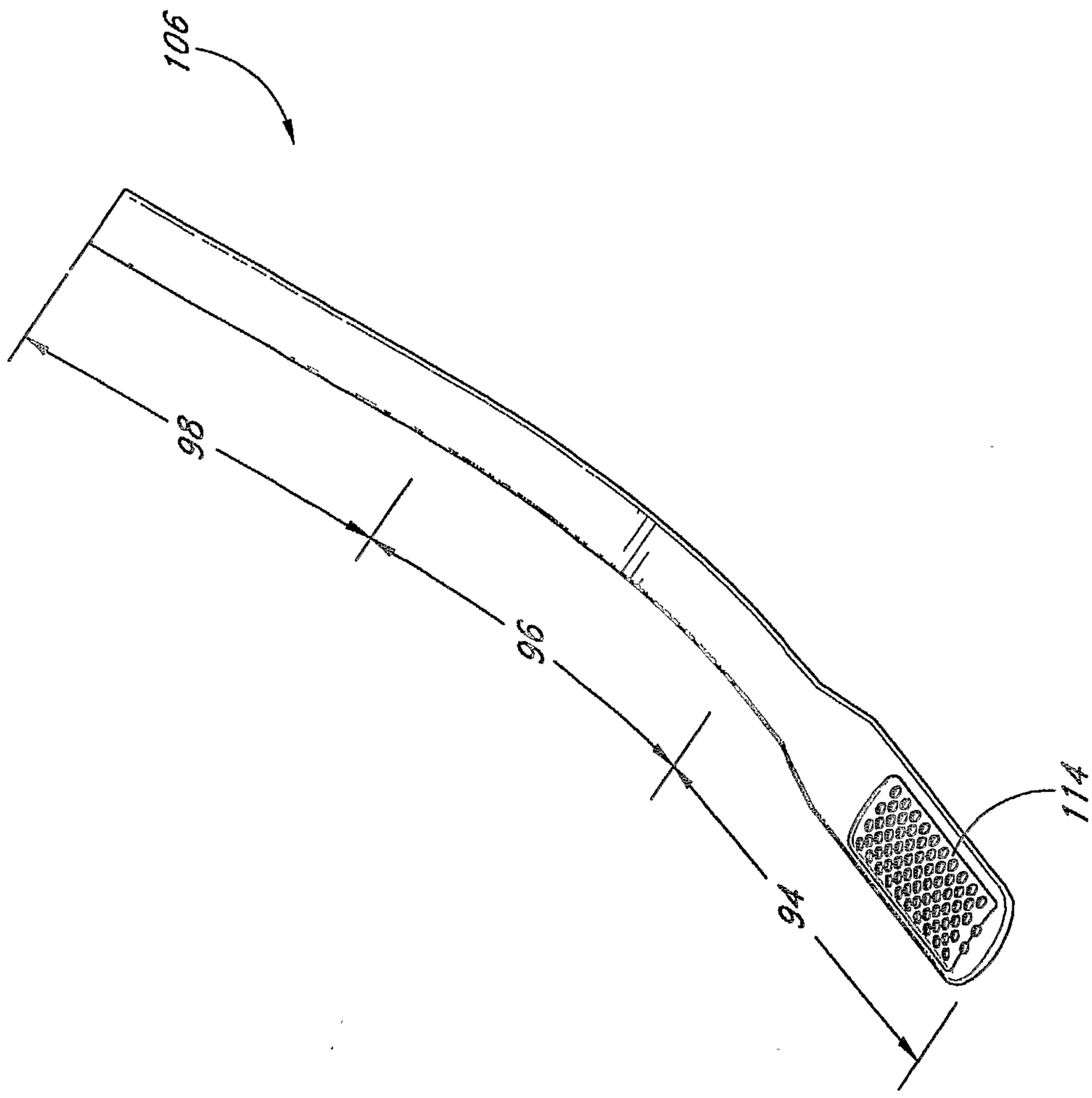

FIG. 12

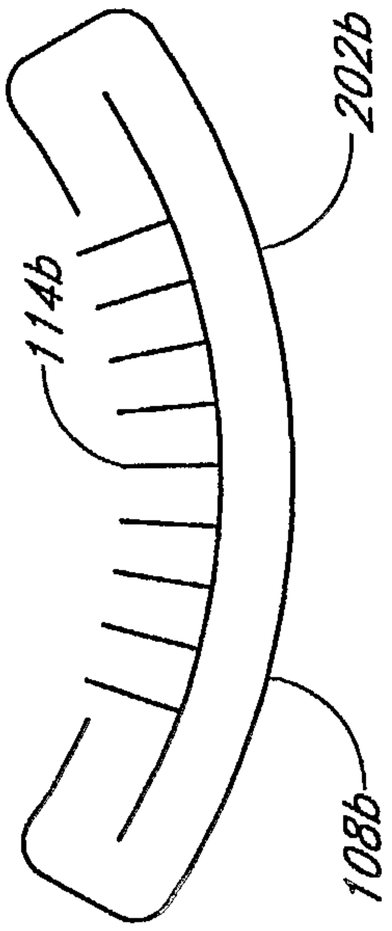

FIG. 14

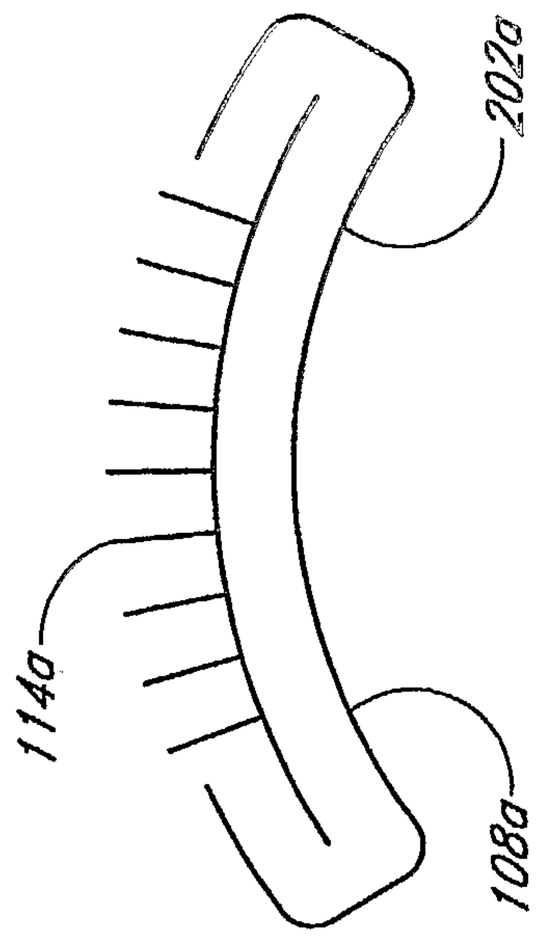

FIG. 13

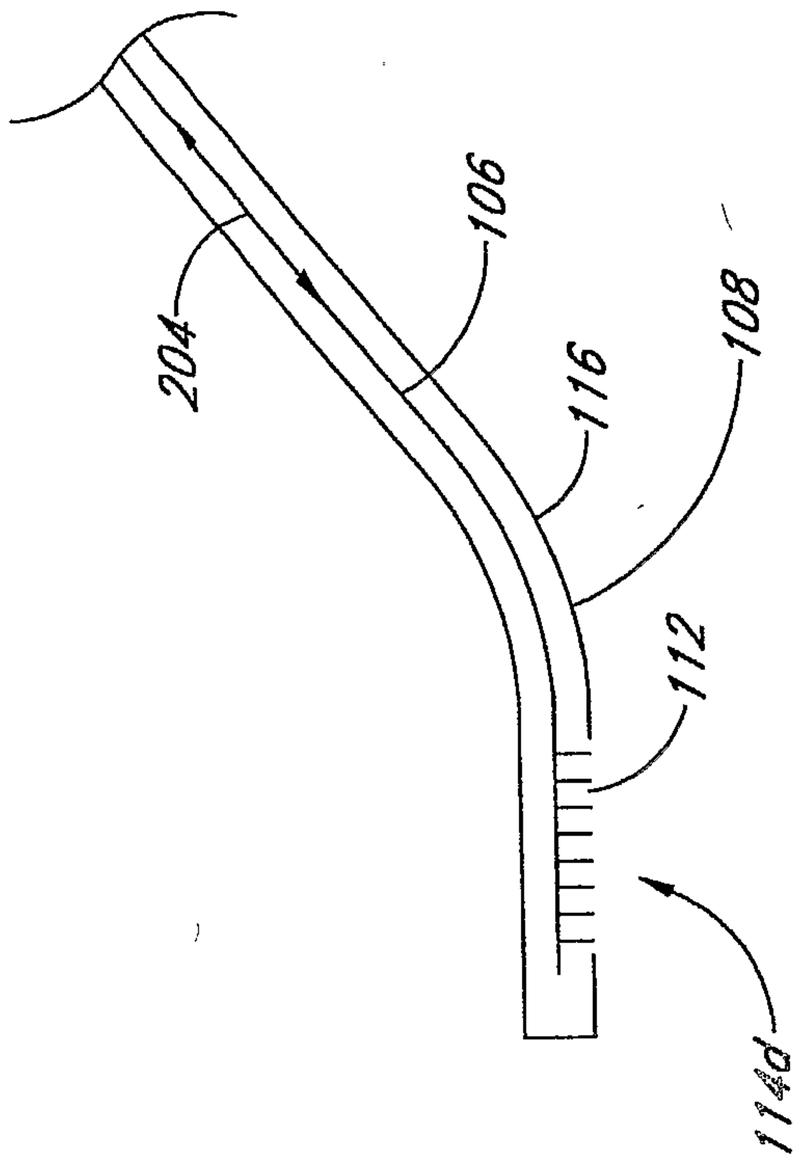

FIG. 16

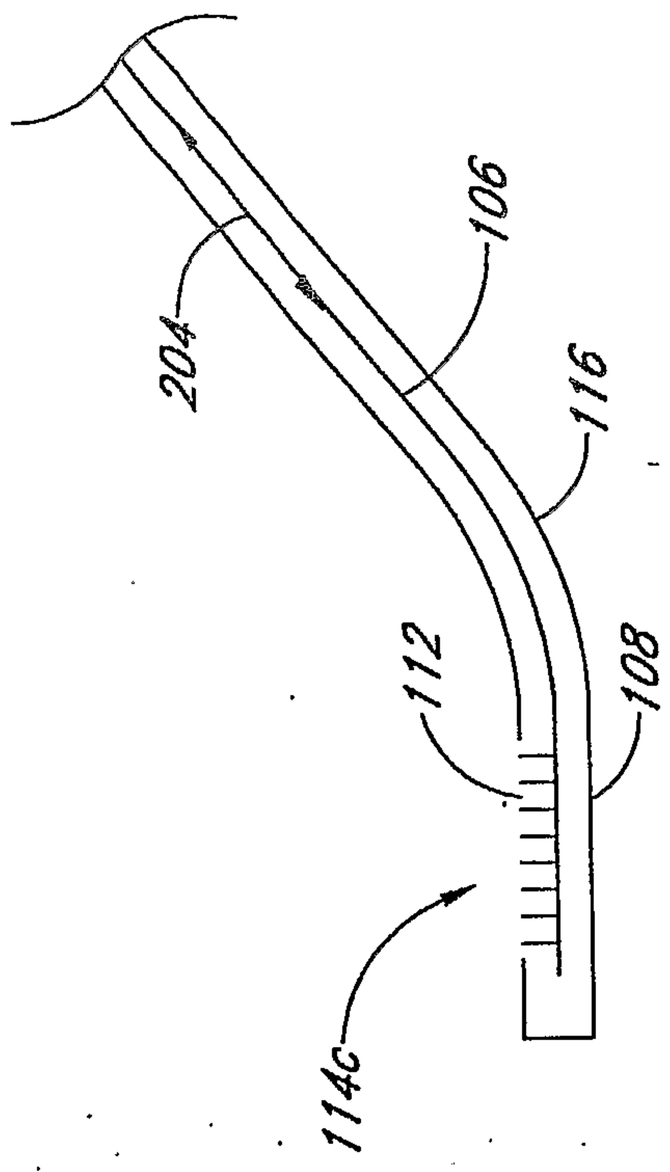

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FIG.

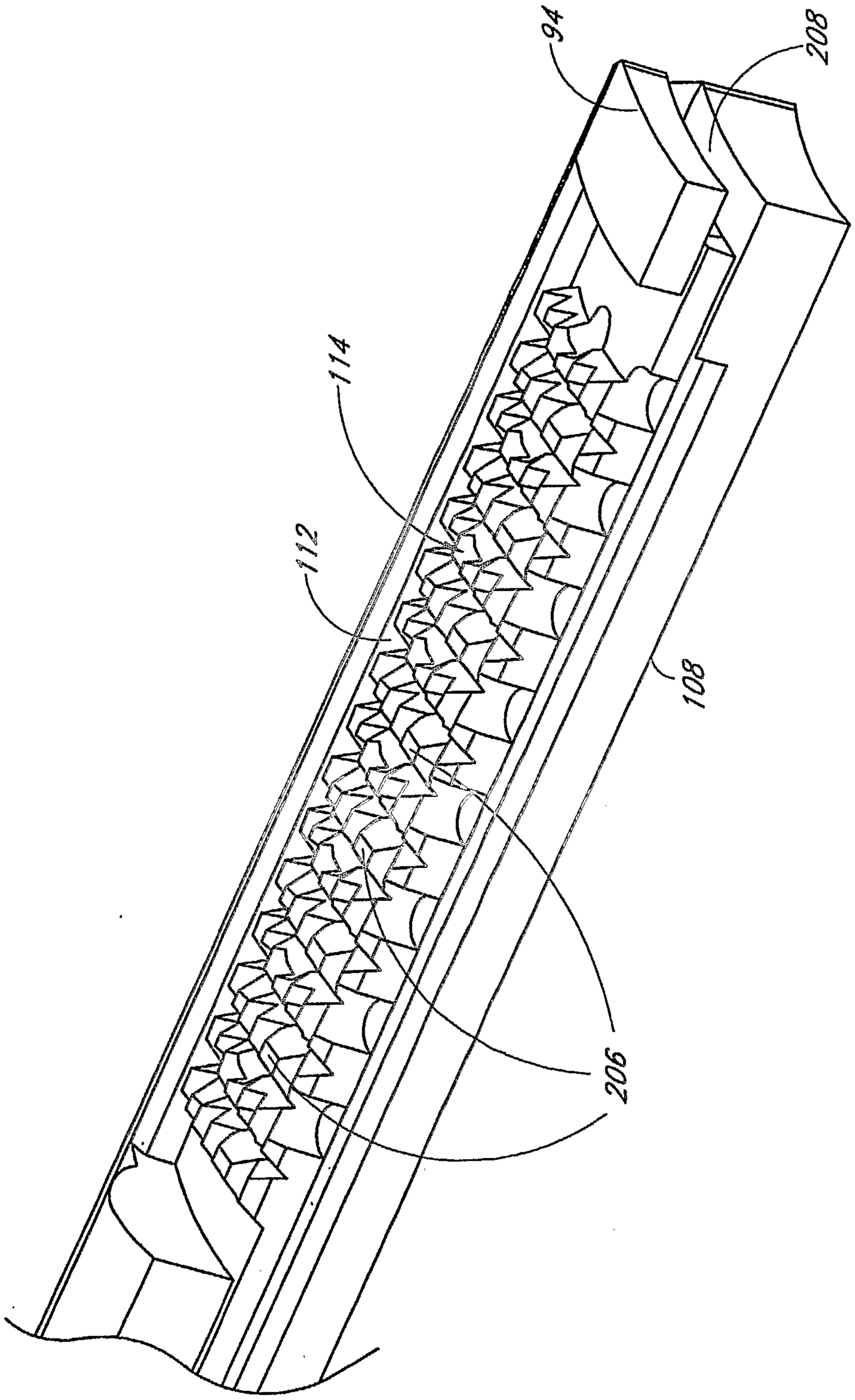


FIG. 17

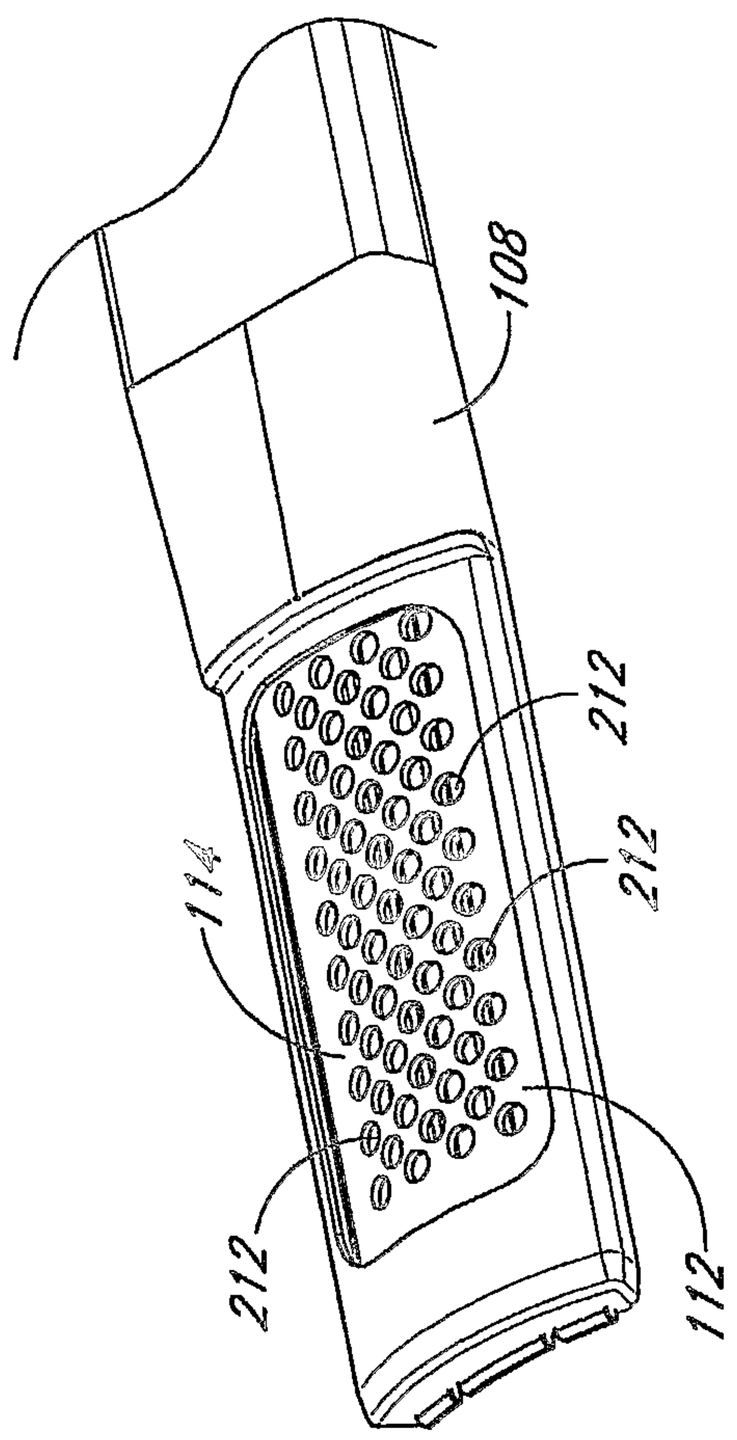


FIG. 18

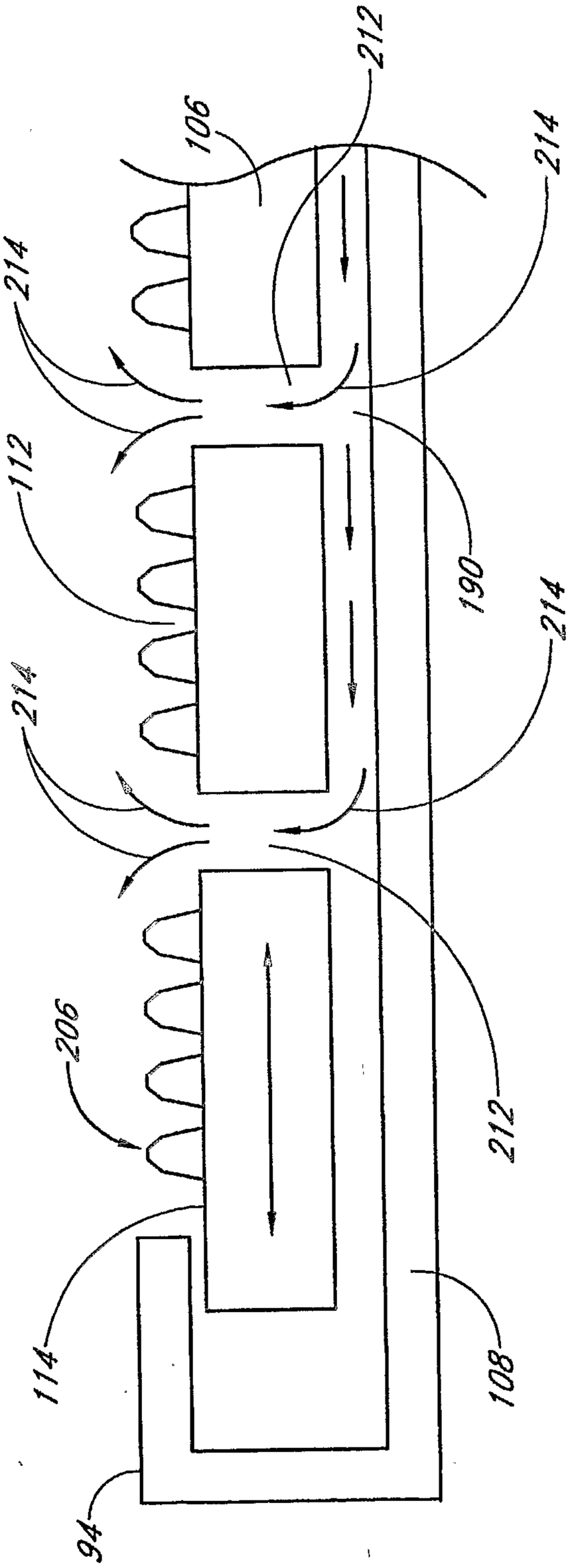


FIG. 19

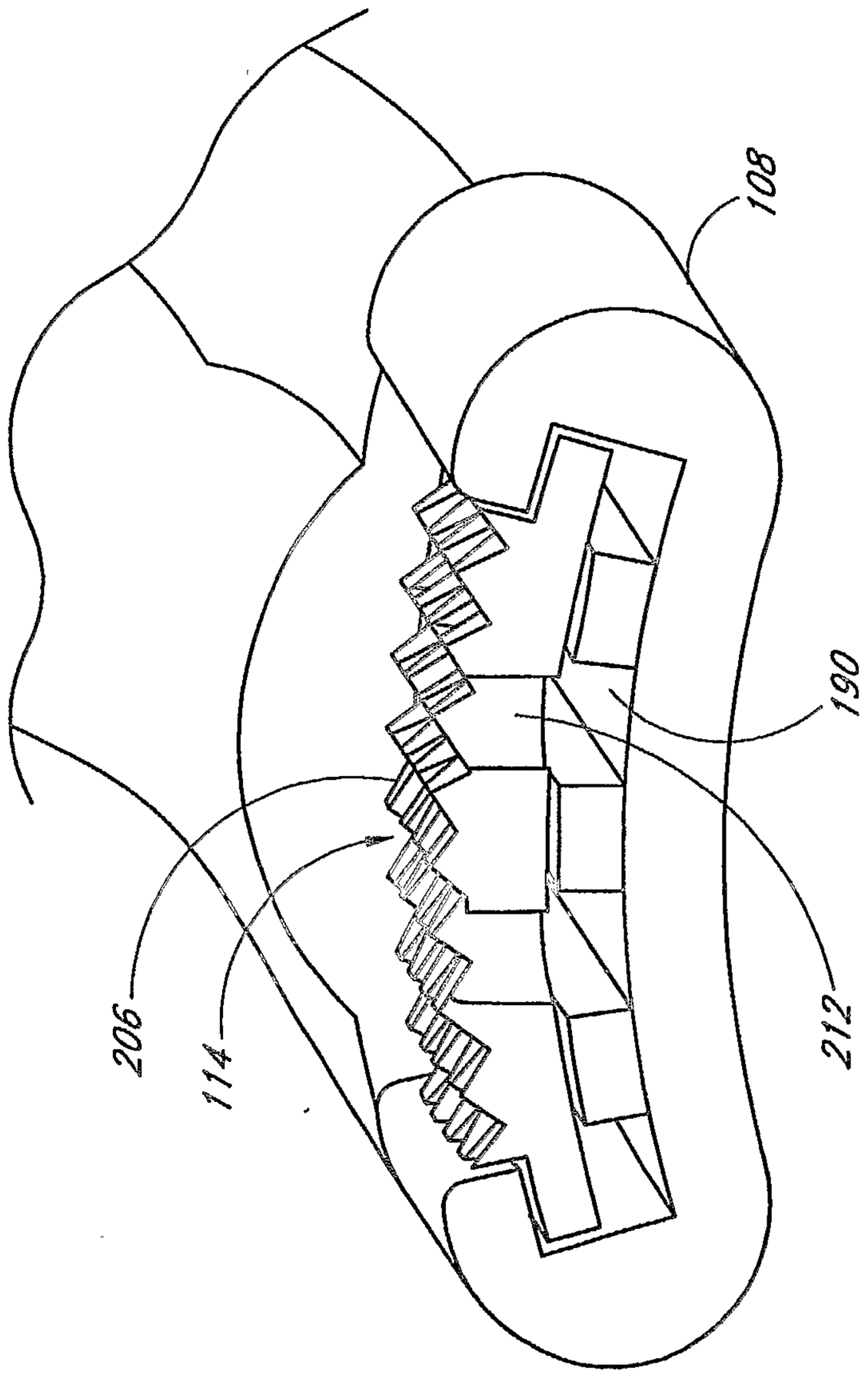


FIG. 20

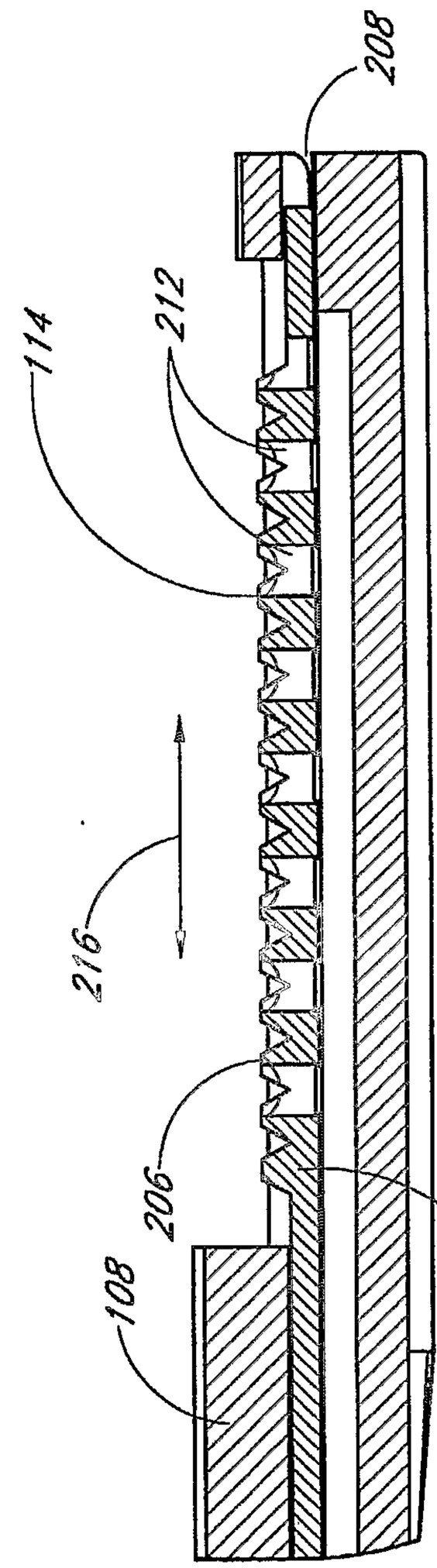


FIG. 21

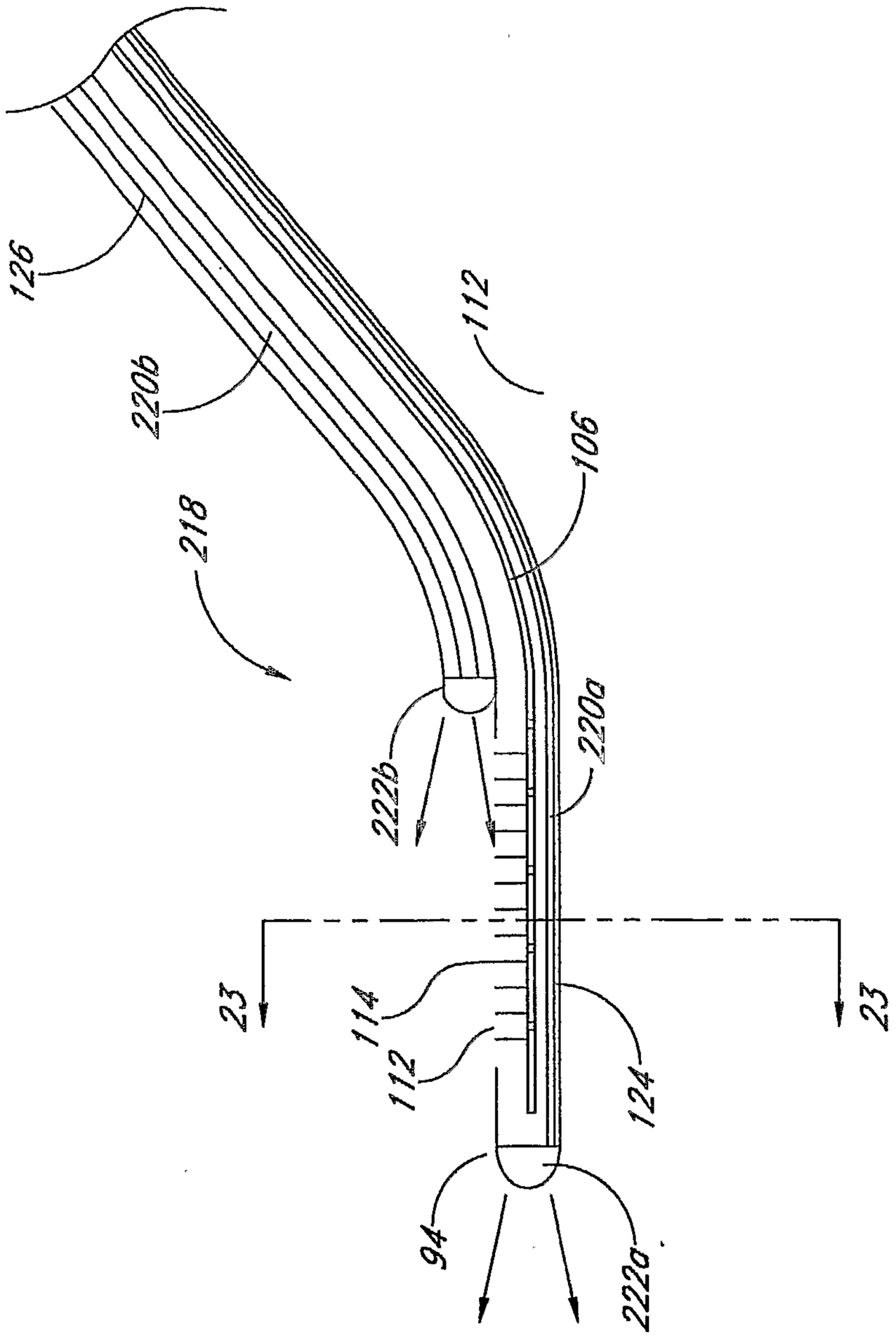


FIG. 22

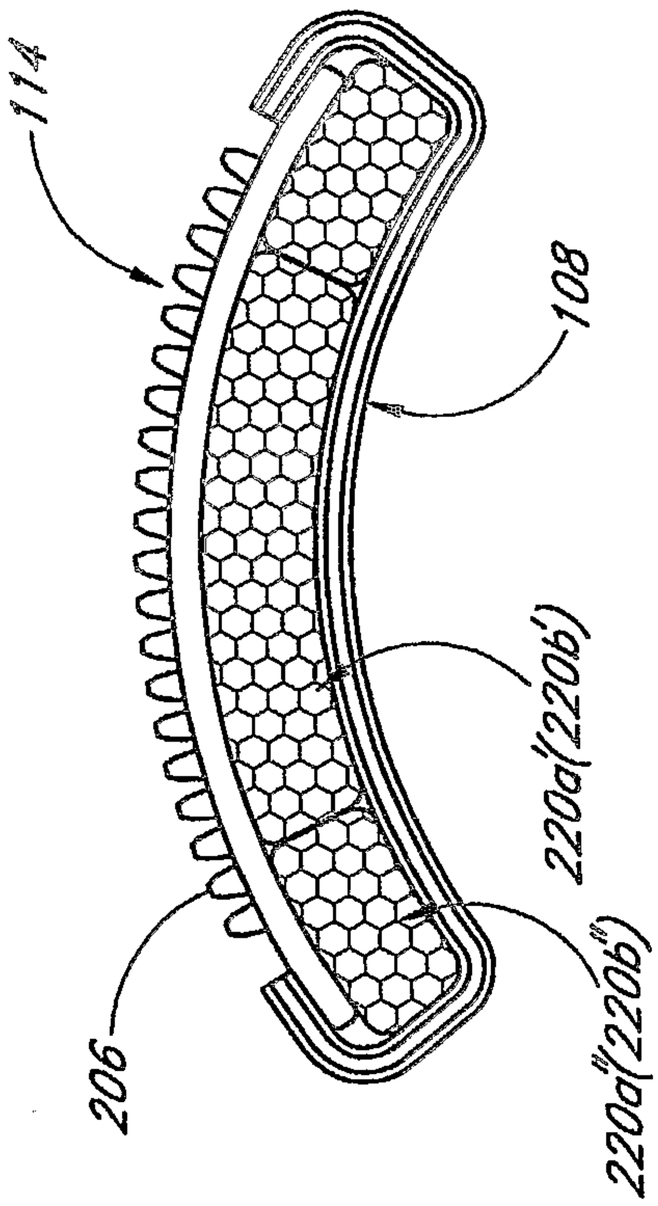


FIG. 23

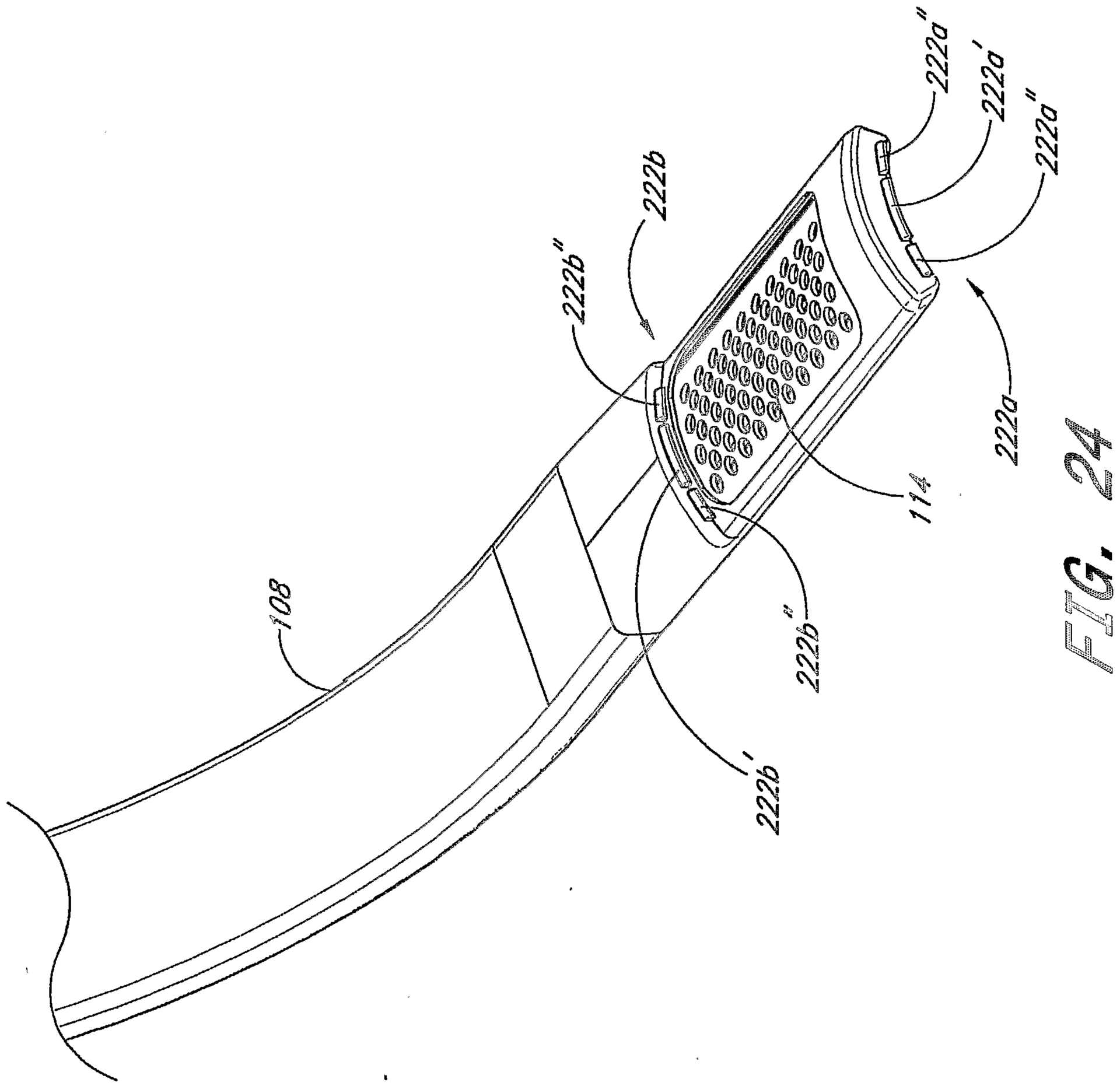
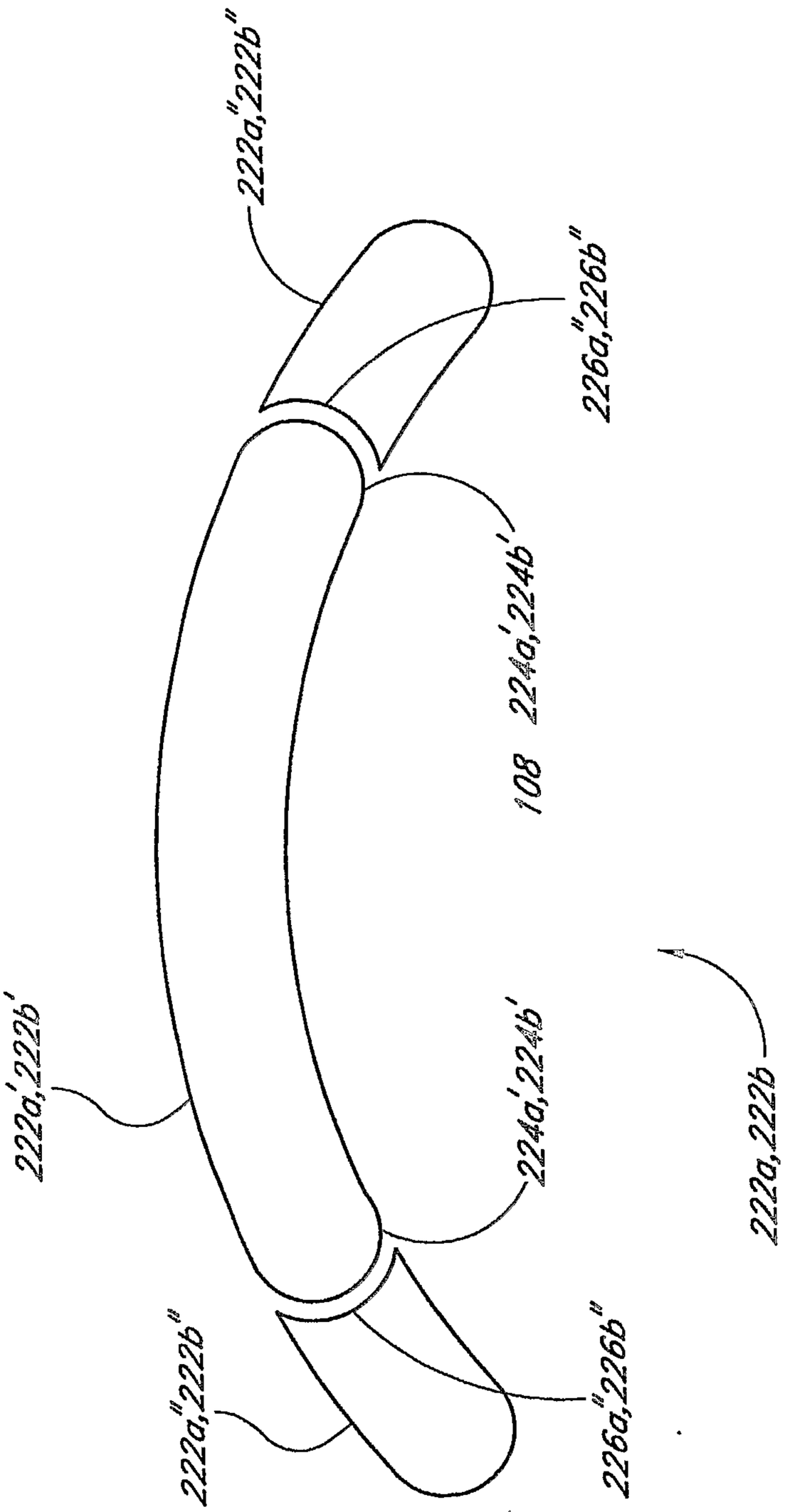


FIG. 24


222a,"222b"
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222a,"222b"
226a,"226b"
222a,222b

FIG. 25

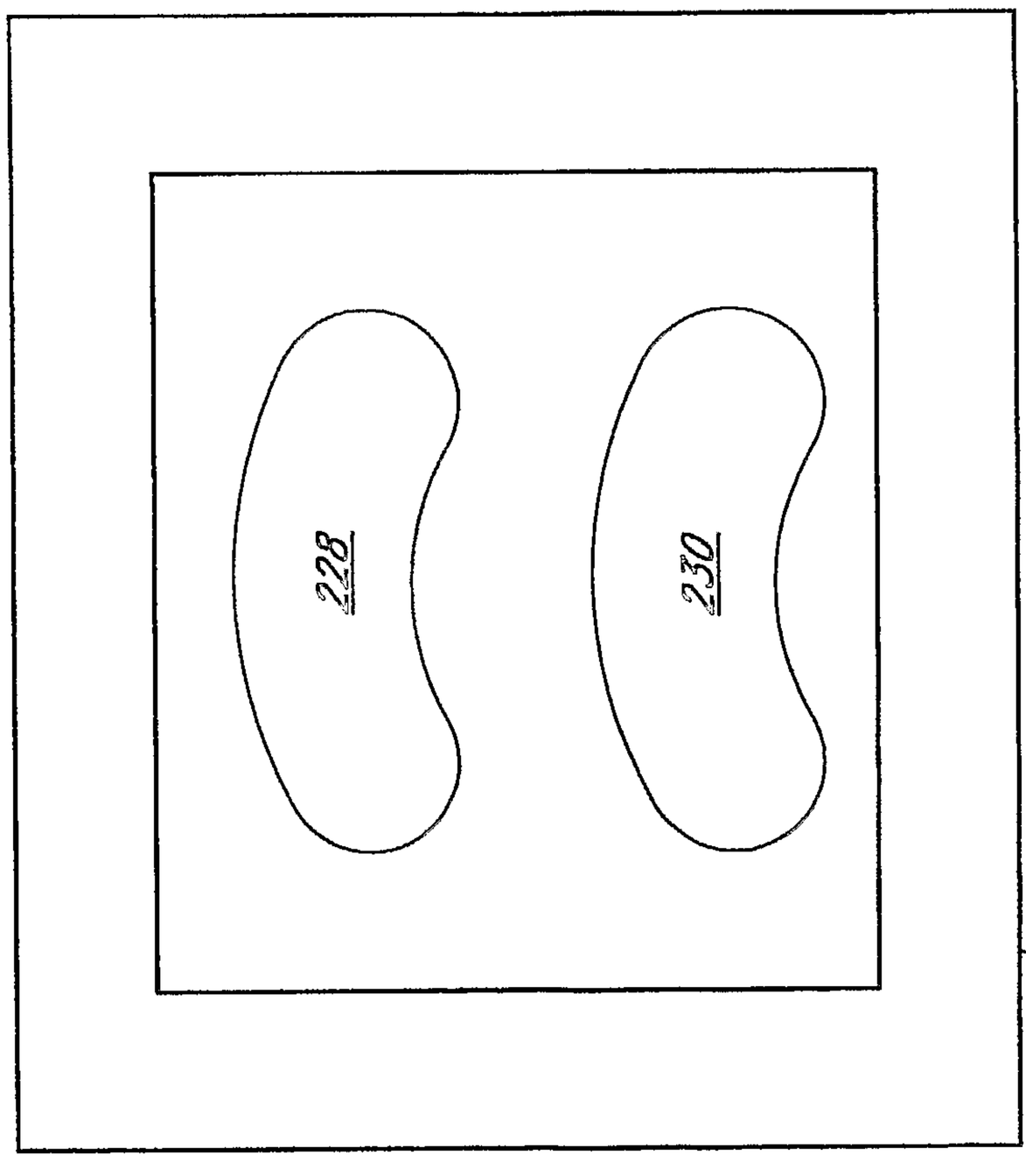


FIG. 26

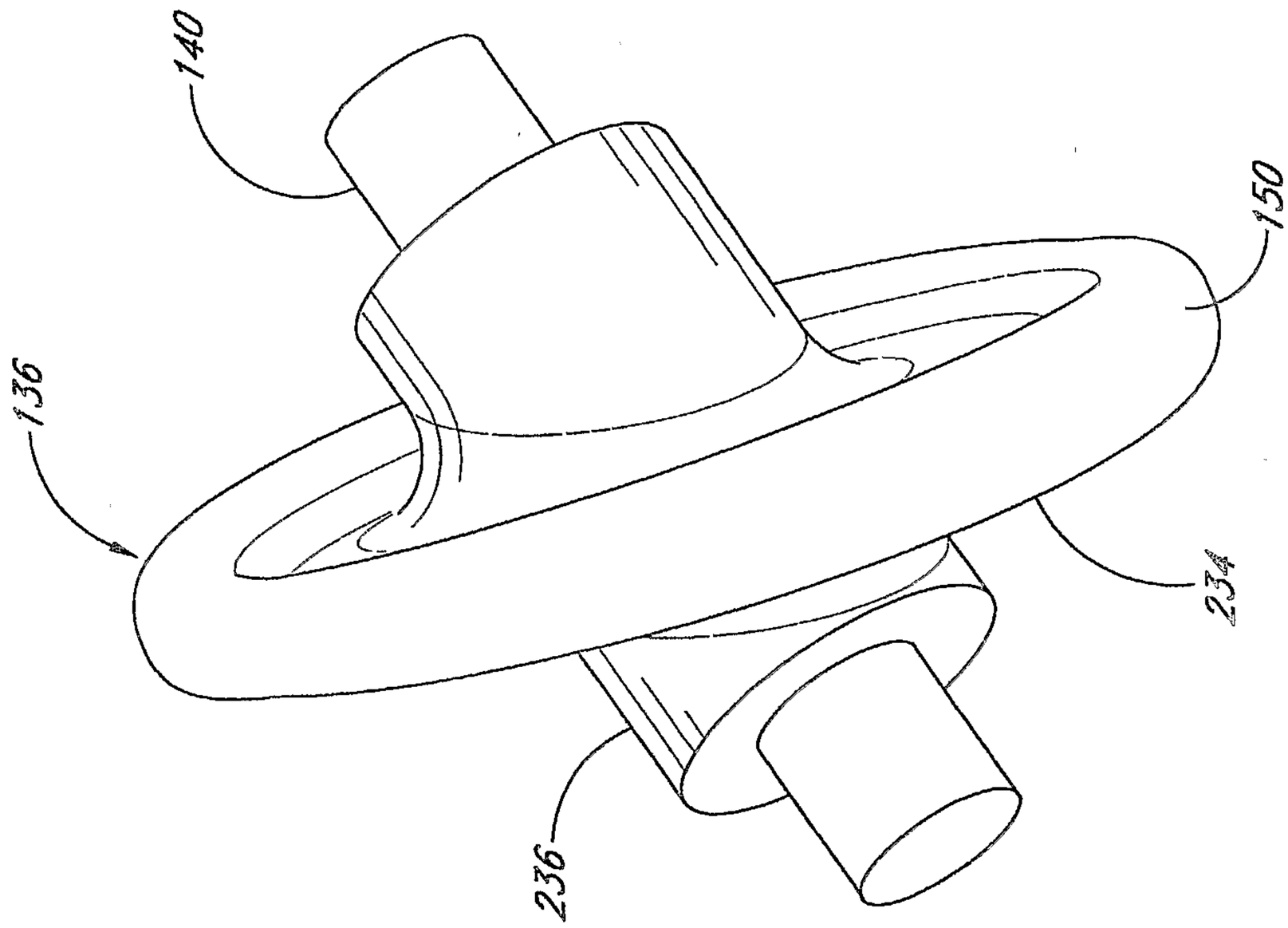


FIG. 27

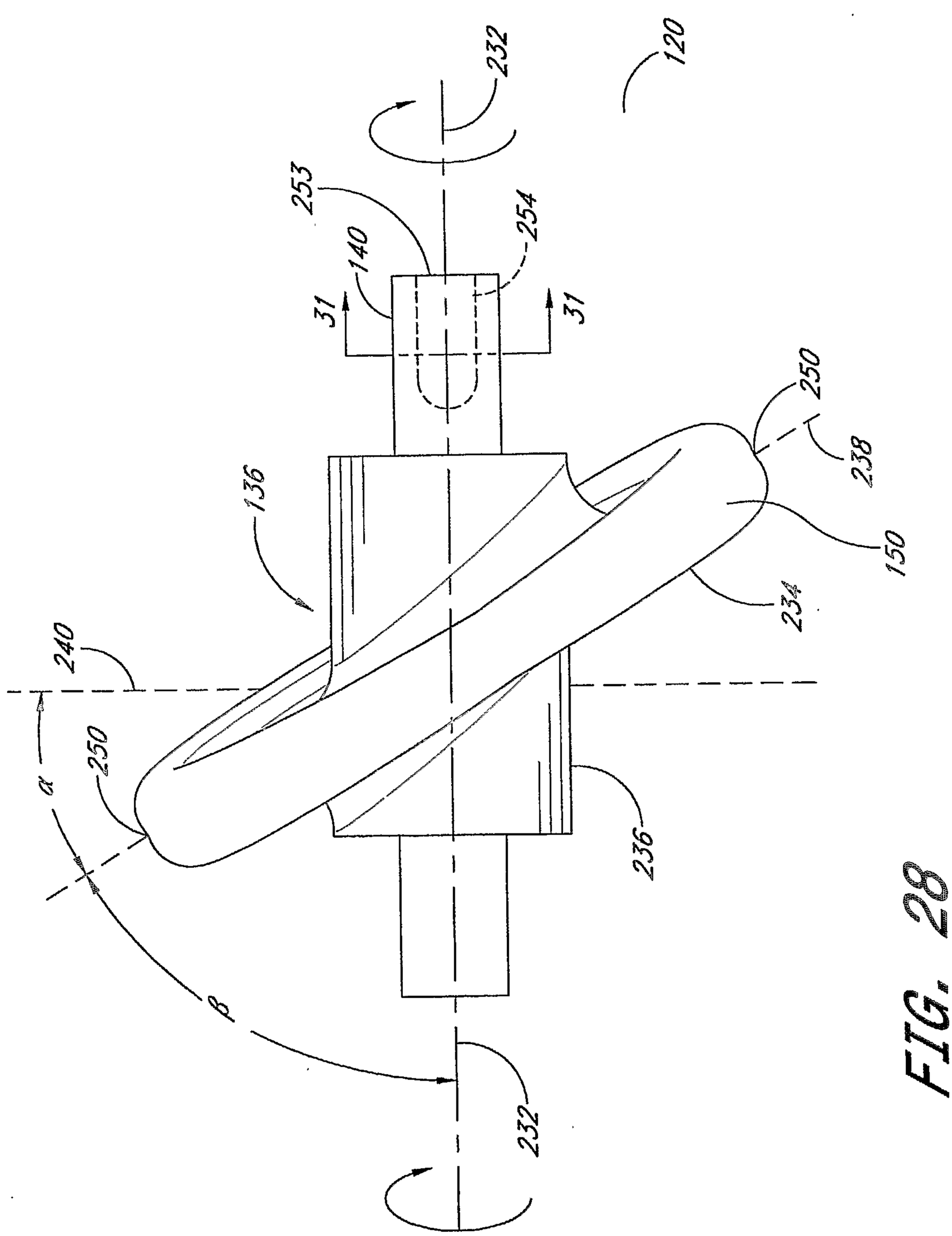


FIG. 28

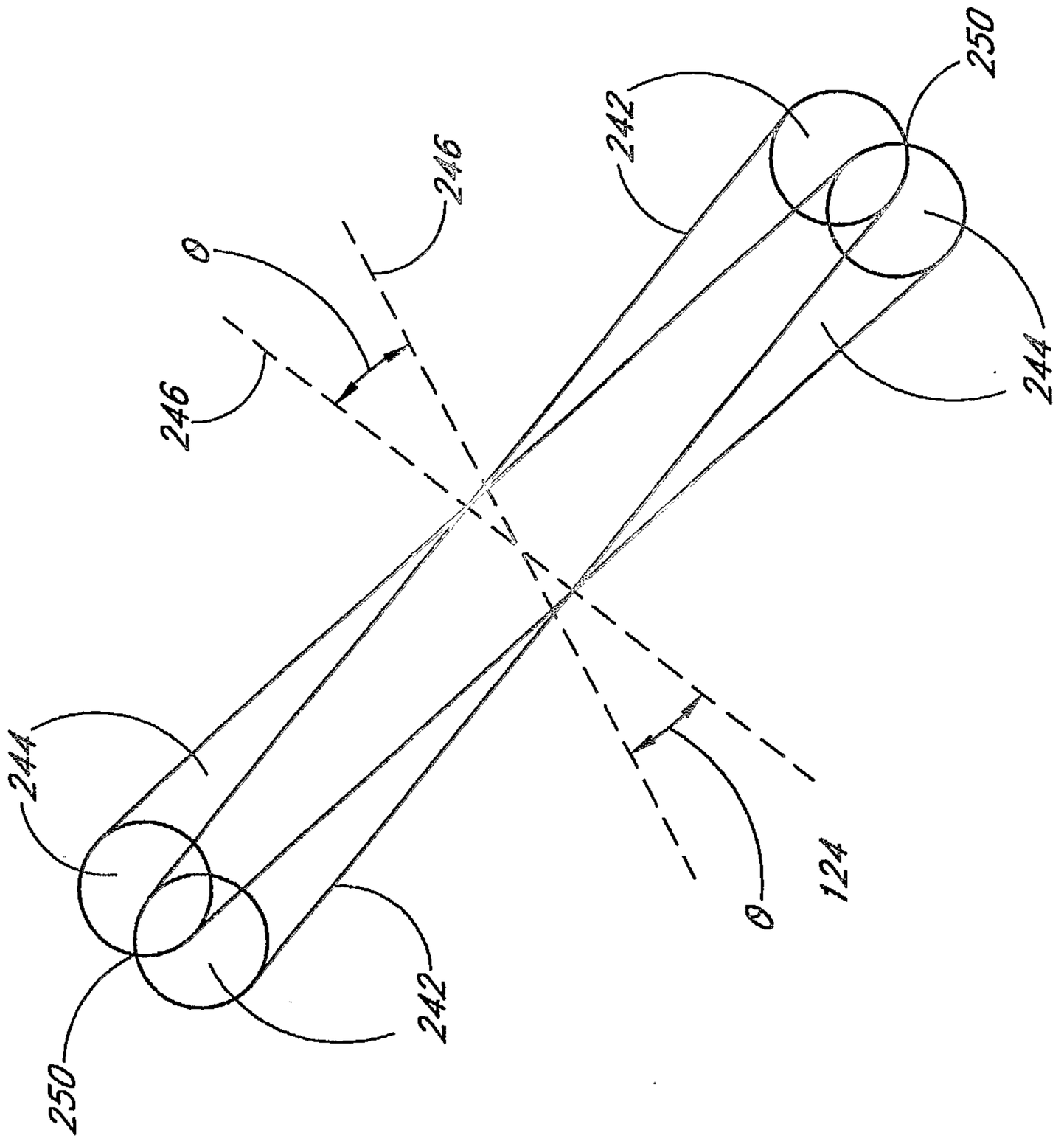
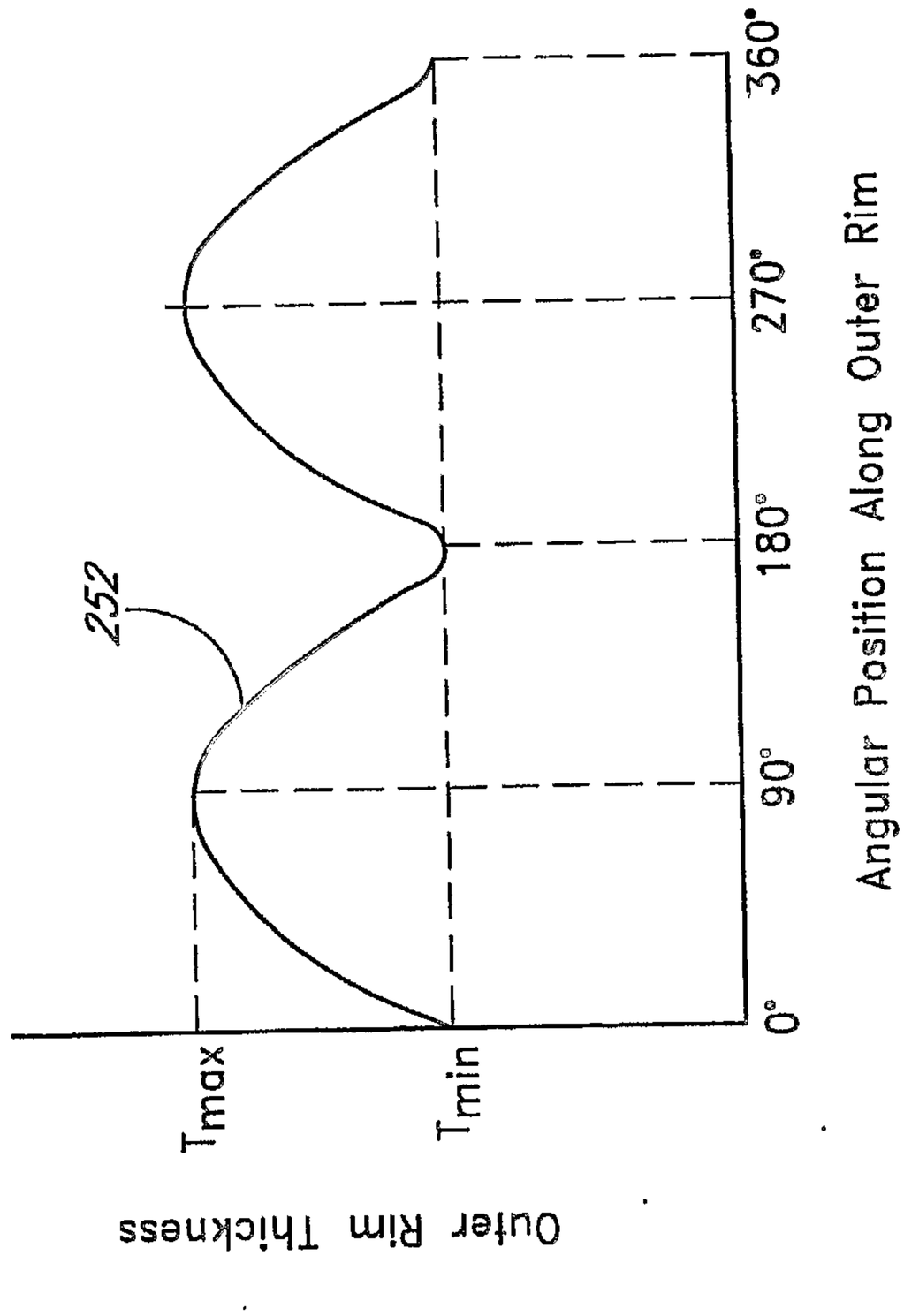


FIG. 29


Outer Rim Thickness
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Angular Position Along Outer Rim

FIG. 30

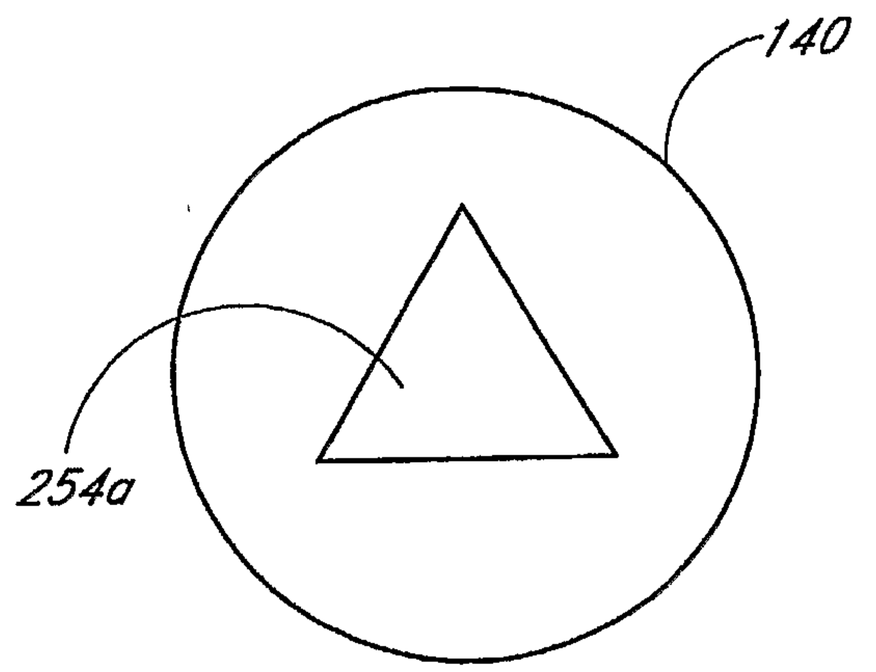

FIG. 31A

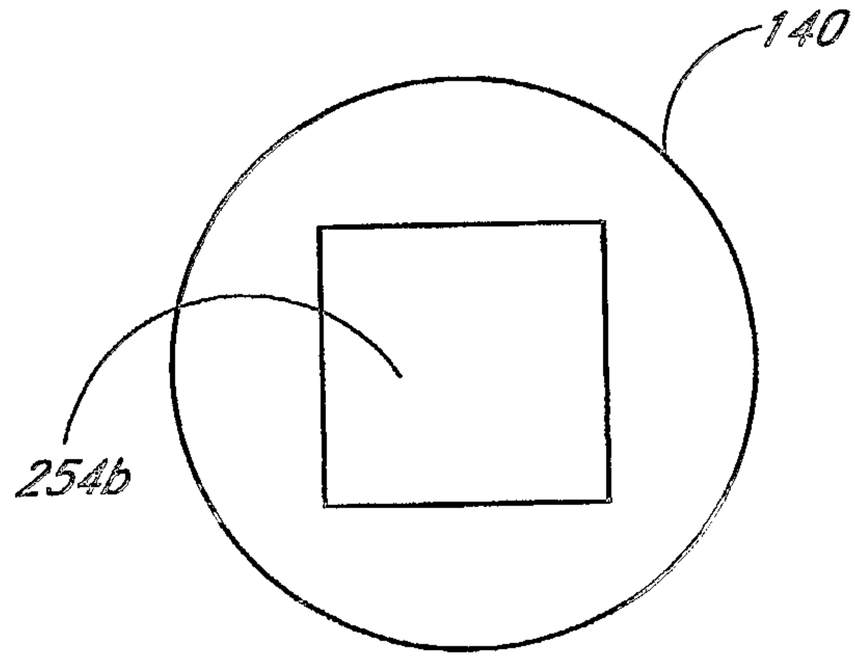

FIG. 31B

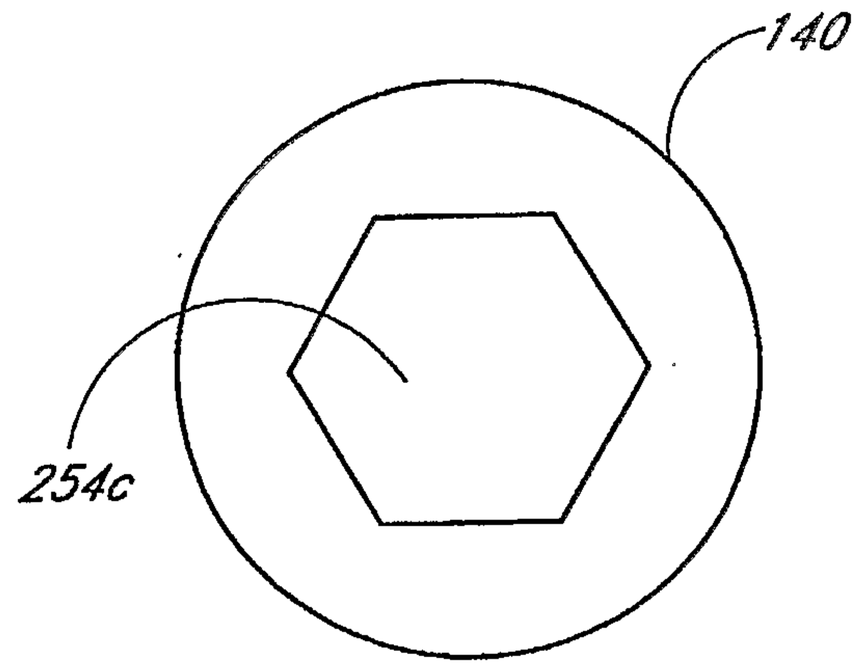

FIG. 31C

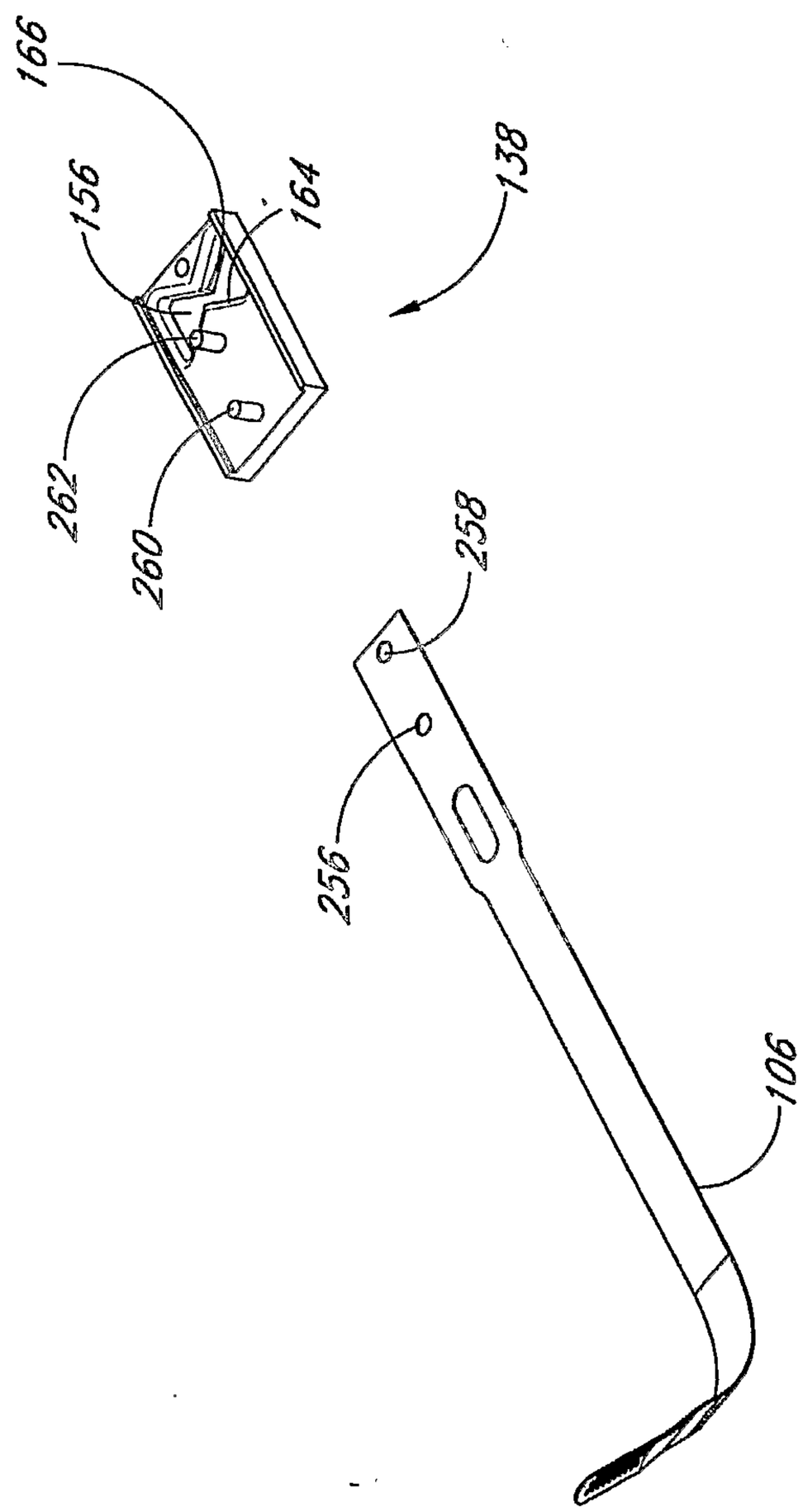

FIG. 32

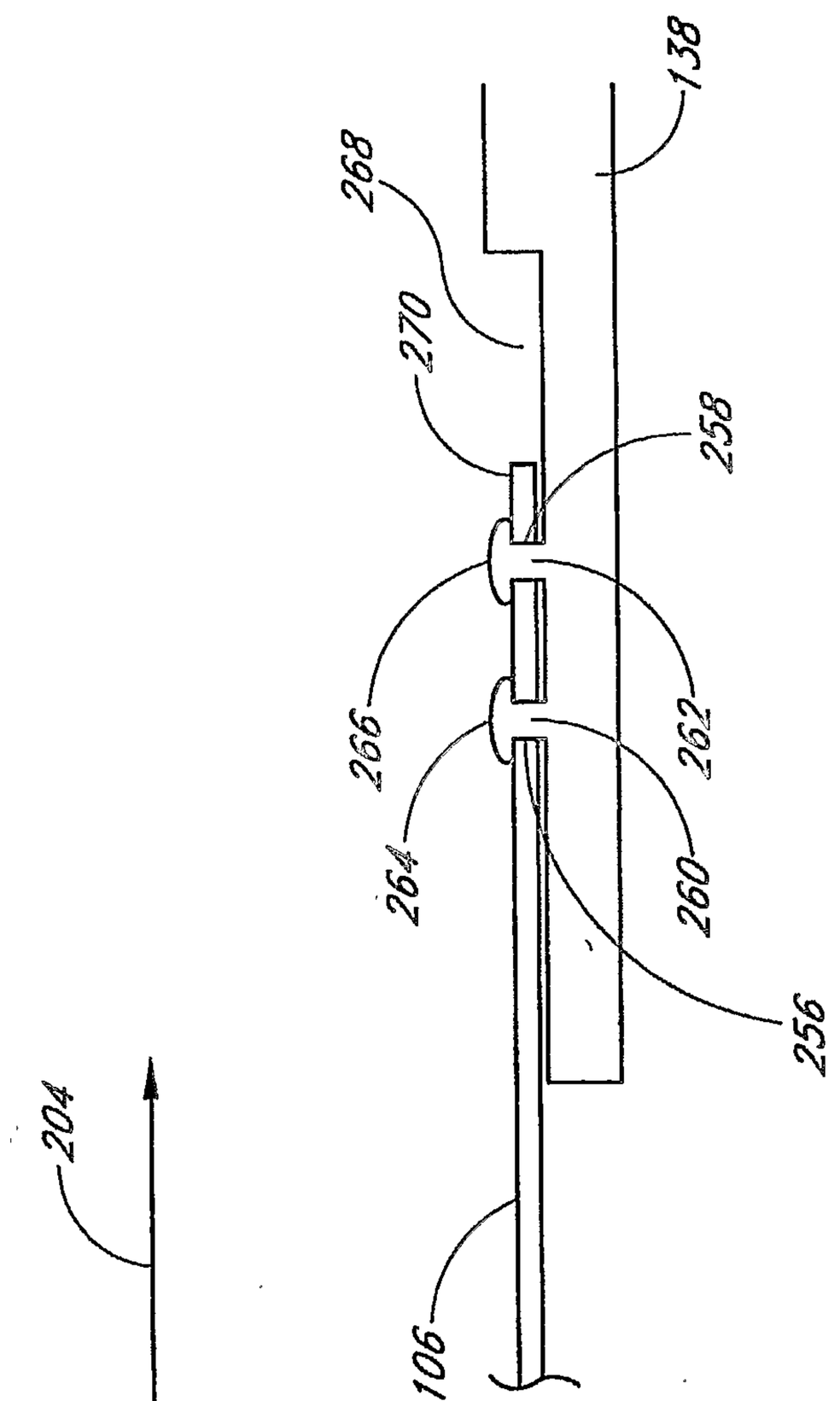

FIG. 33

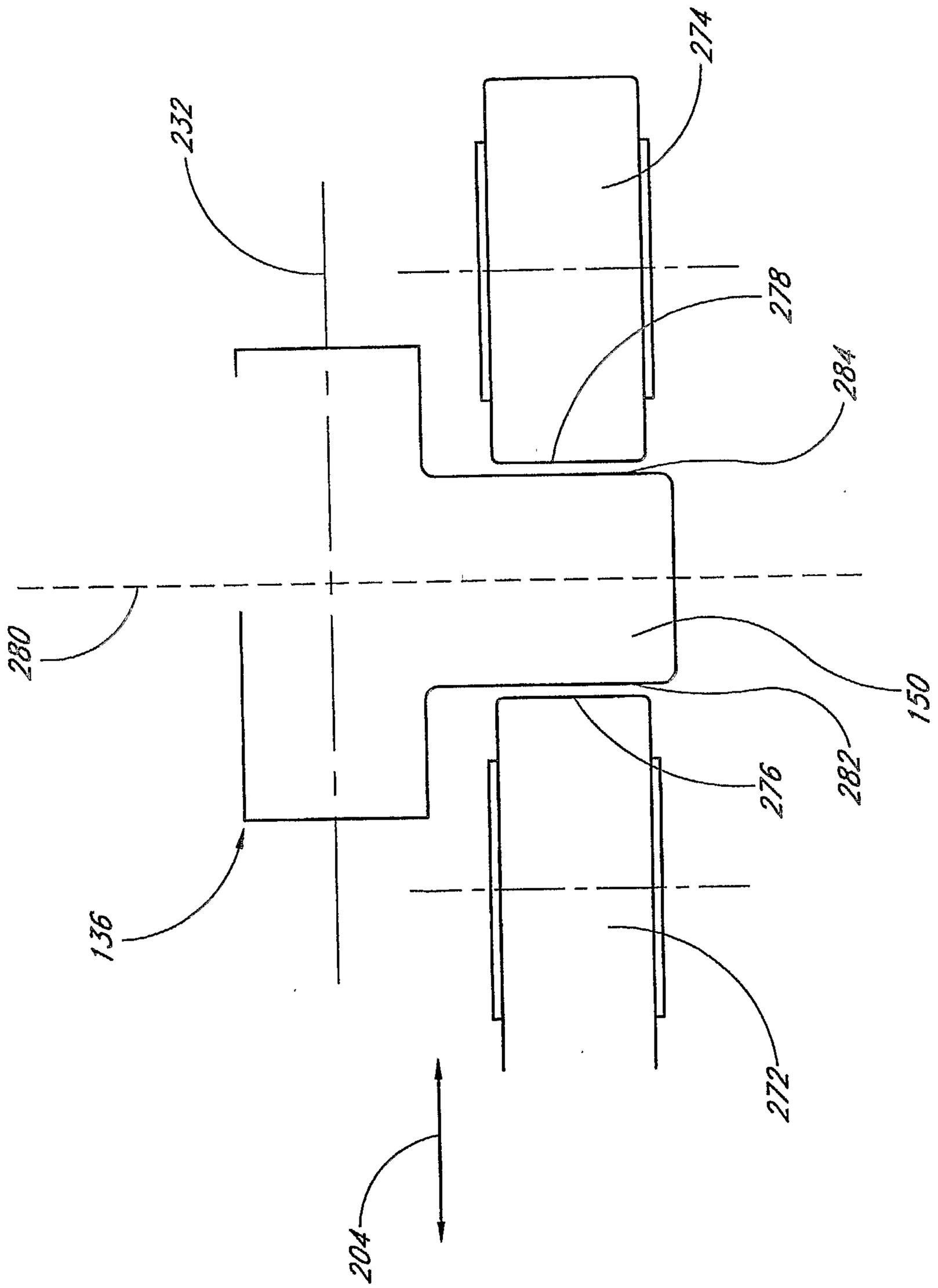

FIG. 34

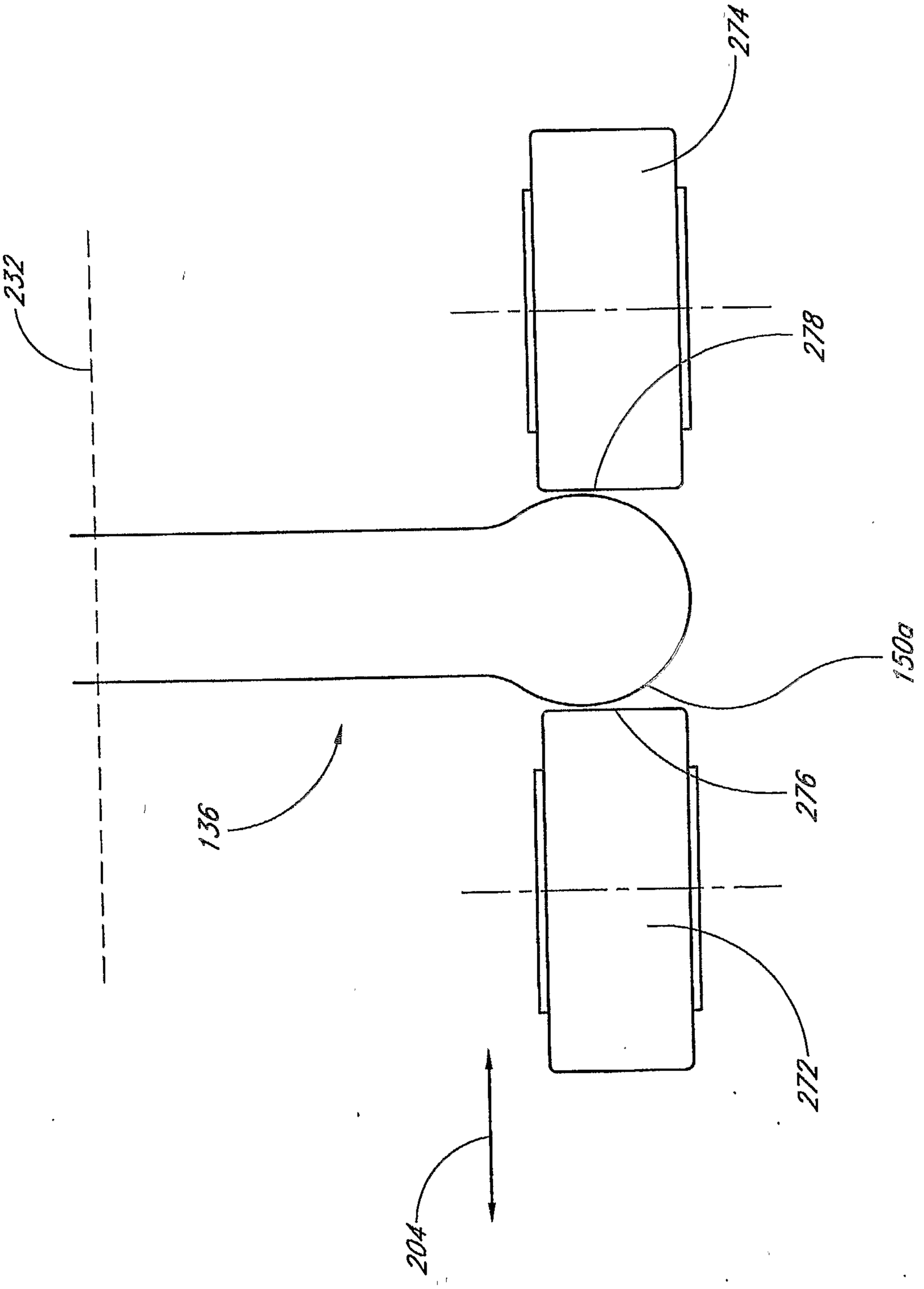

FIG. 35

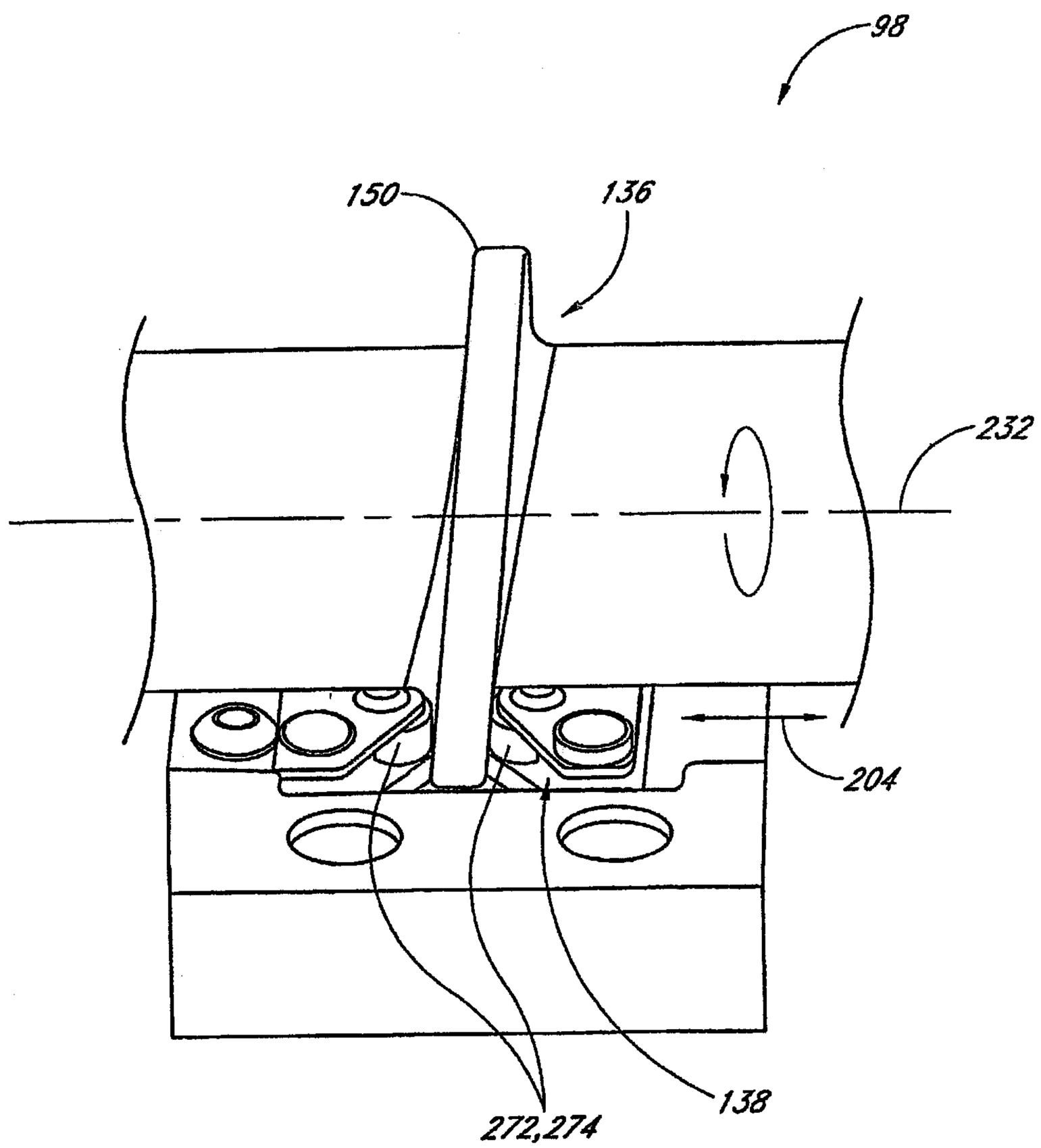

FIG. 36

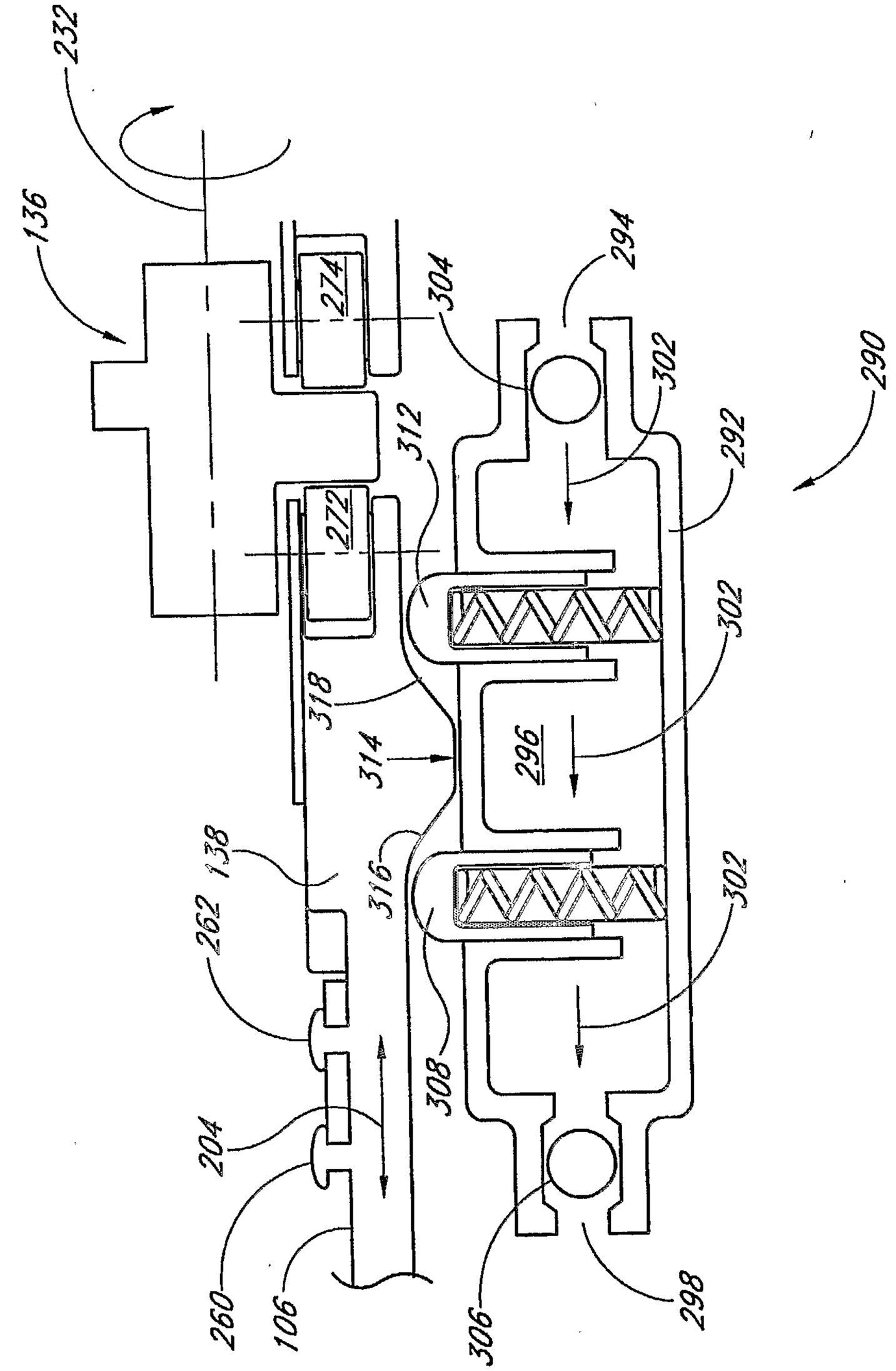
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FIG. 37

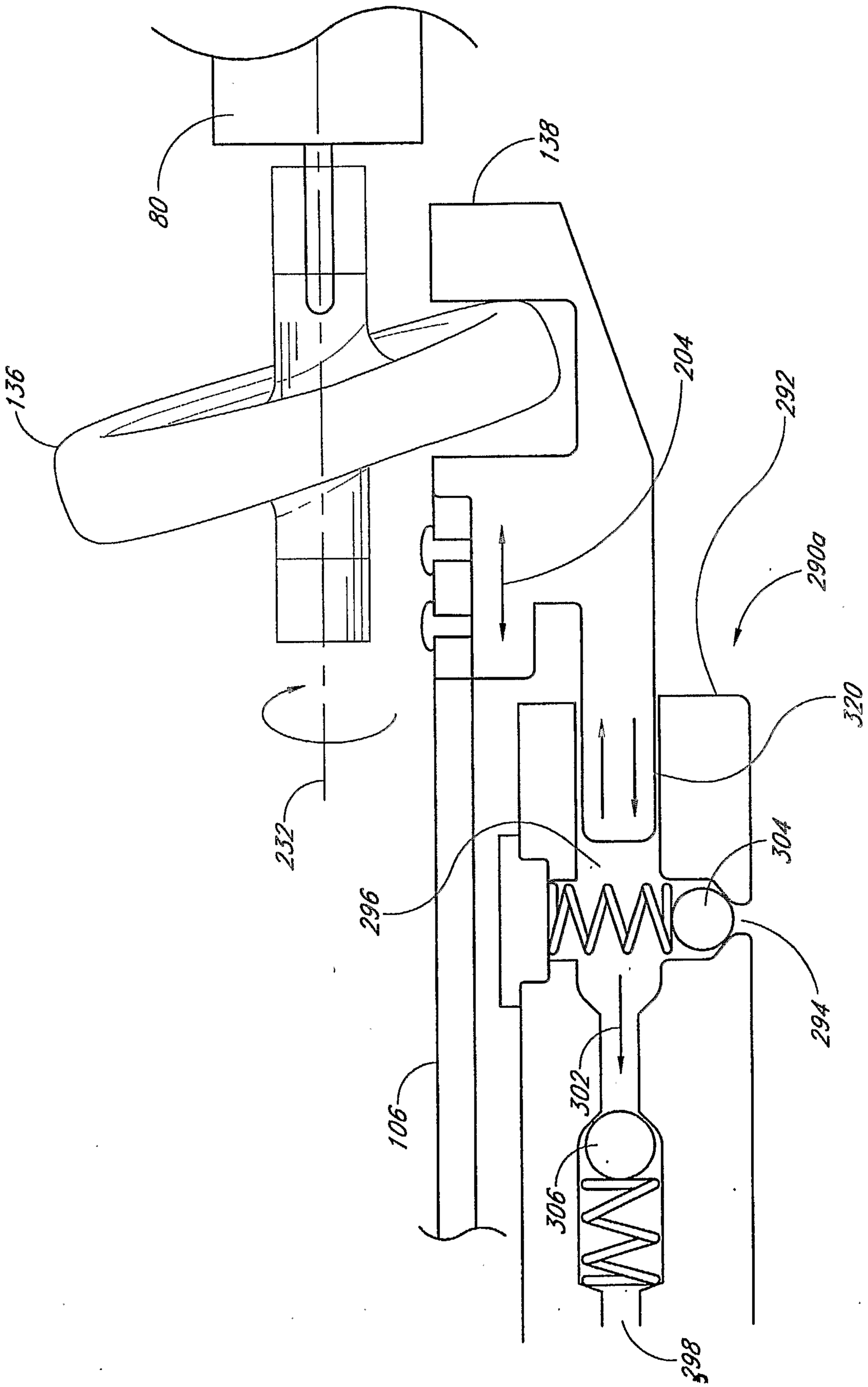

FIG. 38

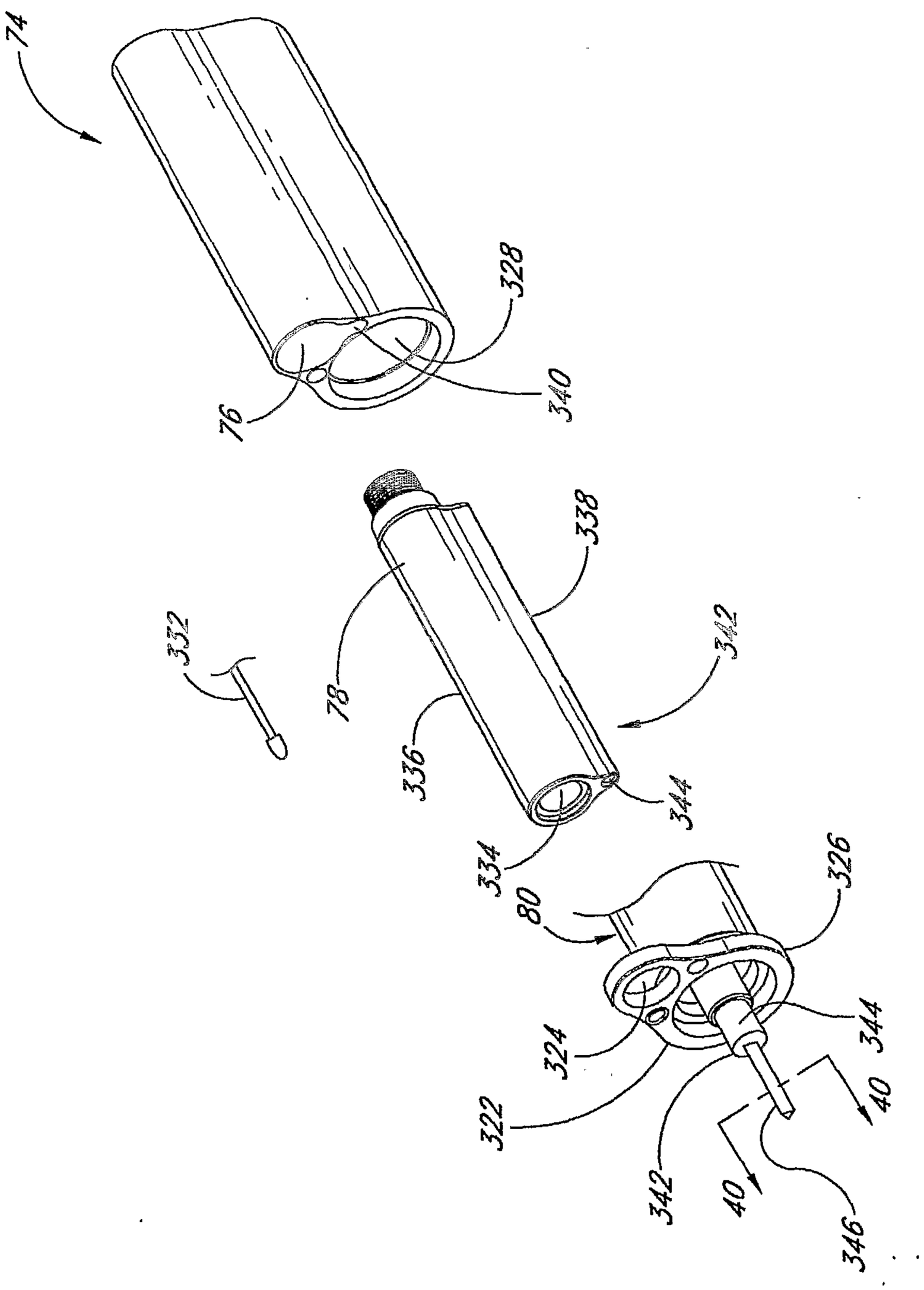
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FIG. 39

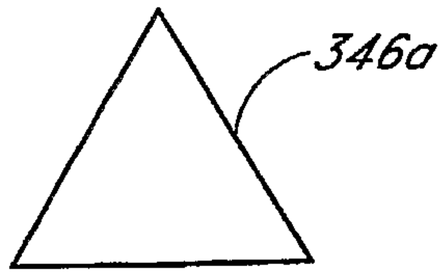


FIG. 40A

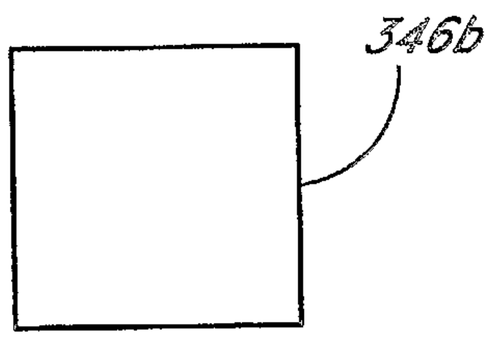


FIG. 40B

FIG. 40C

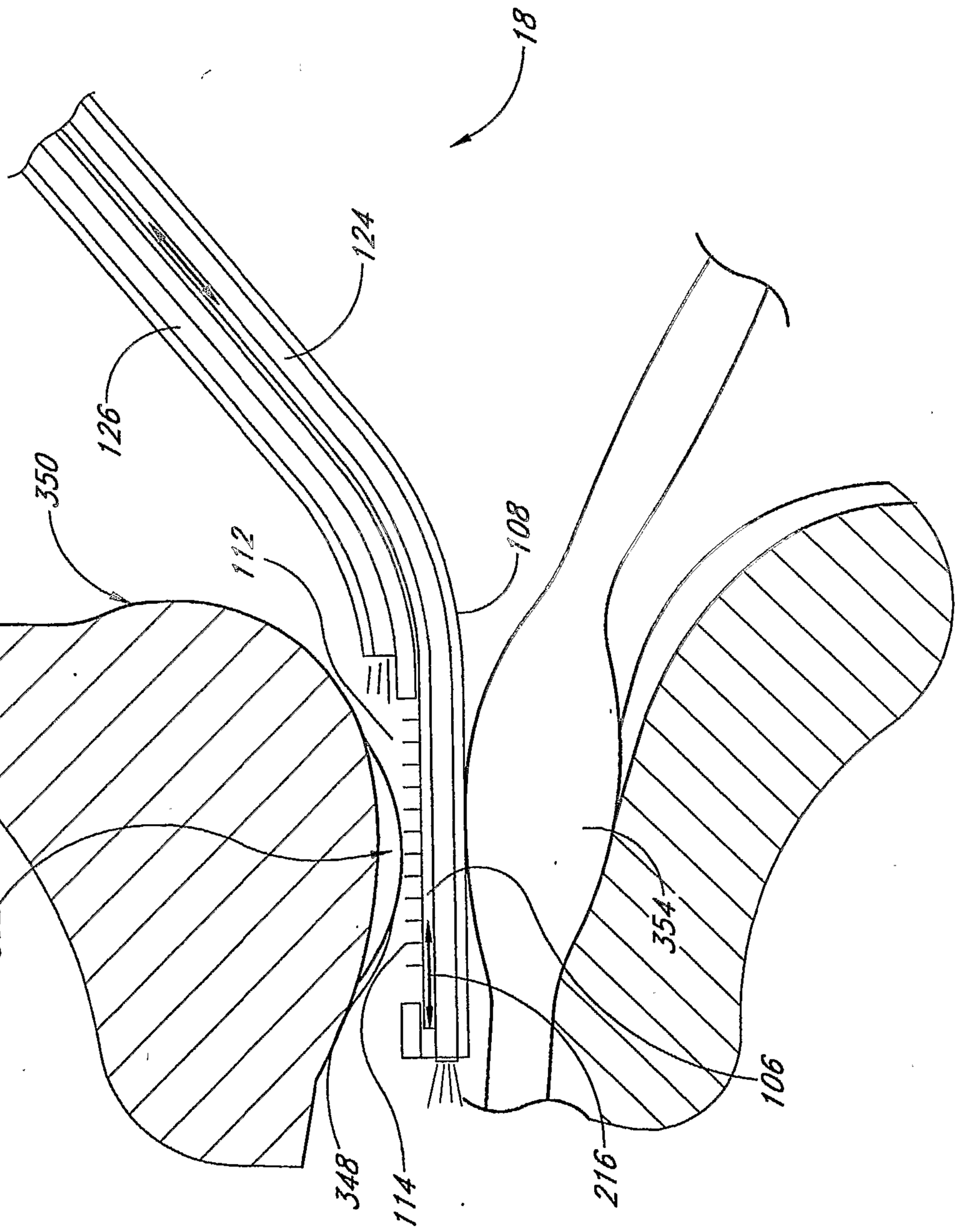


FIG. 41

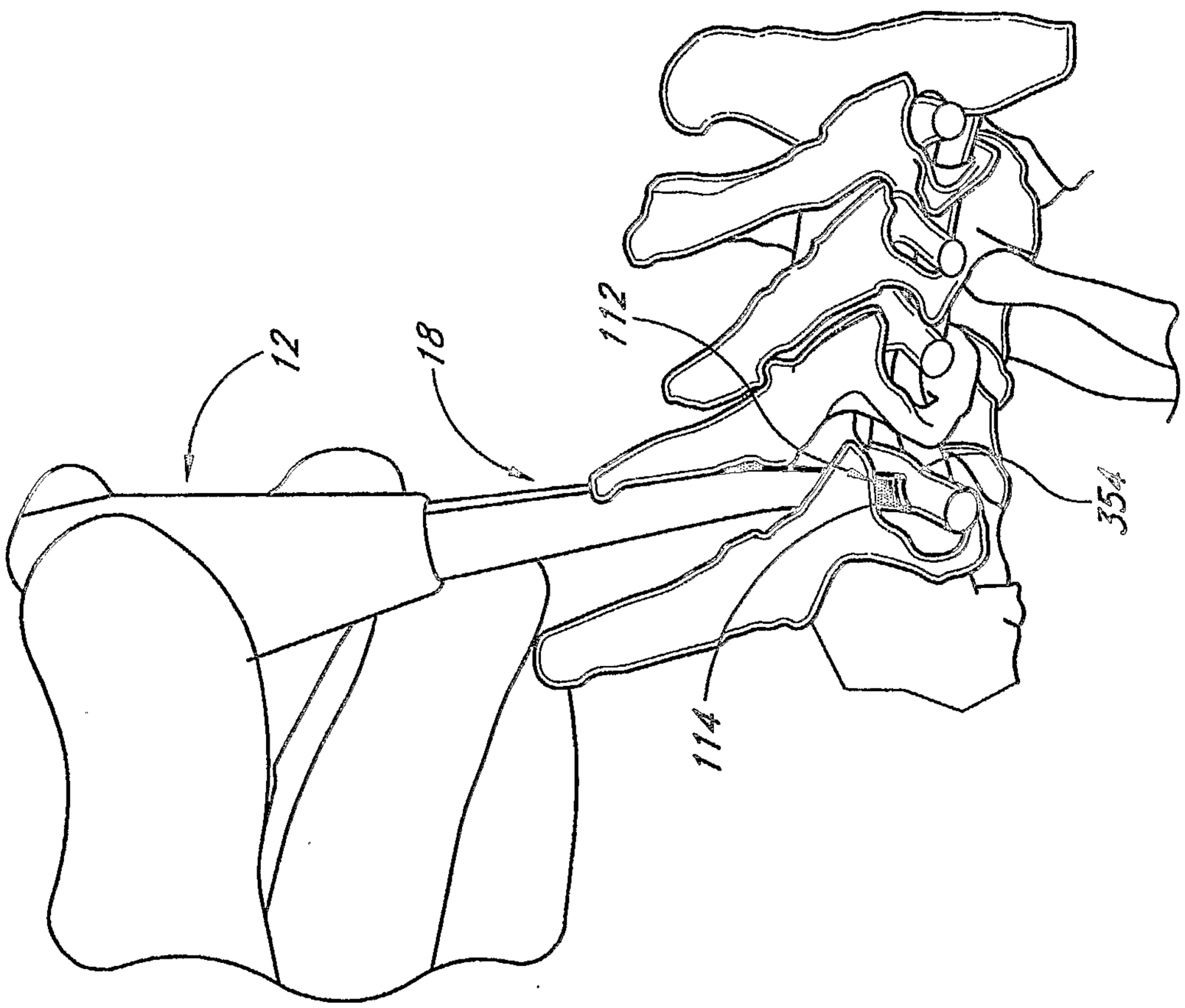


FIG. 42

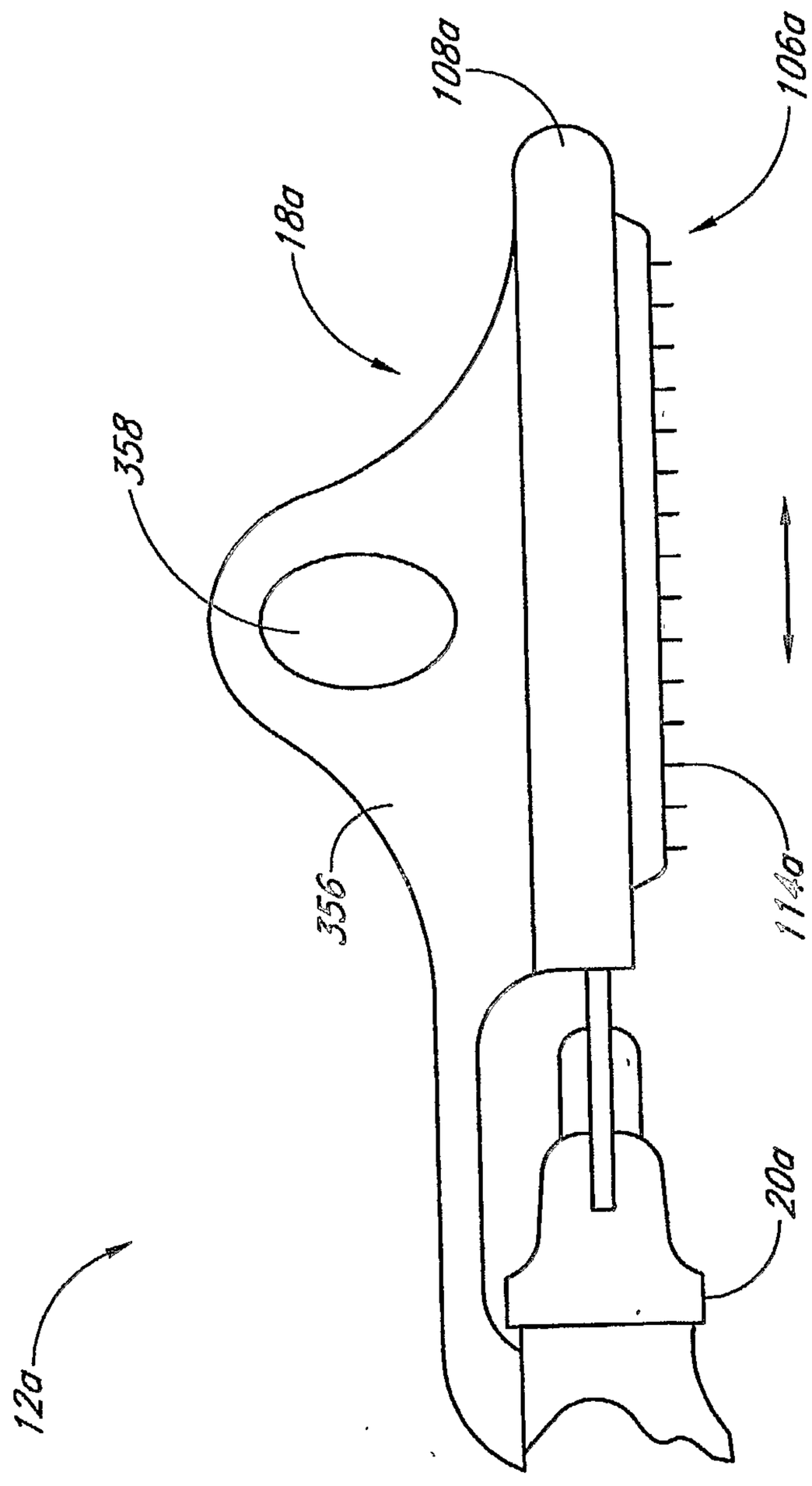


FIG. 43

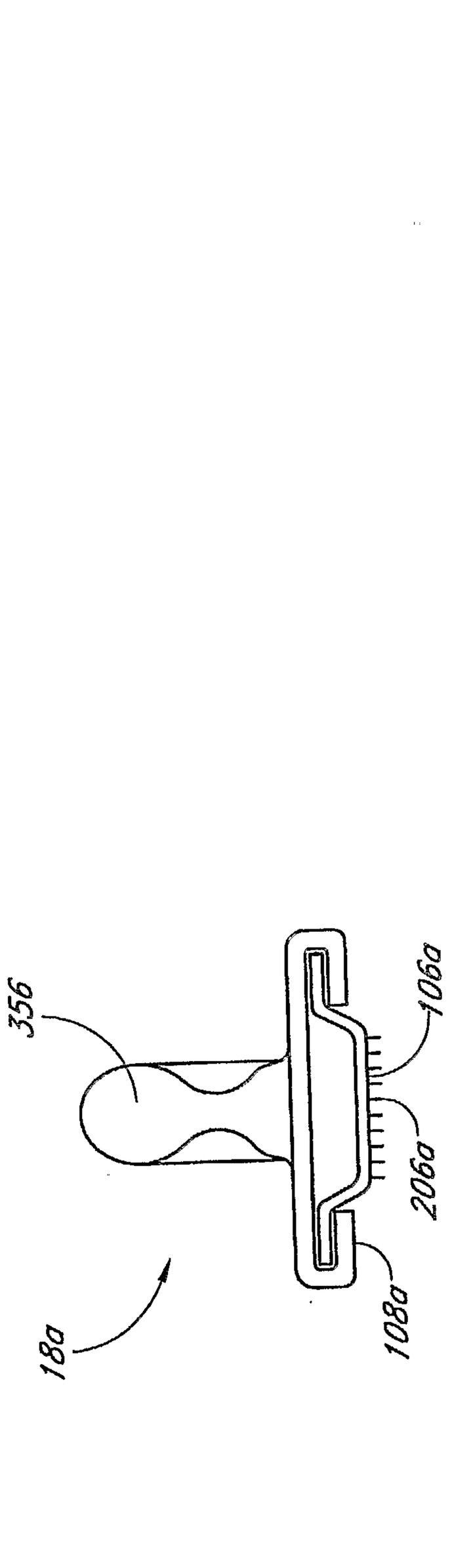


FIG. 44

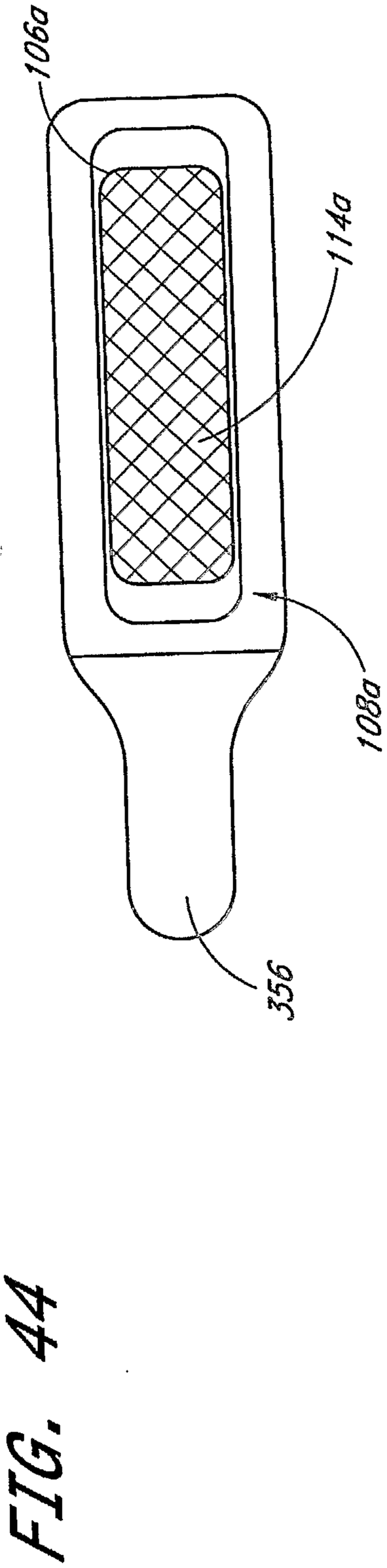
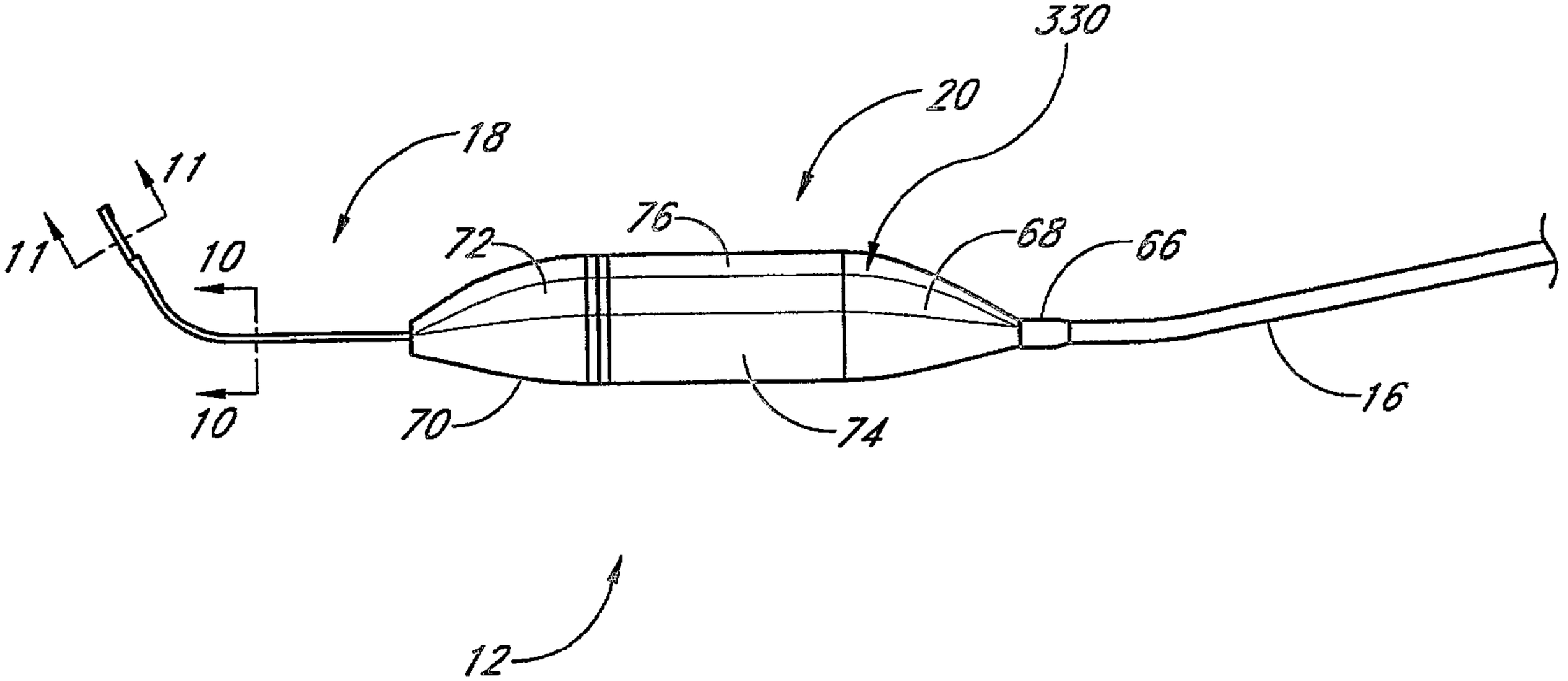


FIG. 45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