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Gouery et al.

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(54) **CUTTING TIPS FOR ULTRASONIC
SURGICAL SYSTEM**

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patent is extended or adjusted under 35
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Related U.S. Application Data

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3, 2012.

(51) **Int. Cl.**
A61B 17/32 (2006.01)
A61C 3/03 (2006.01)

(52) **U.S. Cl.**
CPC **A61B 17/320068** (2013.01); **A61B**
2017/320004 (2013.01); **A61B 2017/320078**
(2017.08); **A61C 3/03** (2013.01)

(58) **Field of Classification Search**

CPC A61B 17/320068; A61B 2017/320072;
A61B 2017/320076; A61B 2017/320004;
A61B 2017/320078; A61B 17/22012;
A61C 3/03
USPC 606/169
See application file for complete search history.

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Primary Examiner — Ryan J Severson

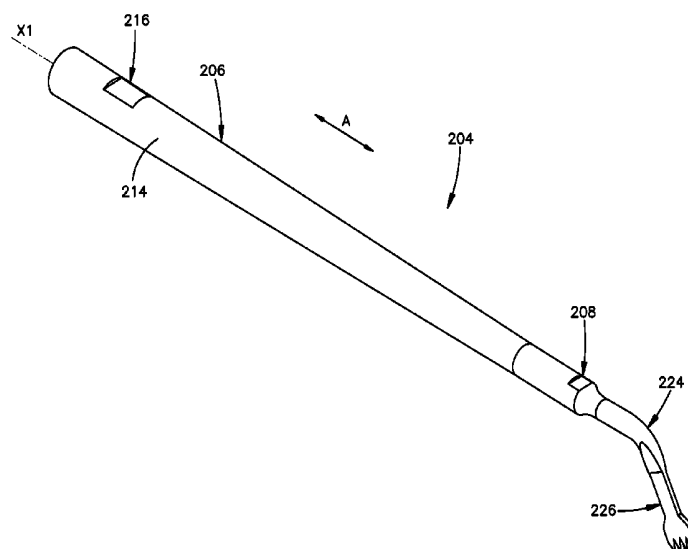
Assistant Examiner — Christian Knauss

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(57) **ABSTRACT**

A tool is configured to cut a tissue body. The tool includes
a first section configured to be coupled to a transducer
assembly, and a second section coupled to the first section.
The first section at least partially includes a first material.
The second section at least partially includes a second
material that is different from the first material and denser
than the first material. The second includes a cutting member
that is configured to vibrate at a predetermined frequency so
as to cut a tissue body an operative portion.

9 Claims, 53 Drawing Sheets



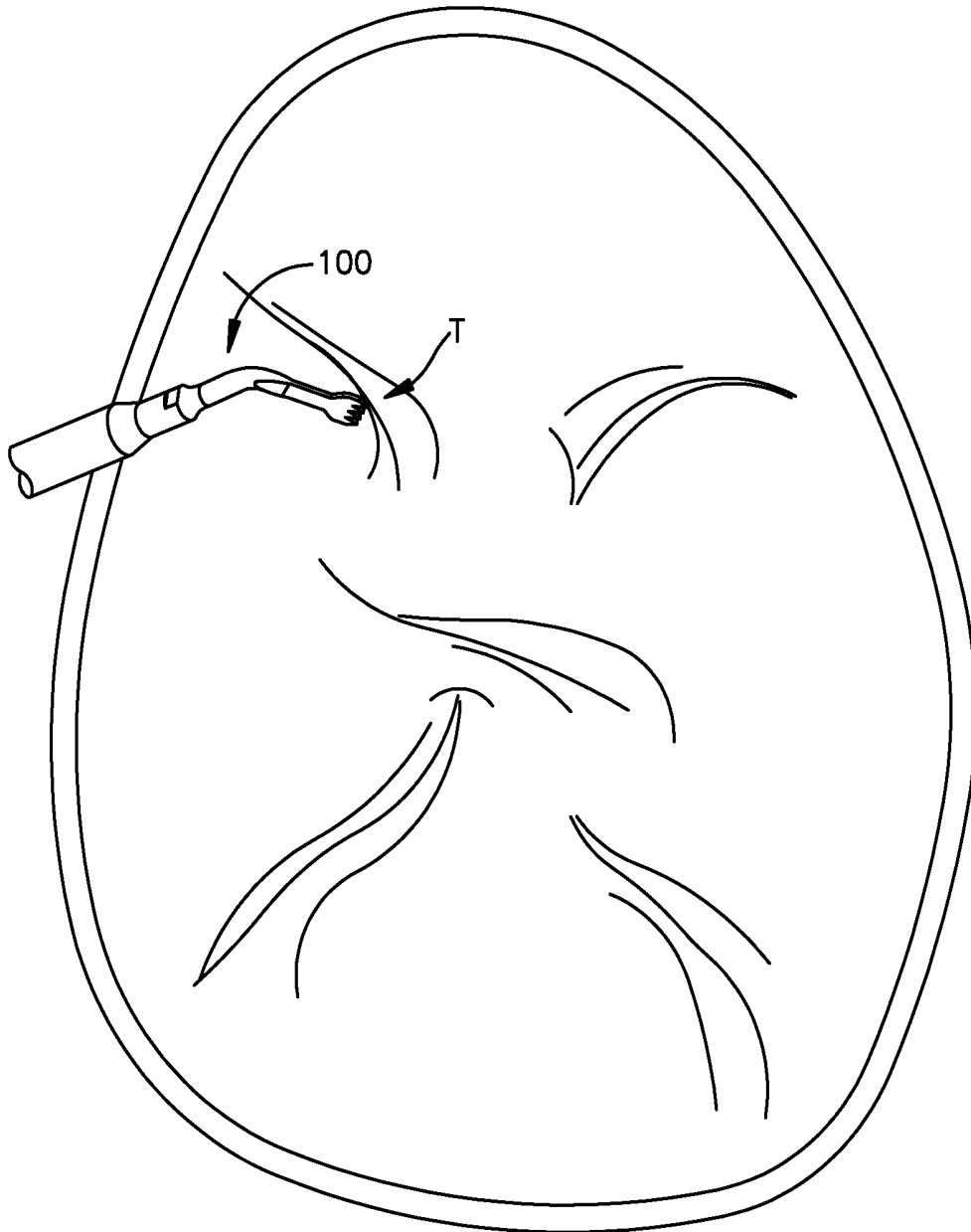
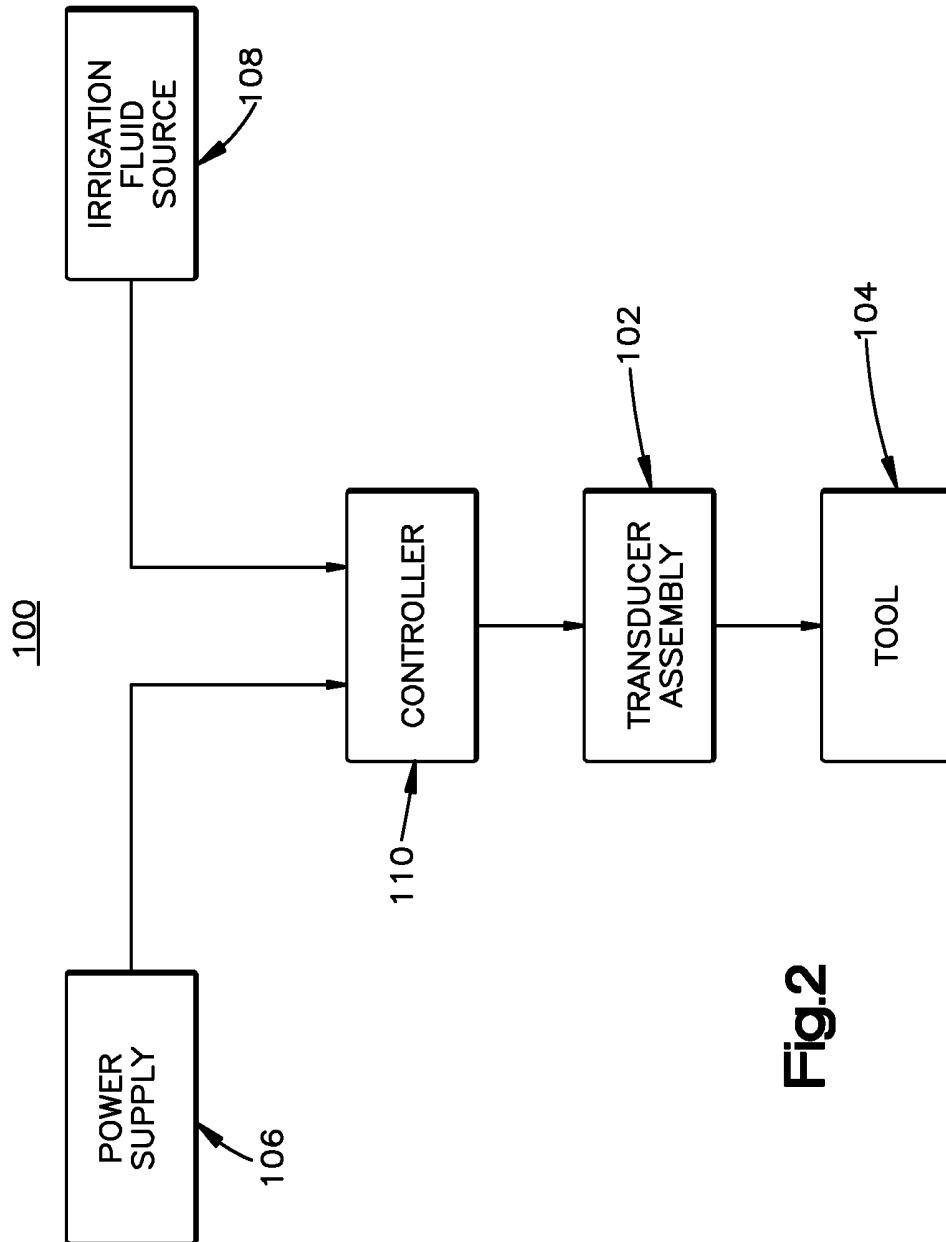


Fig.1

**Fig.2**

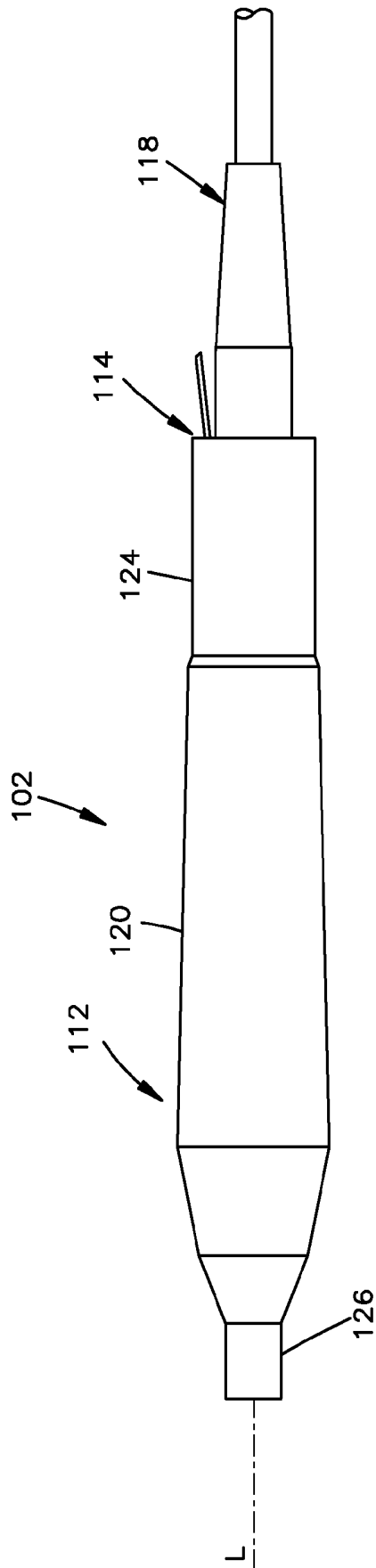


Fig.3A

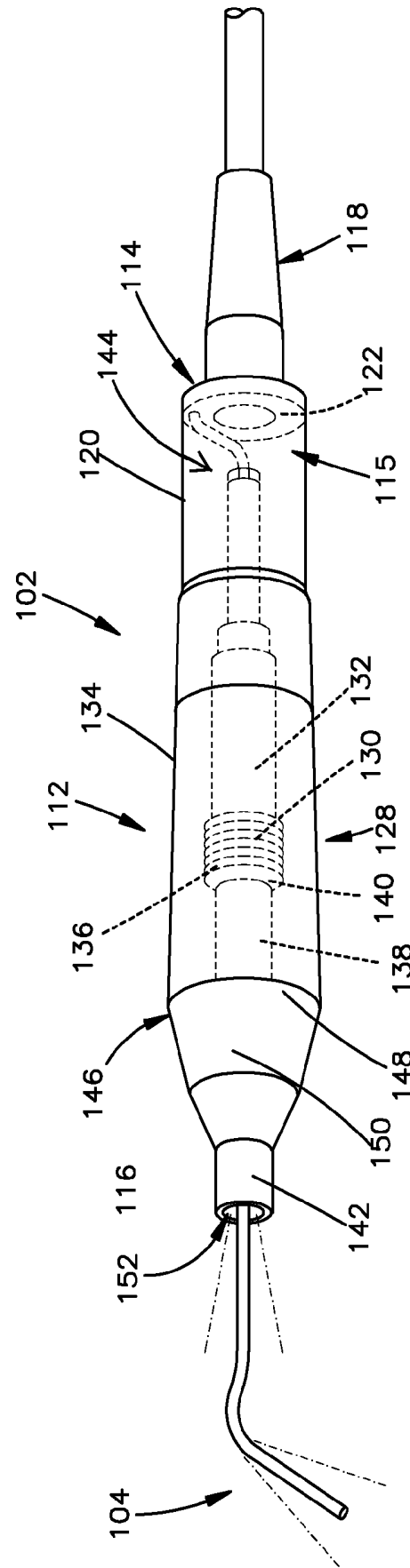
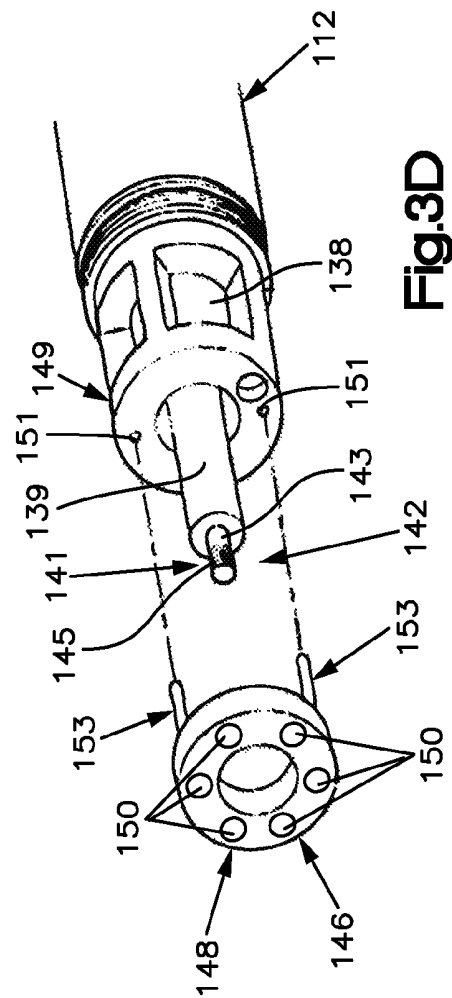
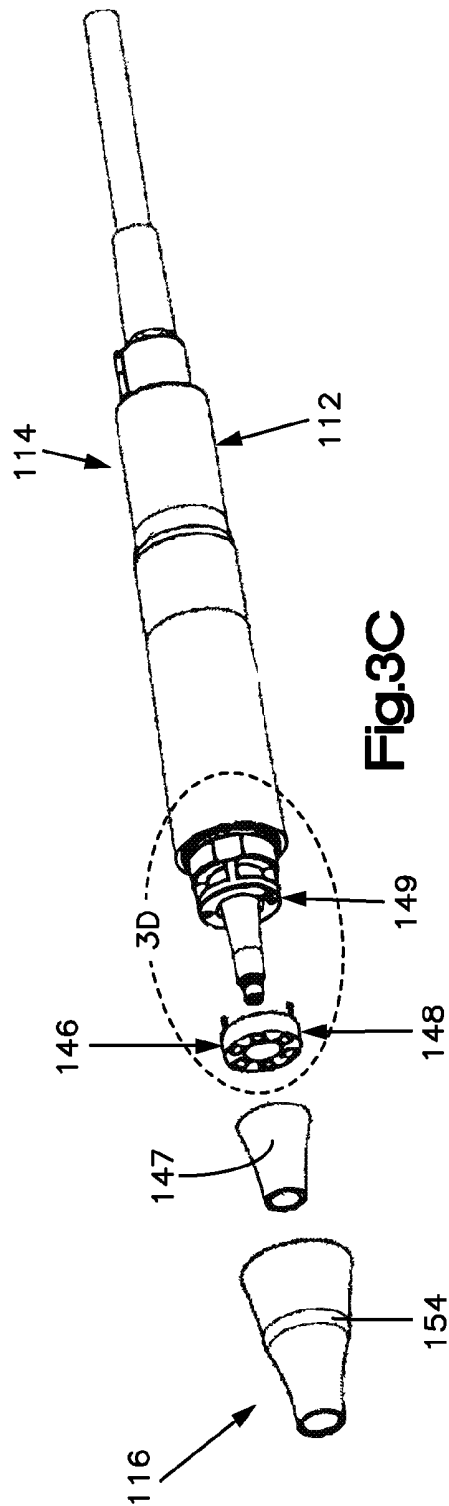


Fig.3B



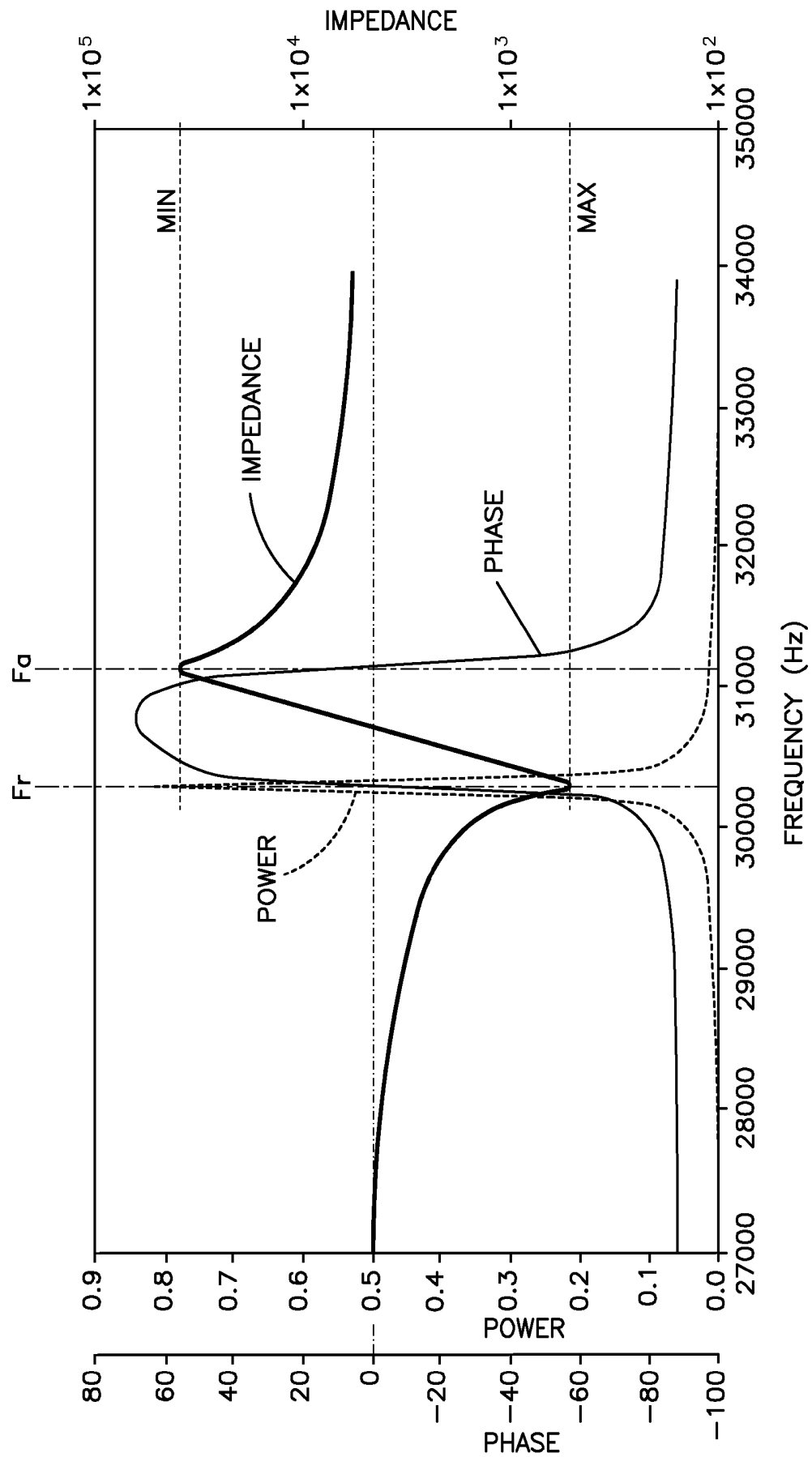


Fig.4

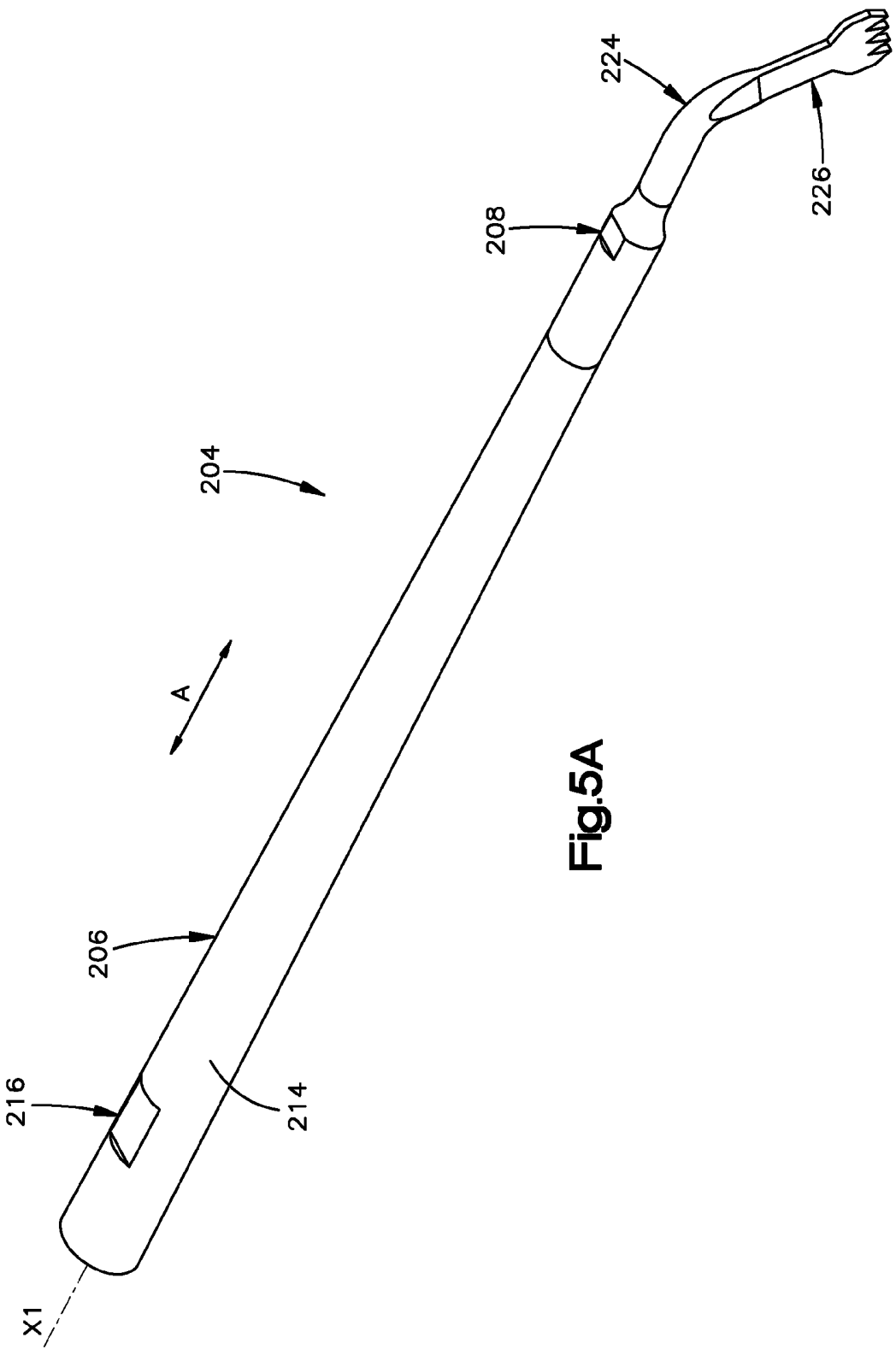
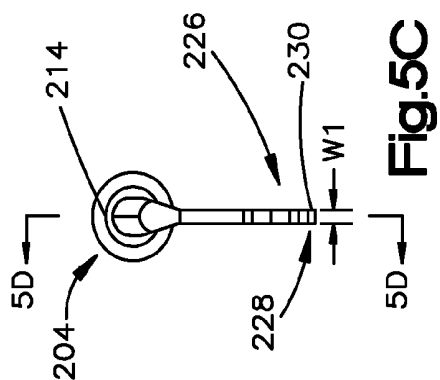
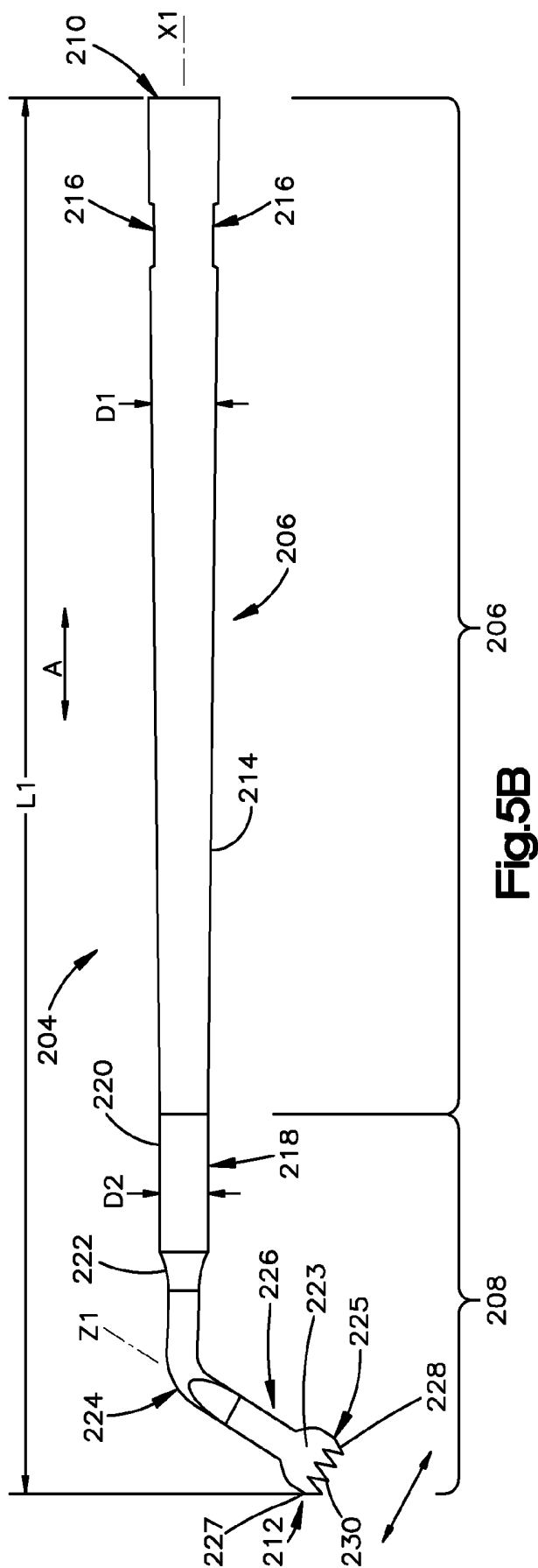
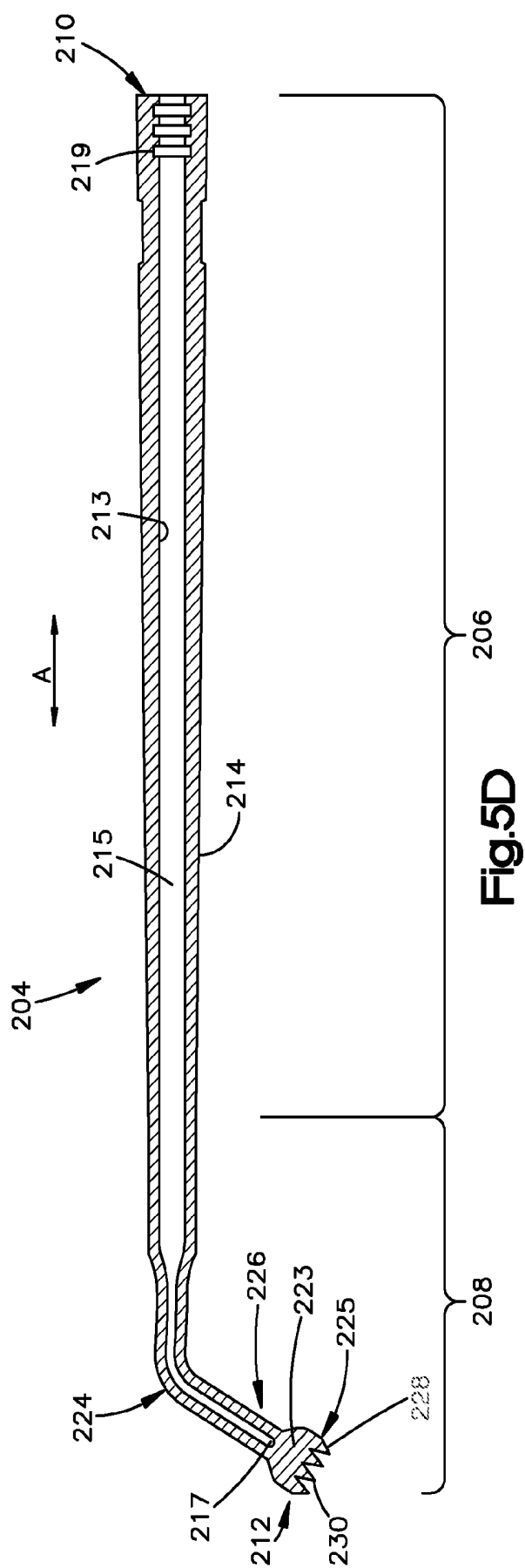


Fig.5A





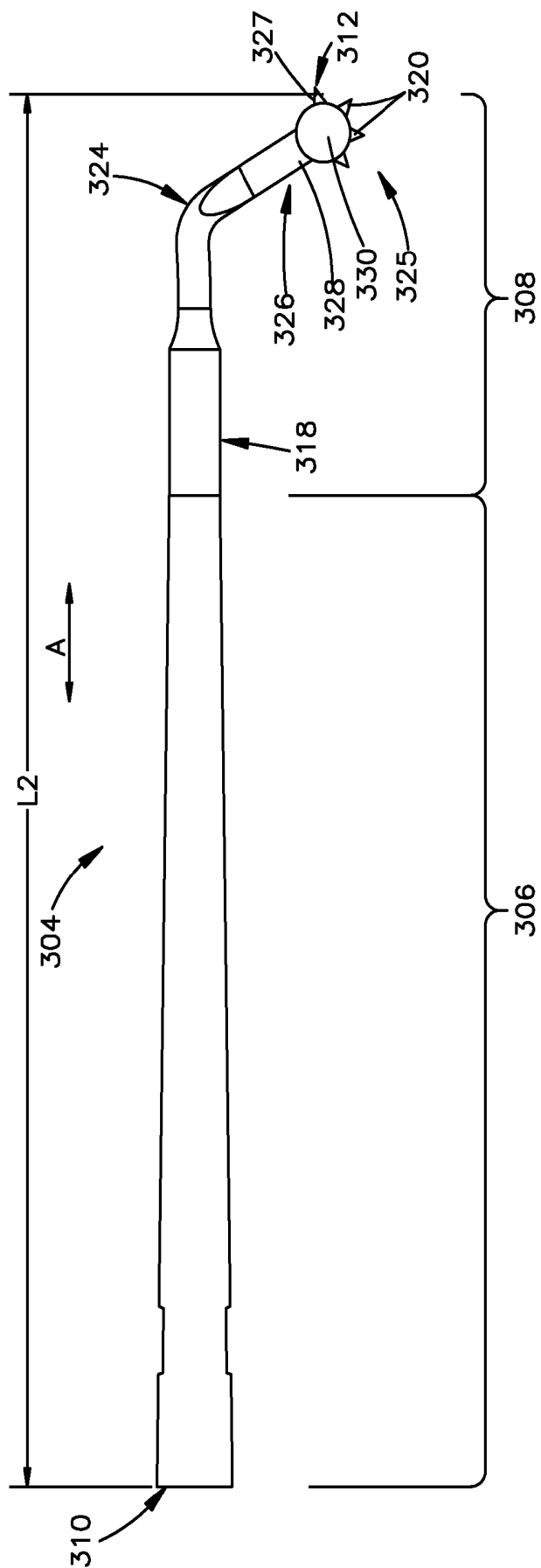


Fig.6

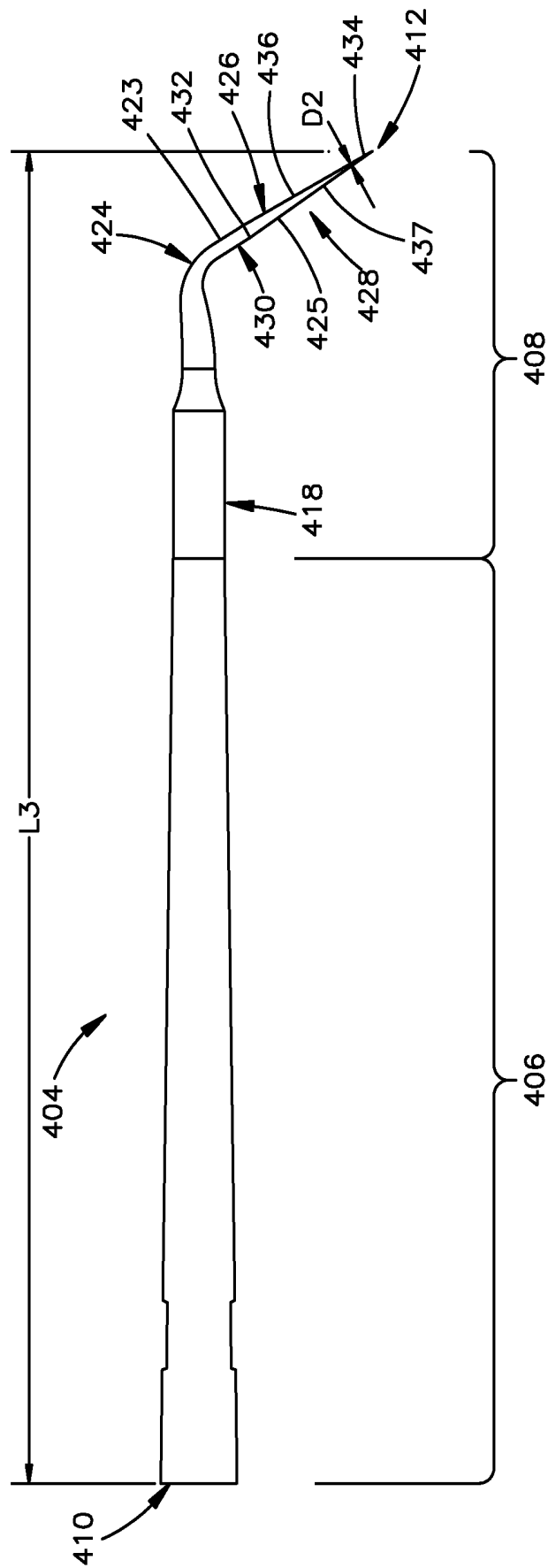


Fig.7

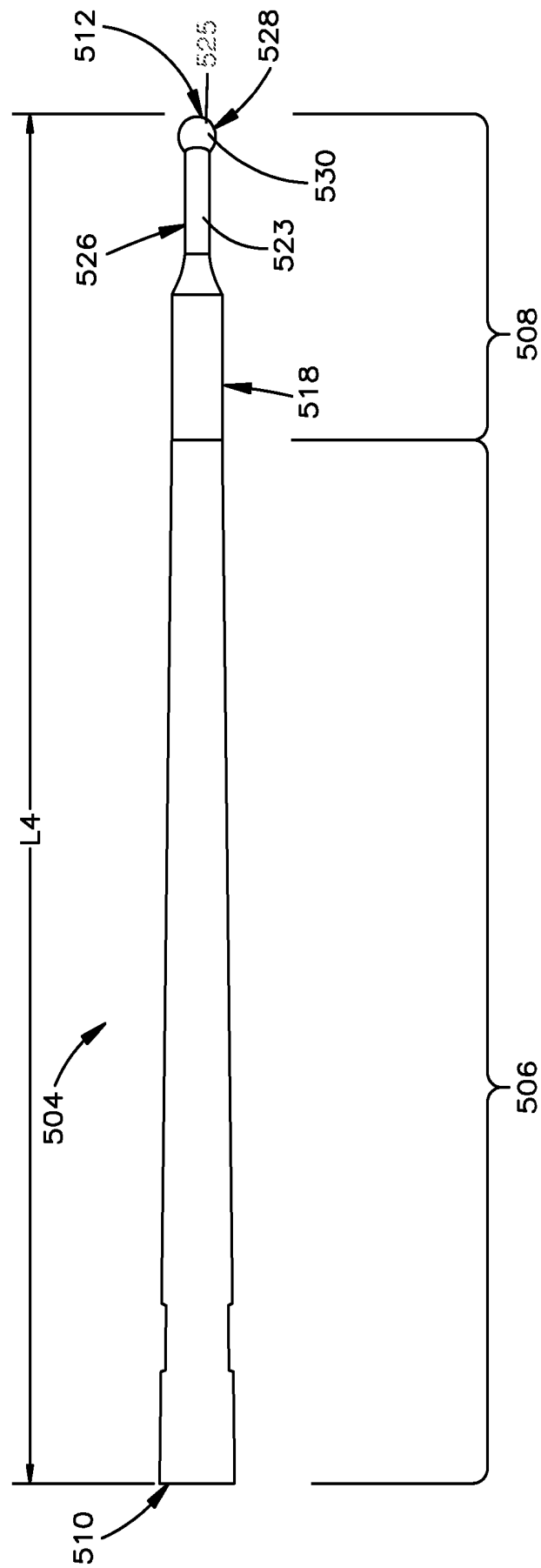


Fig.8

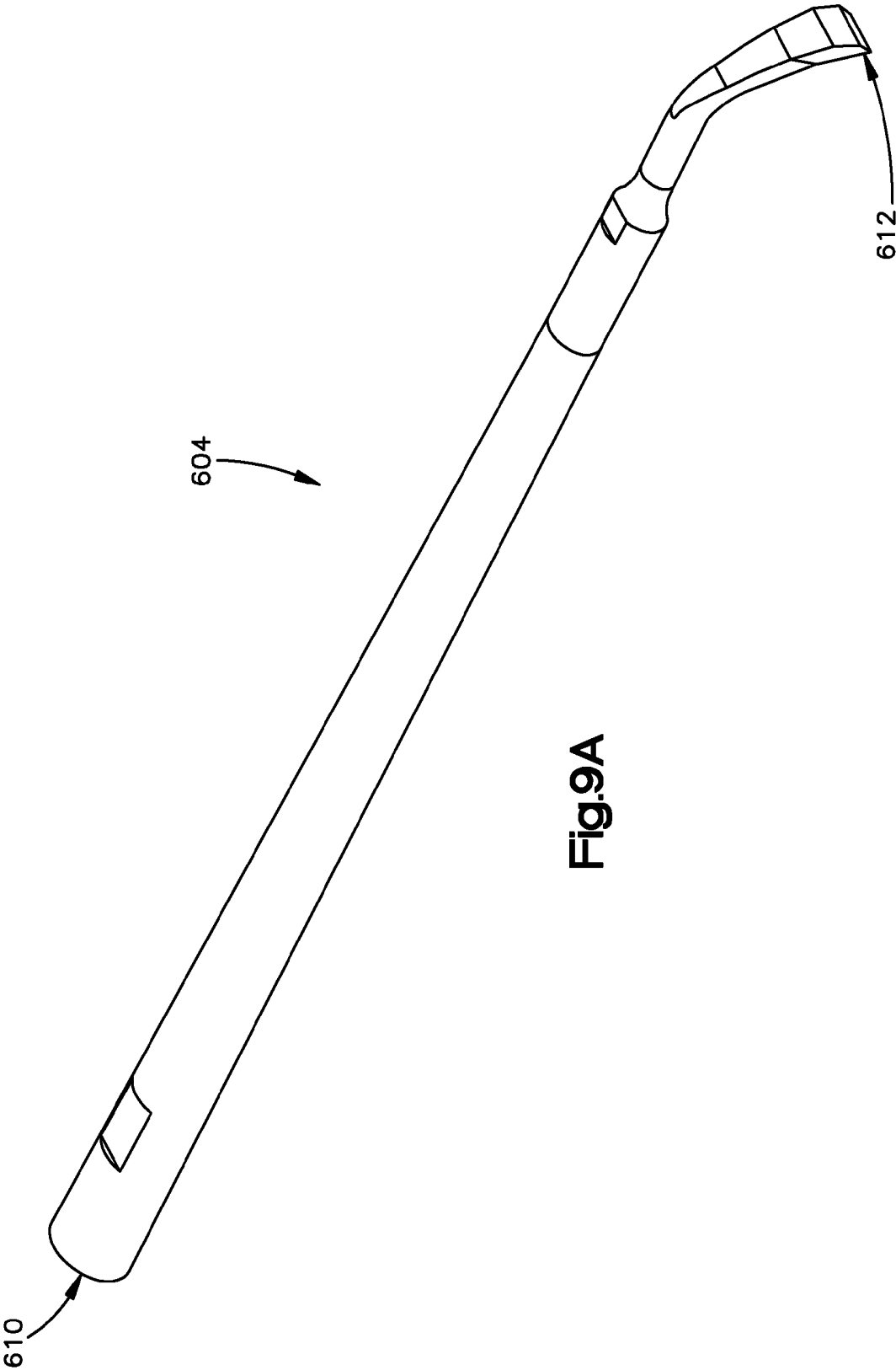
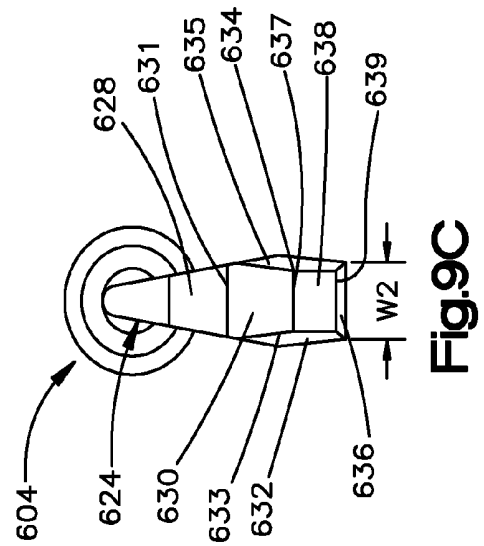
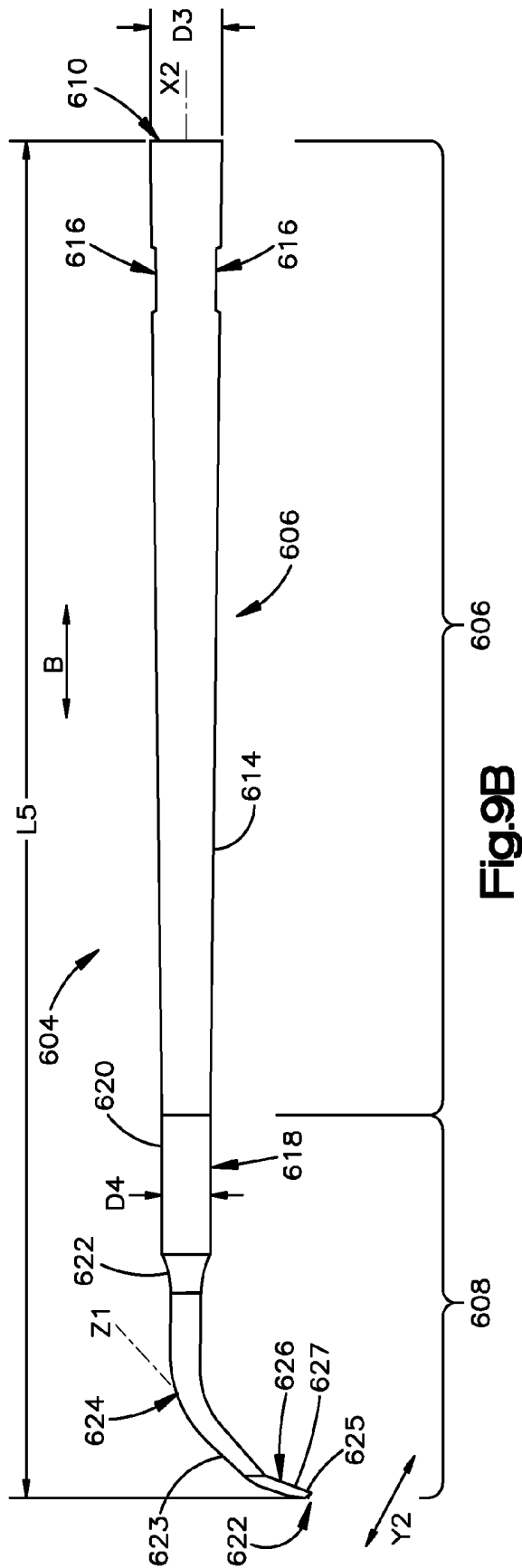


Fig.9A



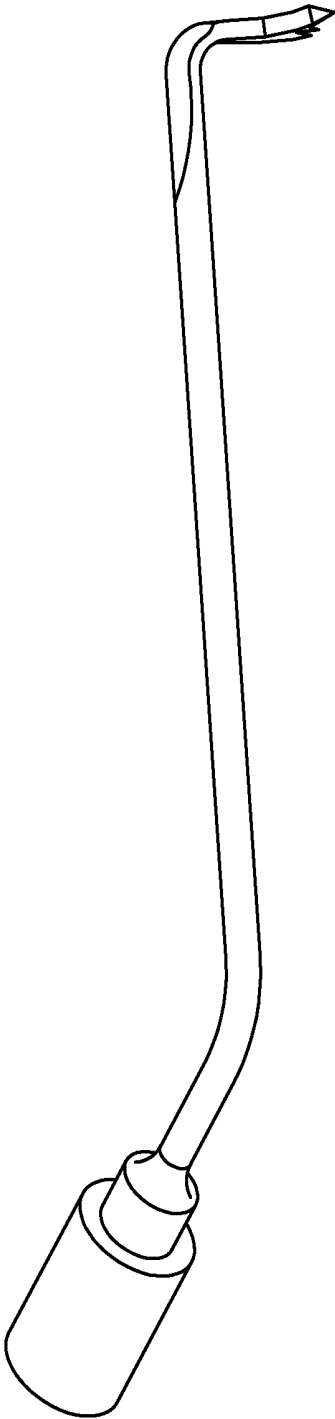


Fig.10A

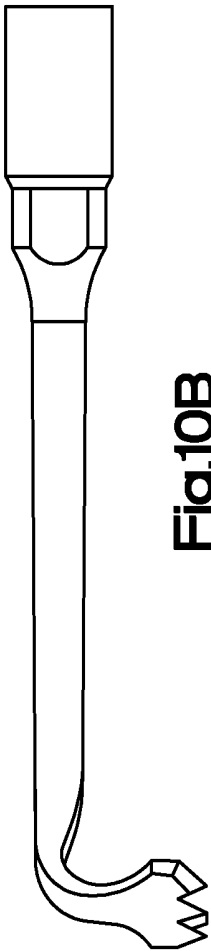


Fig.10B

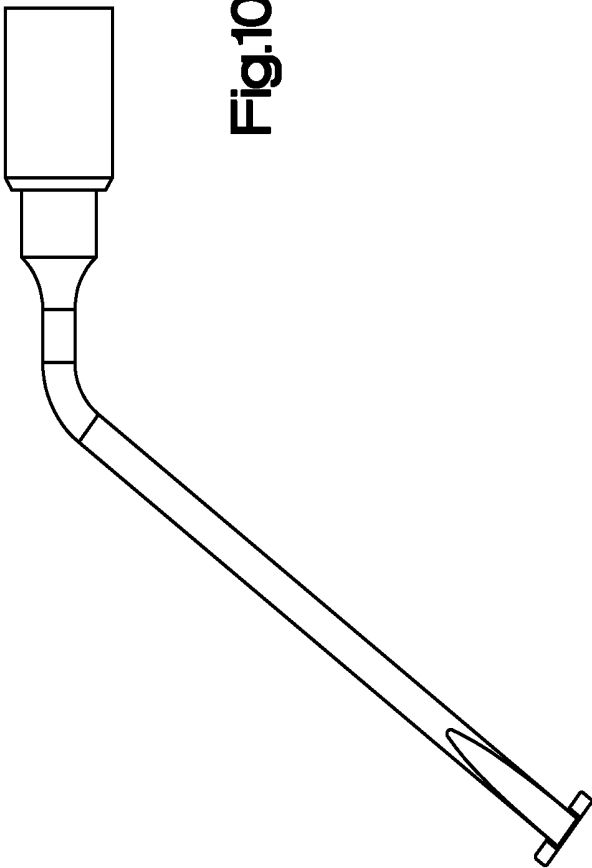


Fig.10C

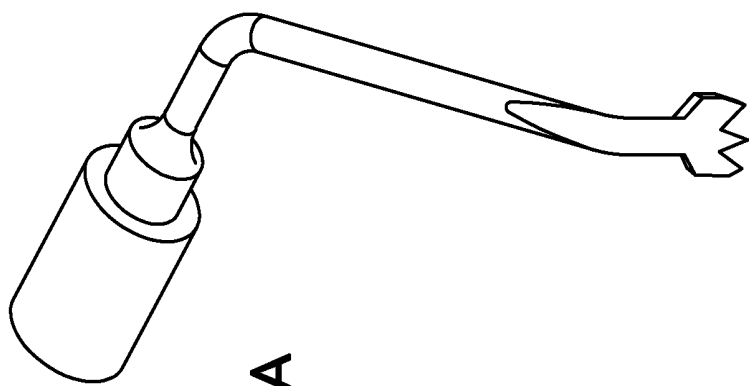


Fig.11A

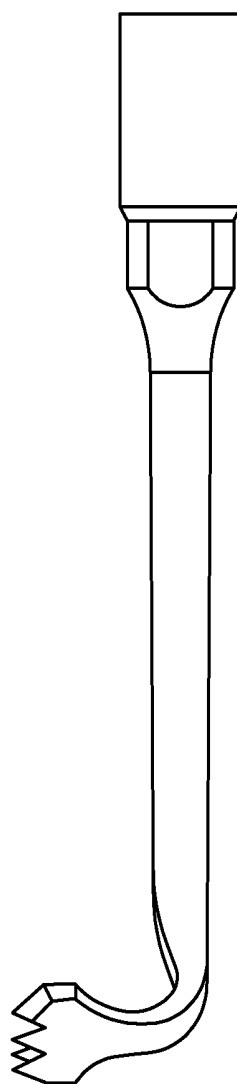


Fig.11B

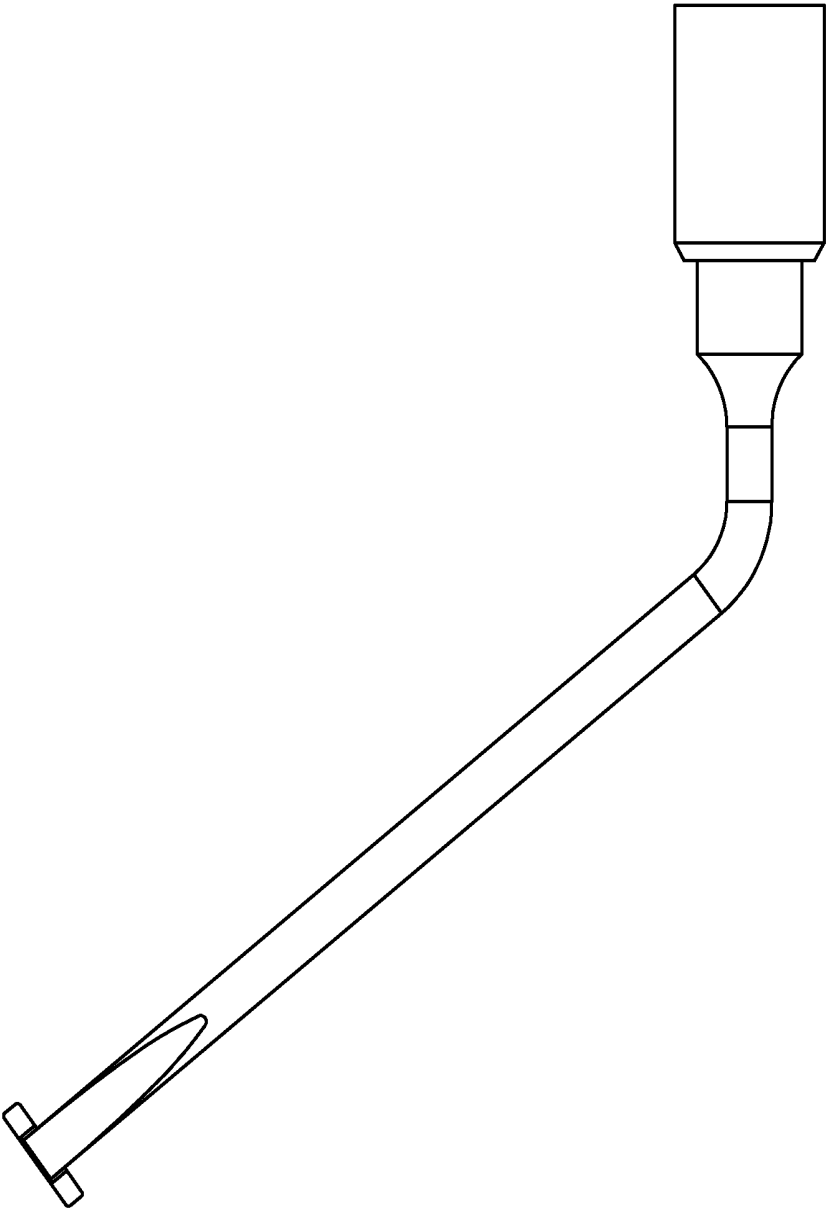


Fig.11C

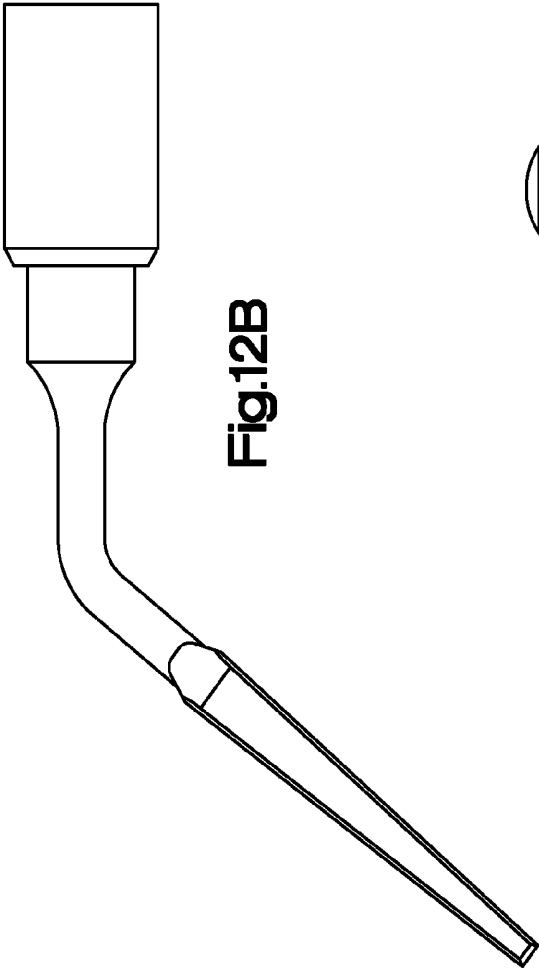


Fig.12B

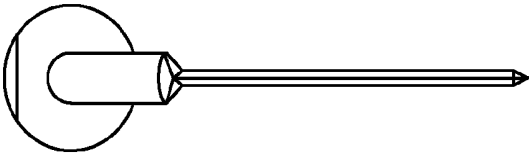


Fig.12C

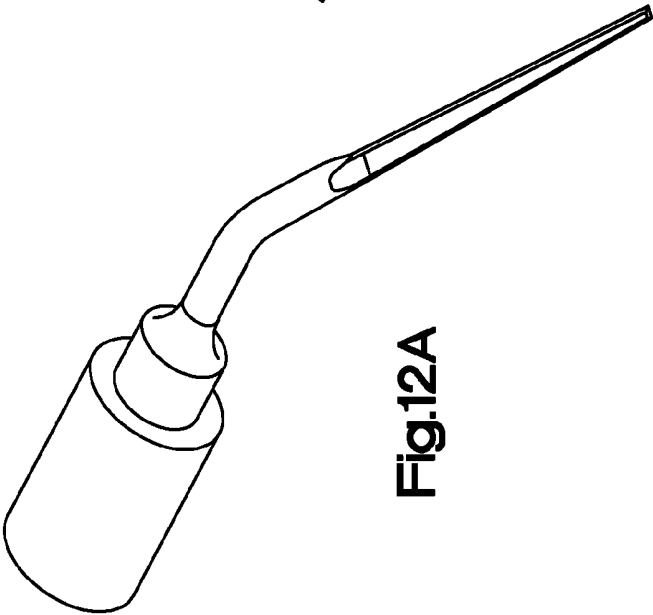


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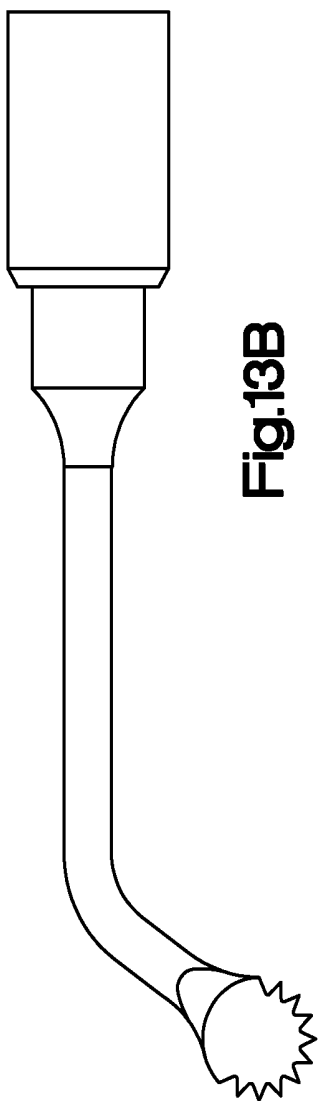


Fig.13B

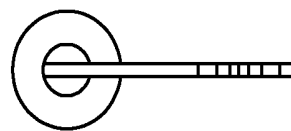


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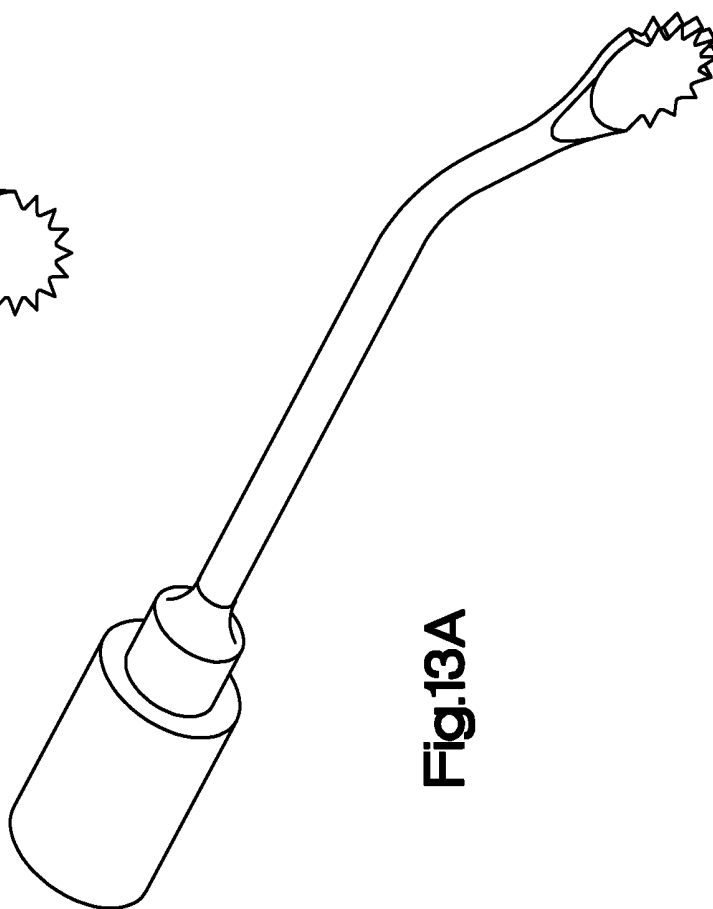


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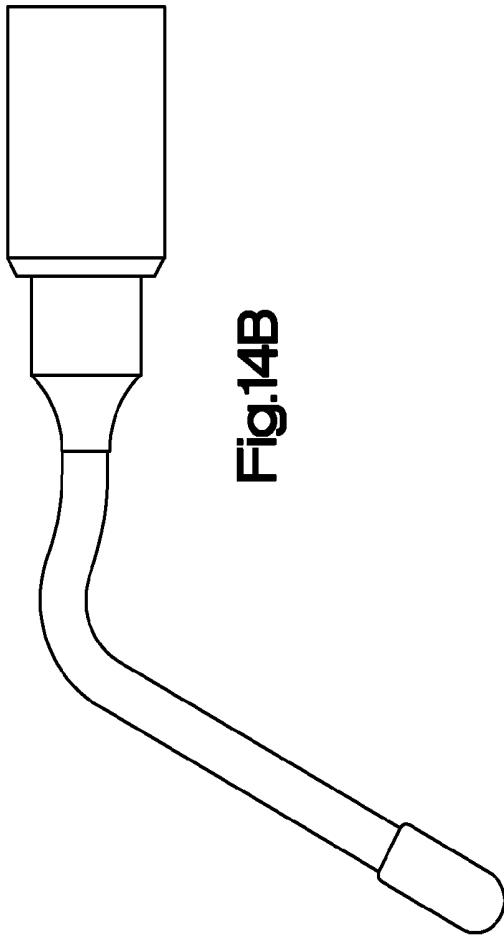


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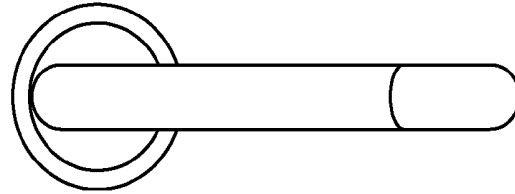


Fig.14C

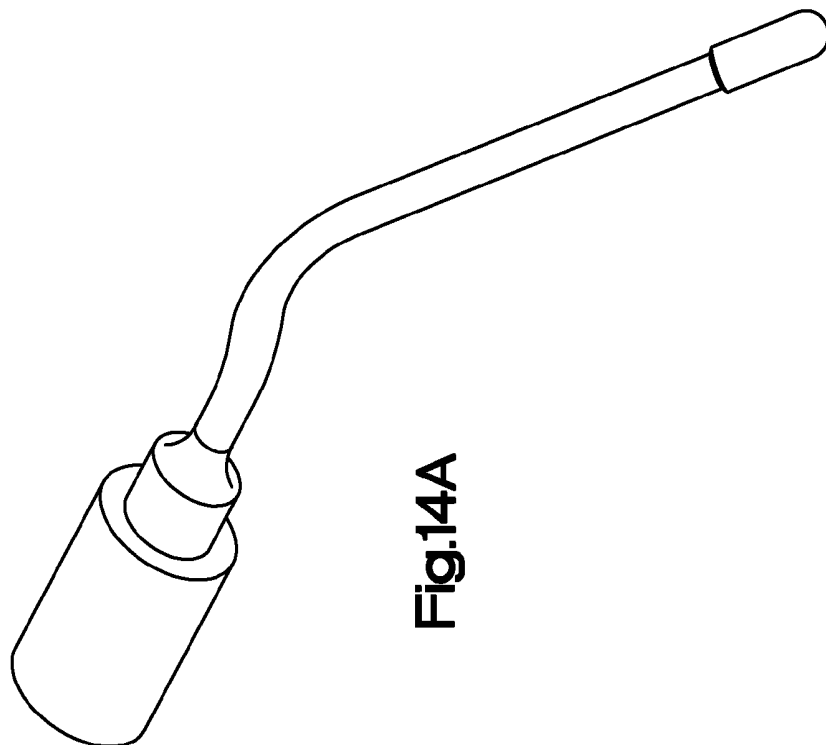


Fig.14A

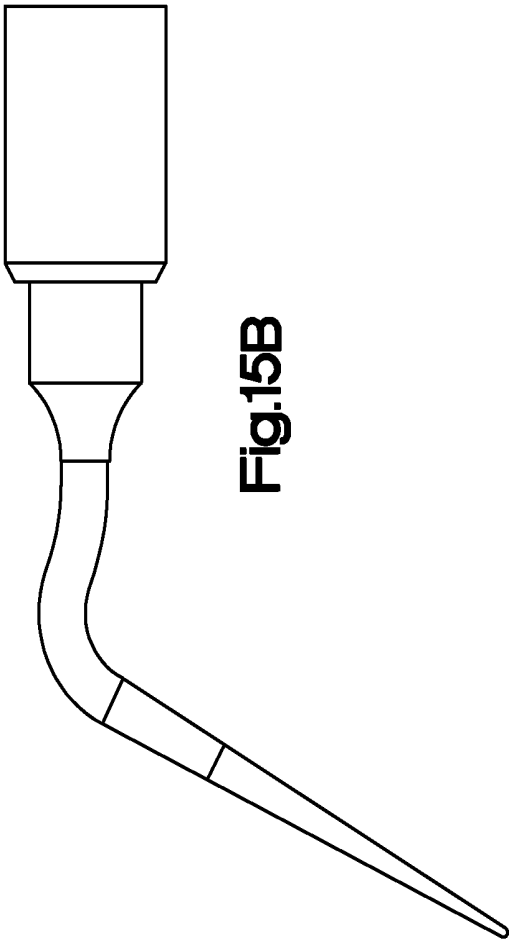


Fig.15B

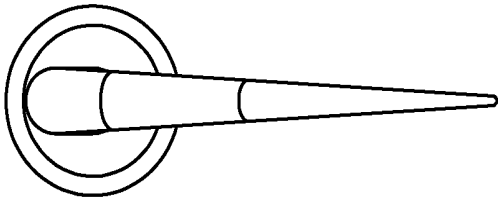


Fig.15C

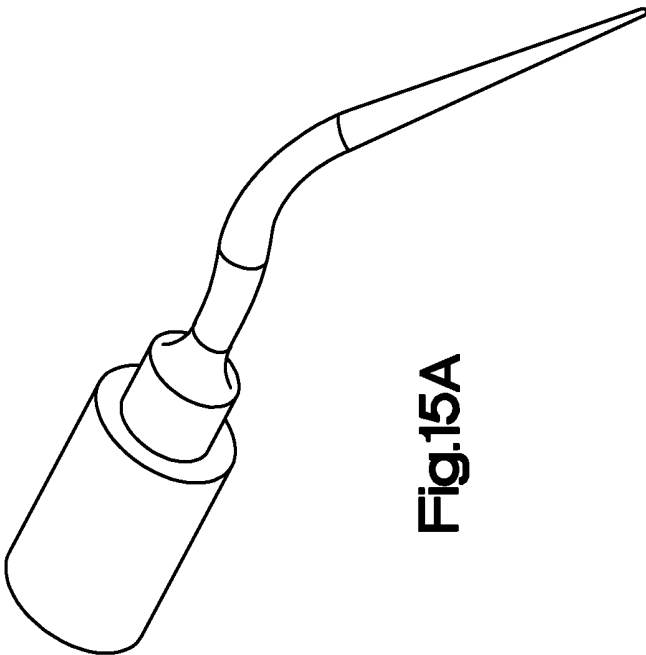


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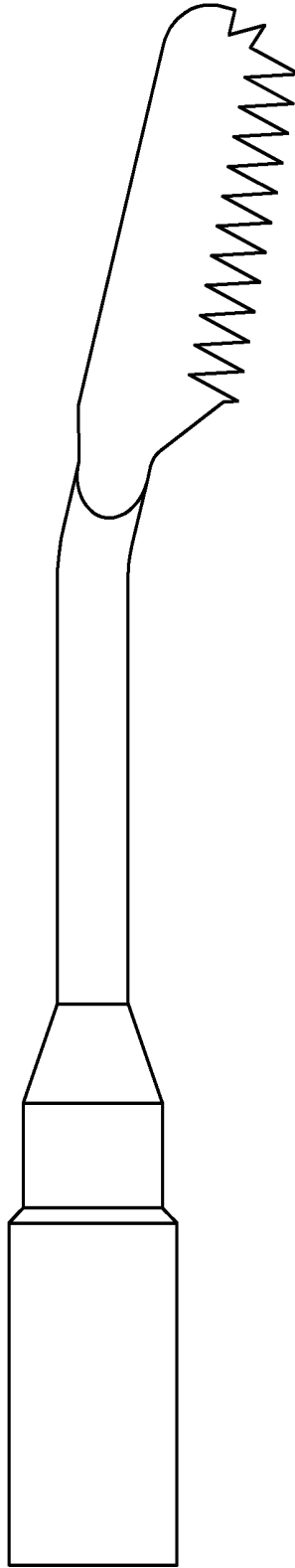


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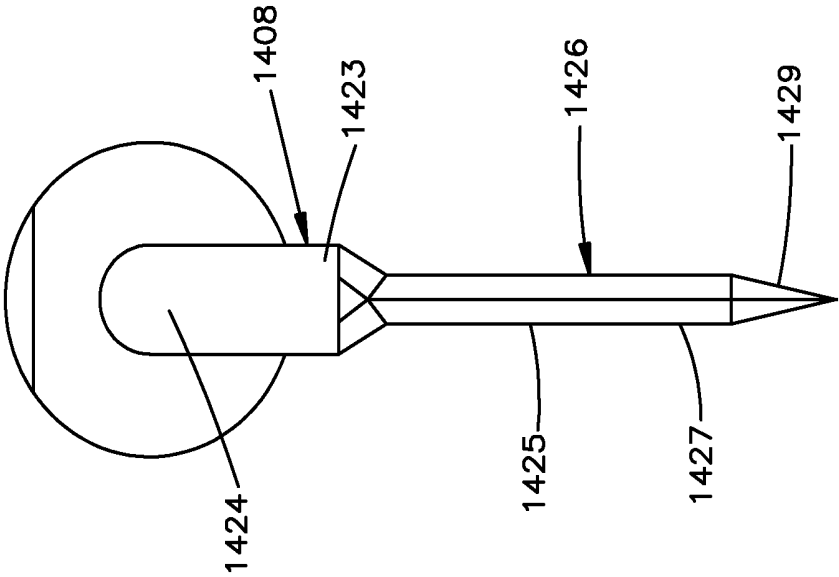


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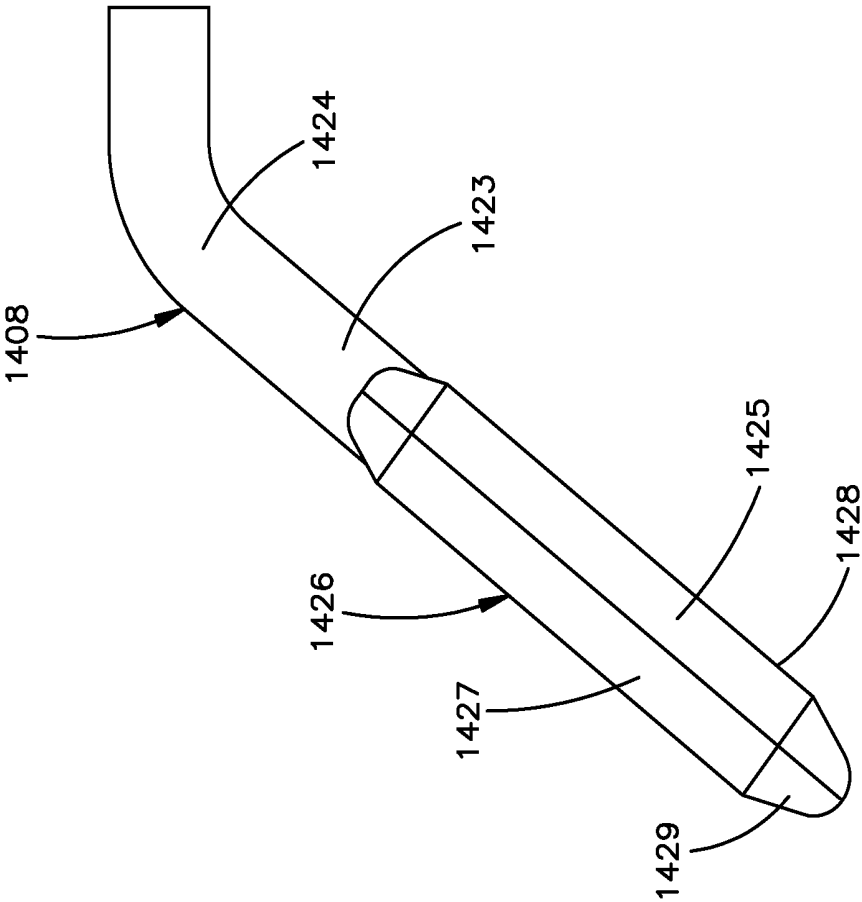


Fig.17A

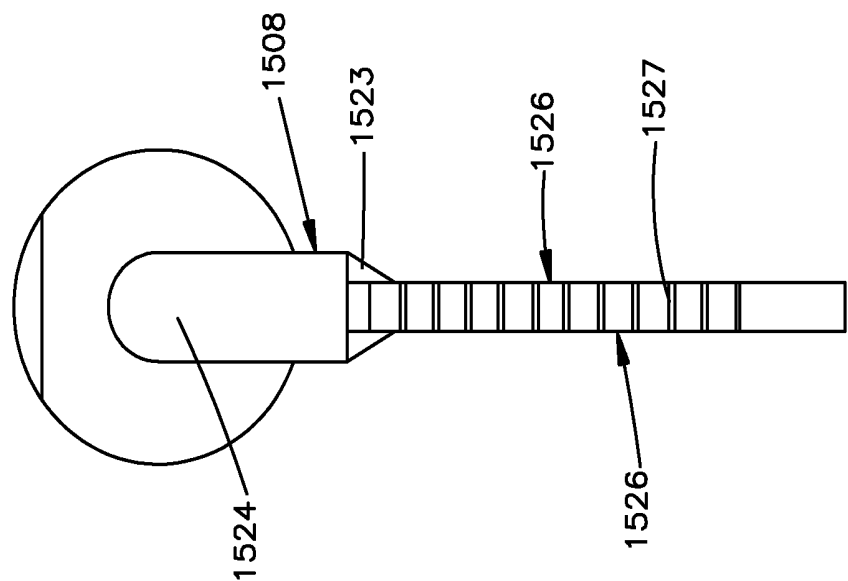


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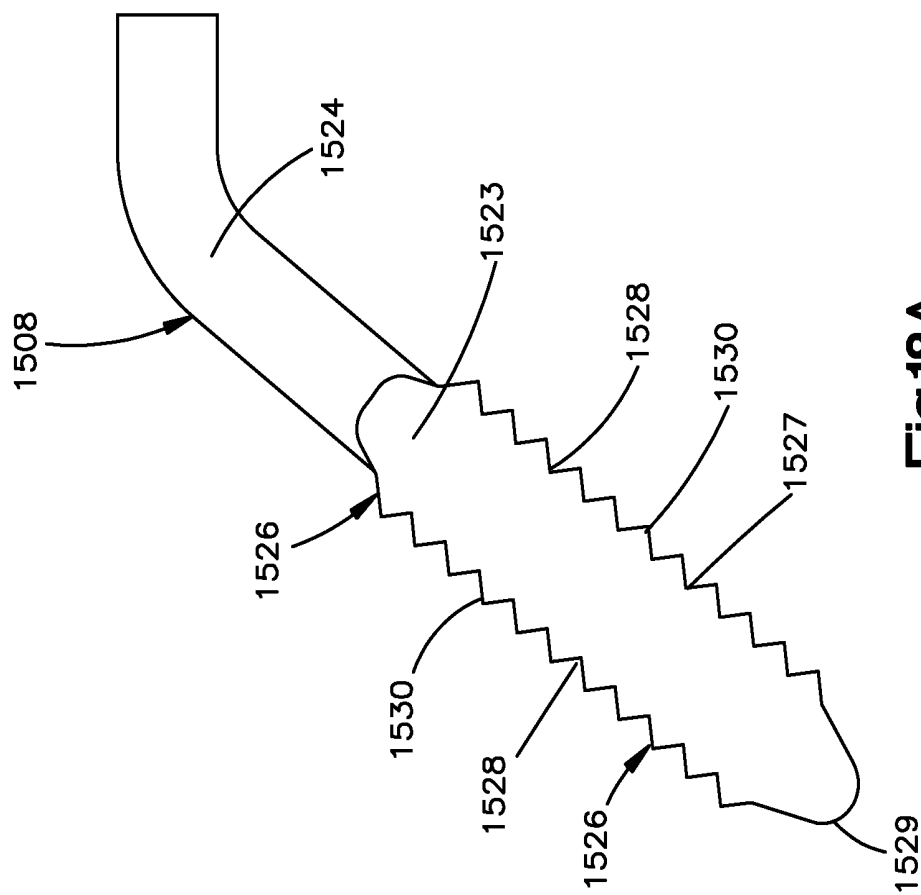


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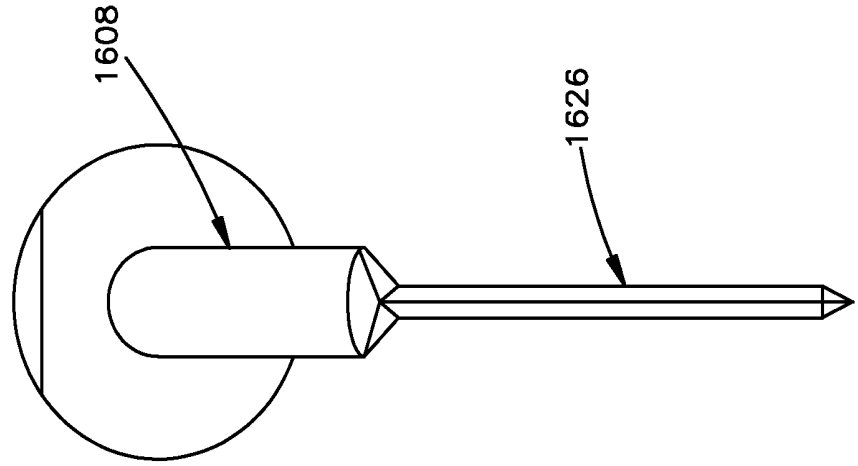


Fig.19B

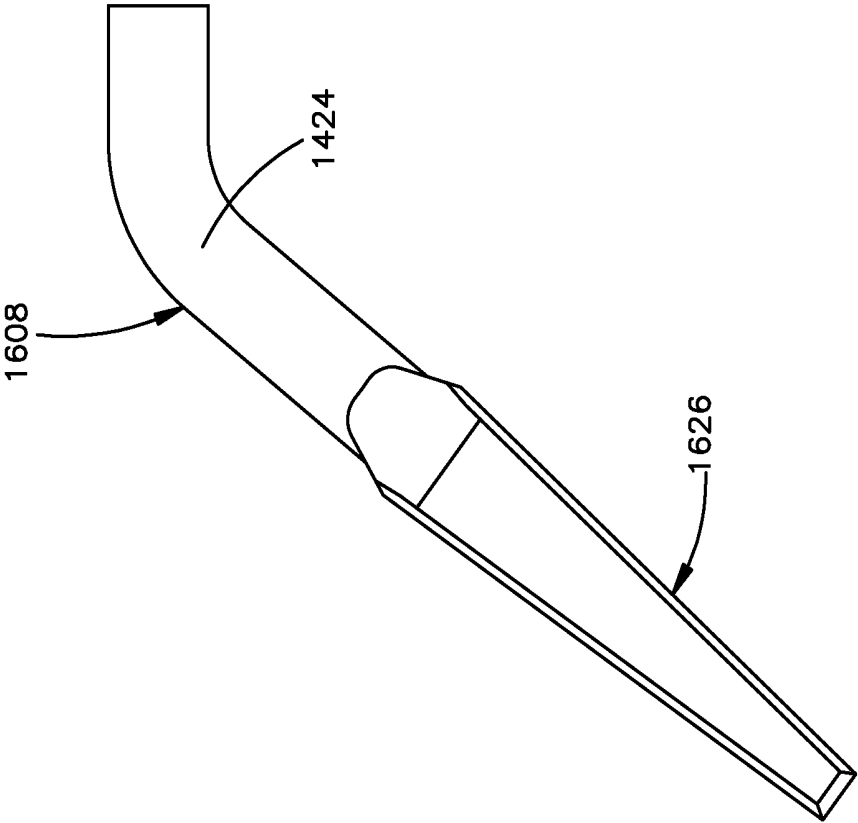


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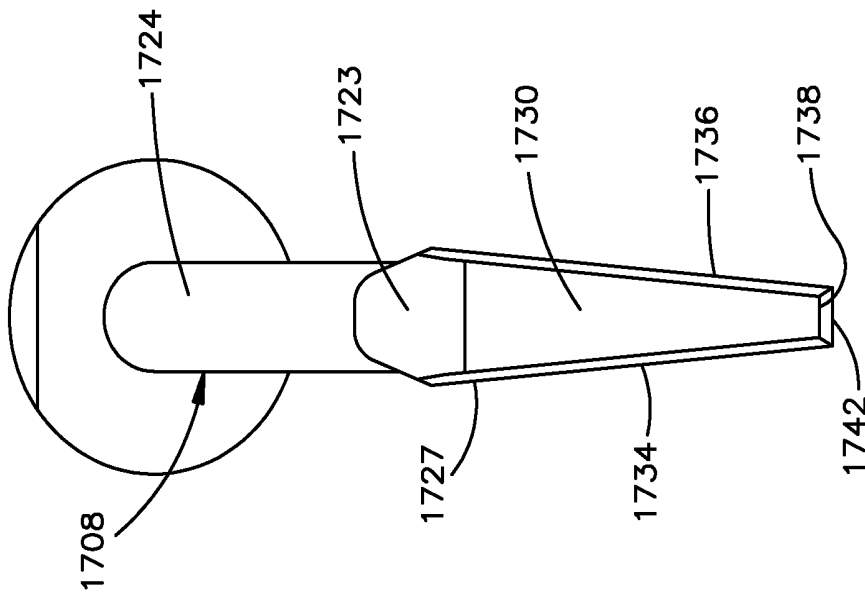


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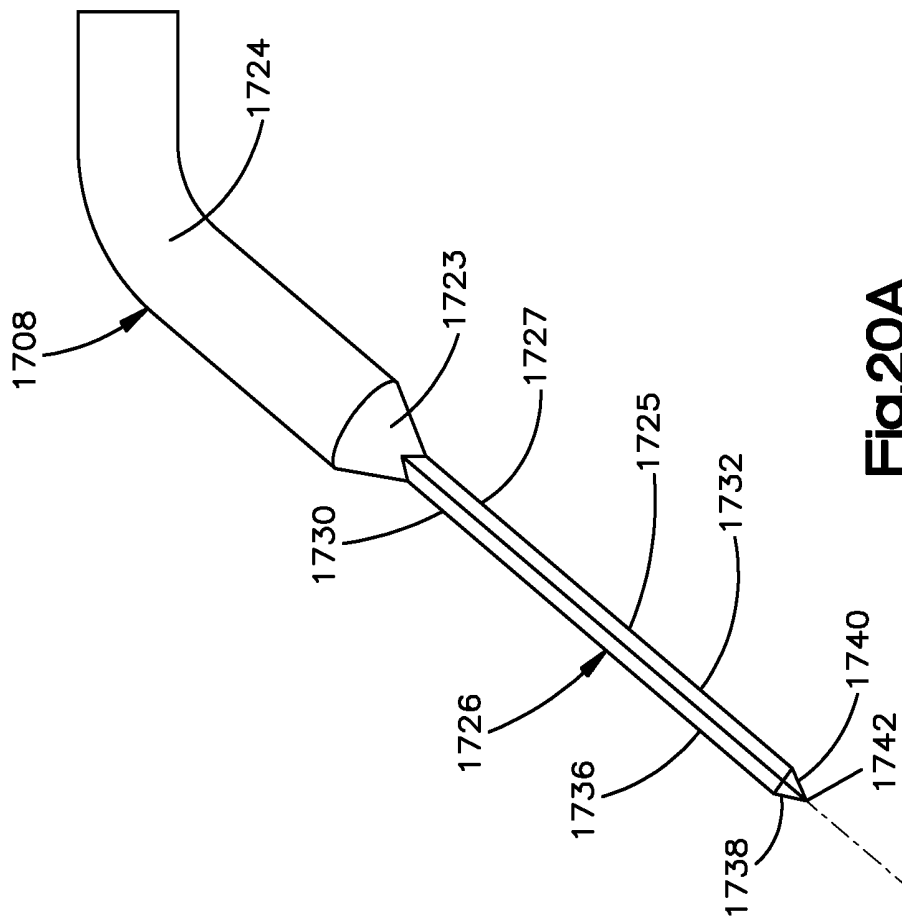


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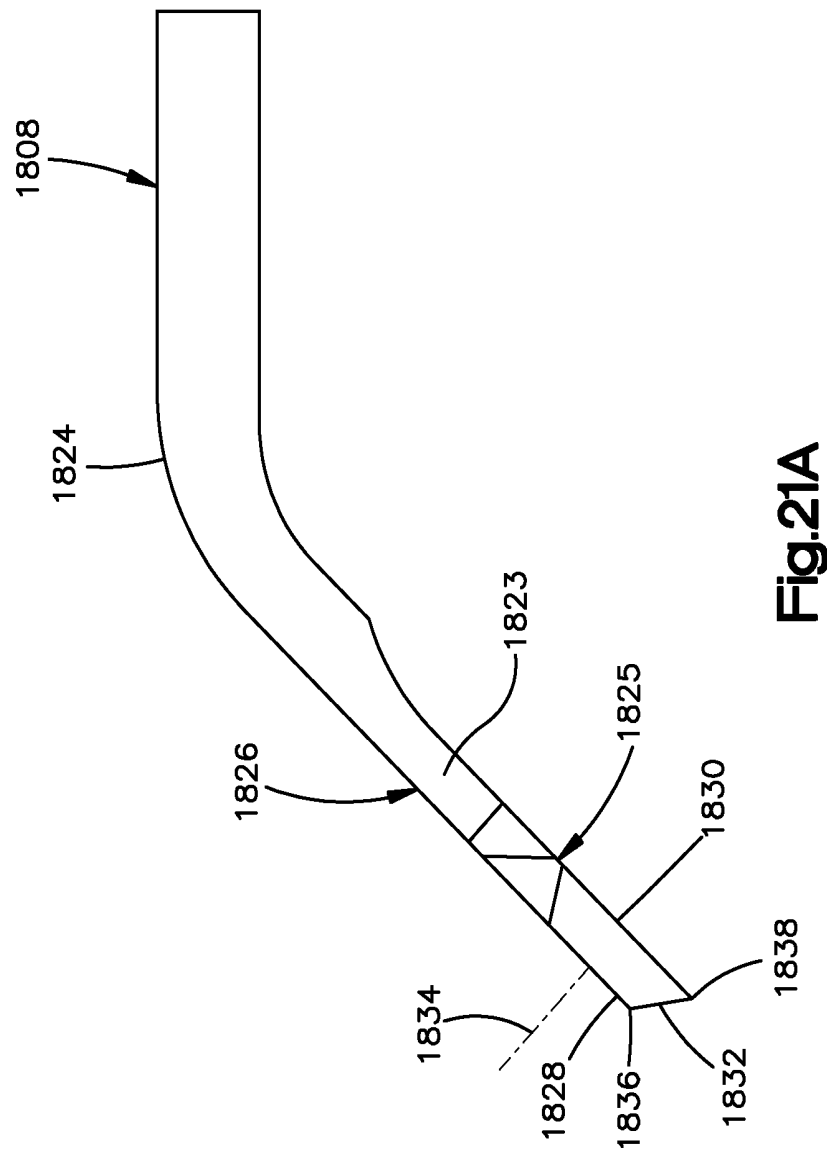


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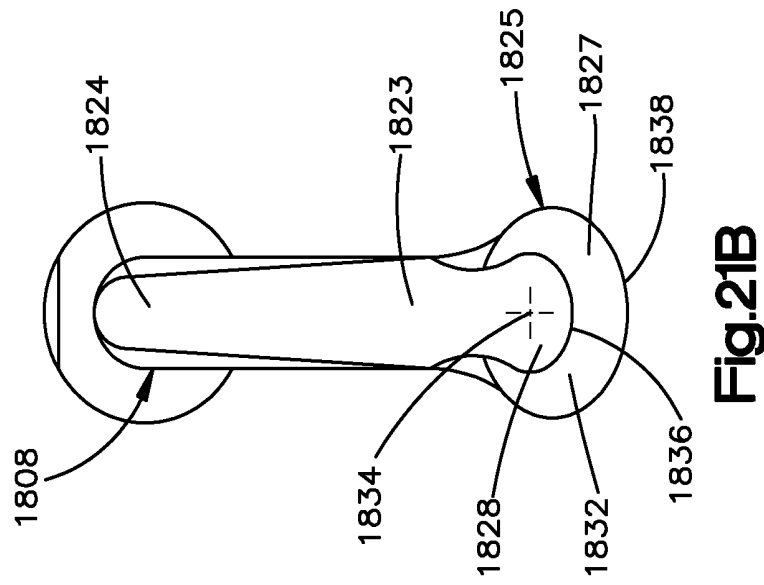


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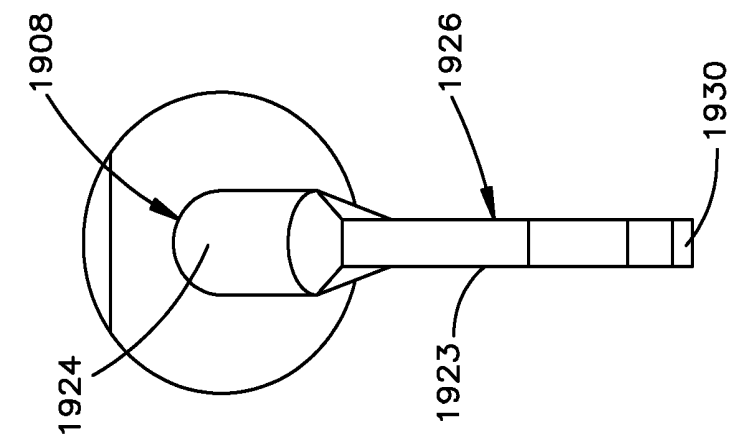


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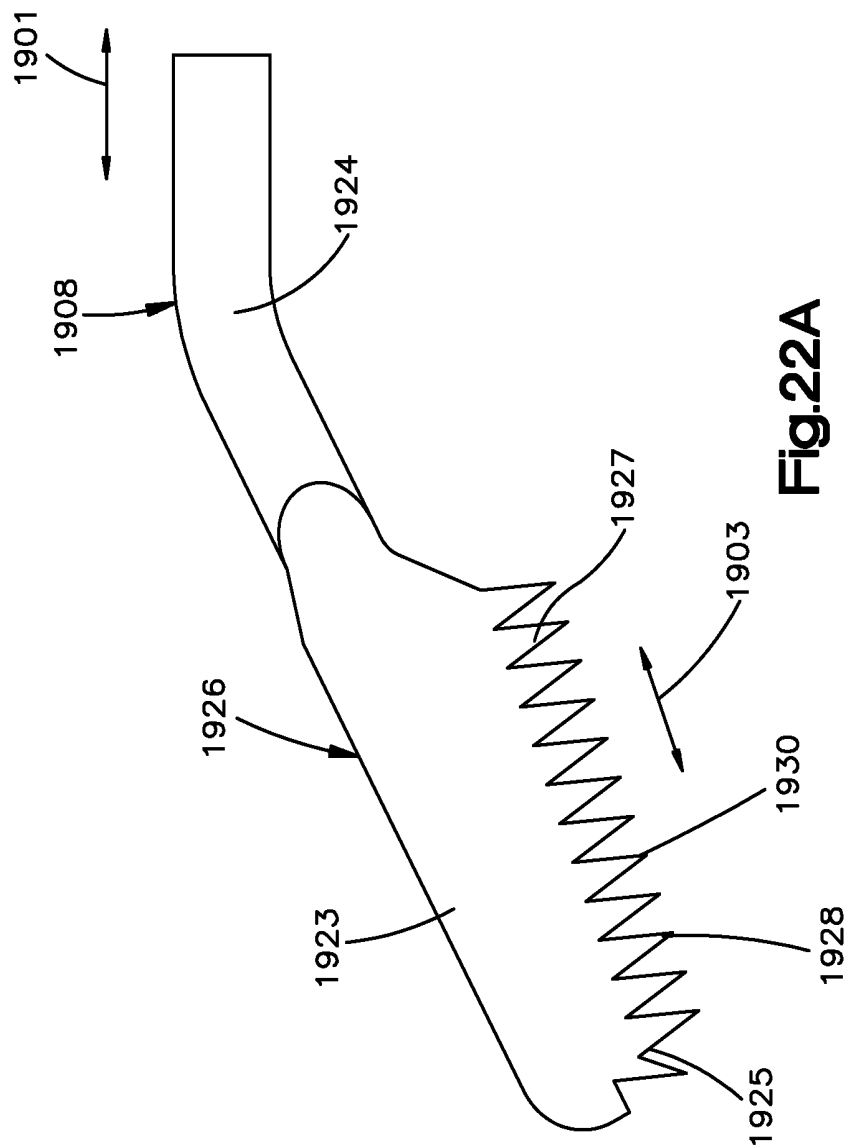


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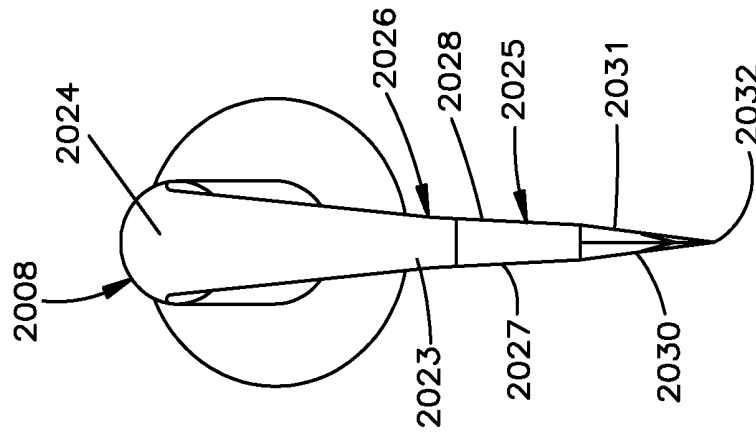


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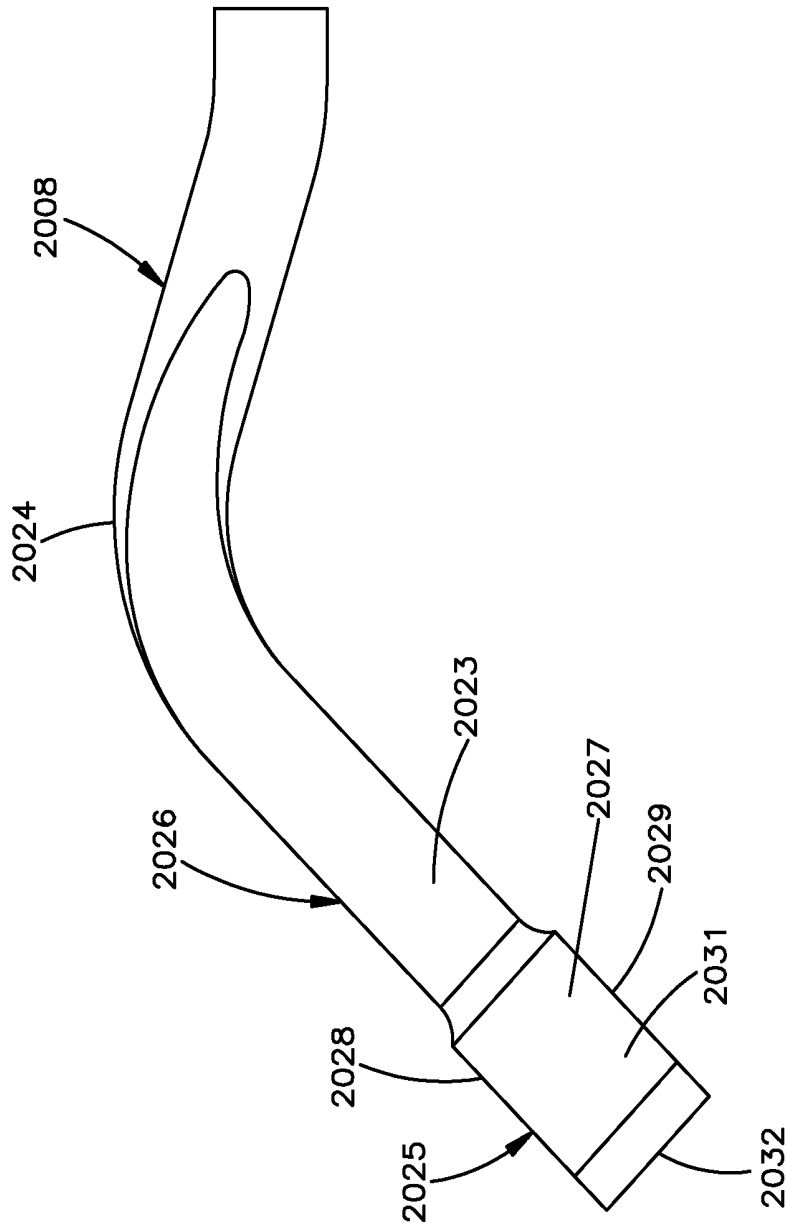


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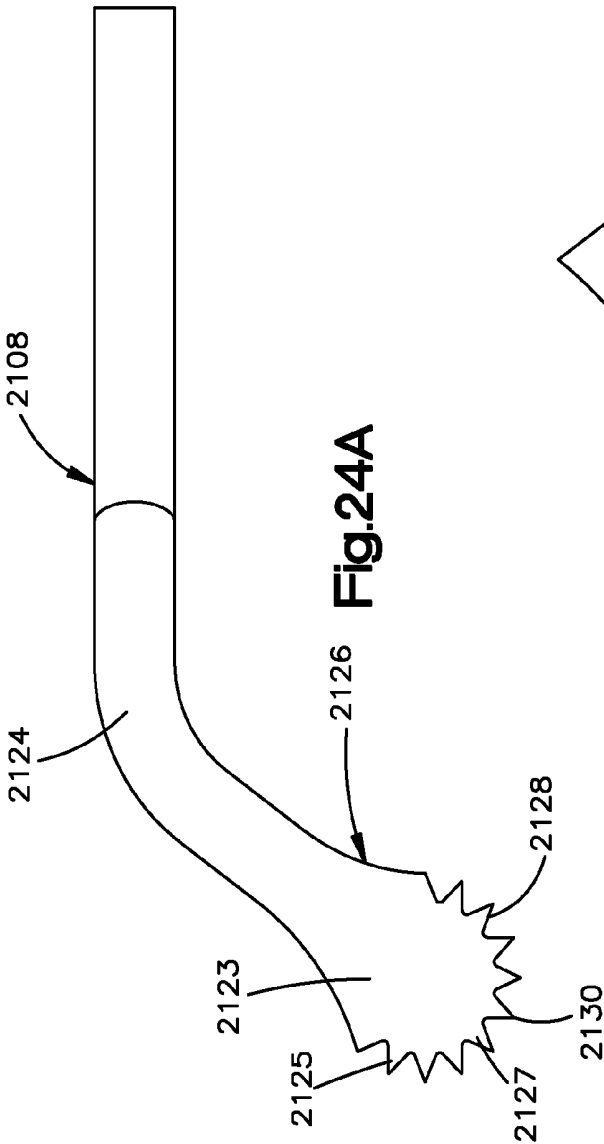


Fig. 24A

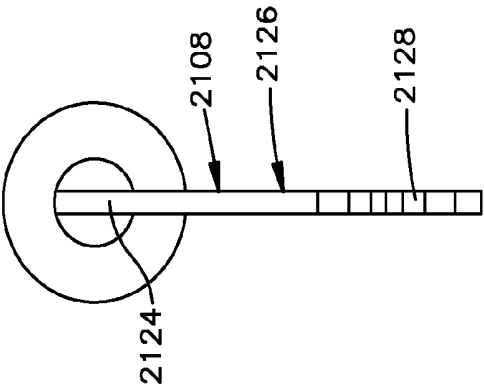


Fig. 24B

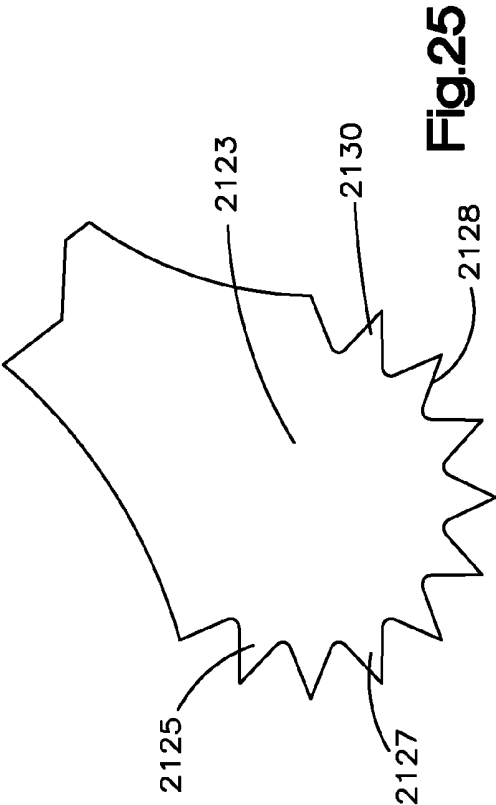
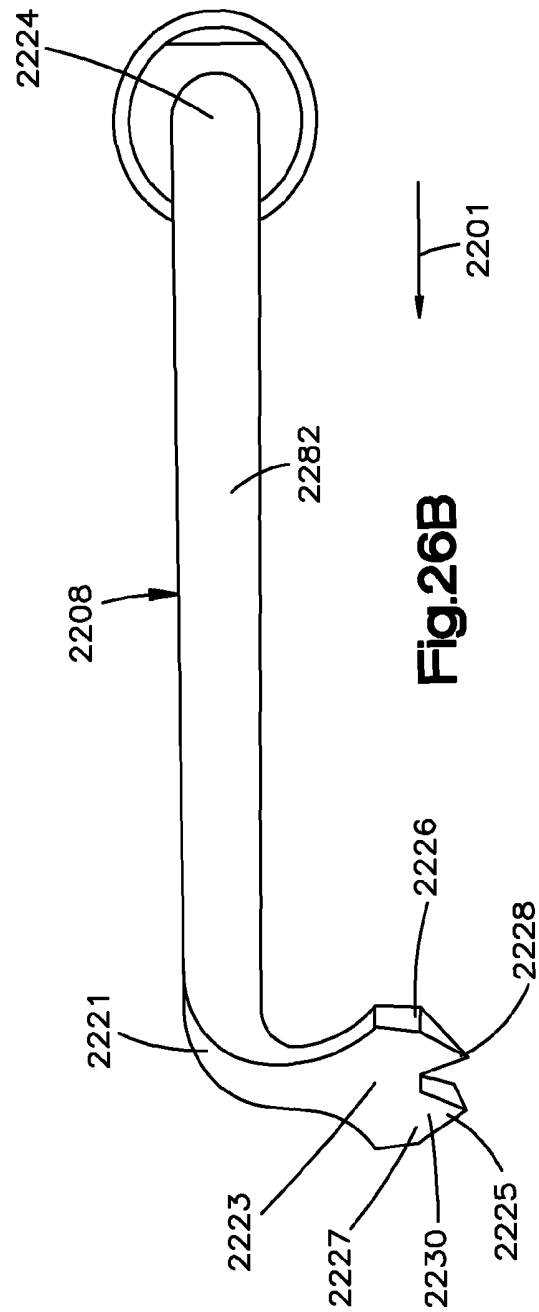
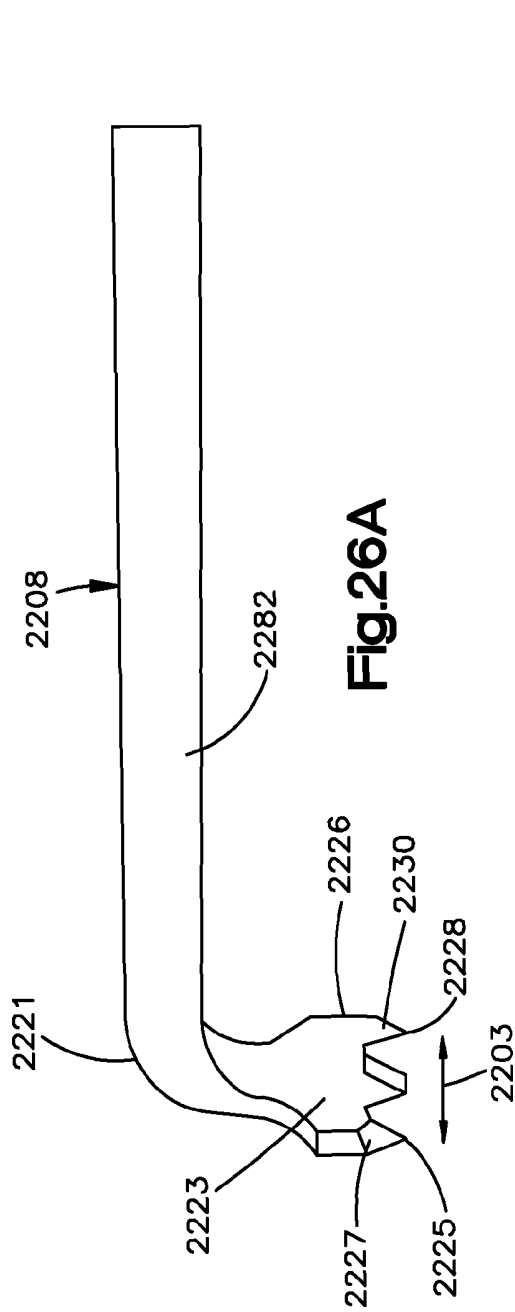
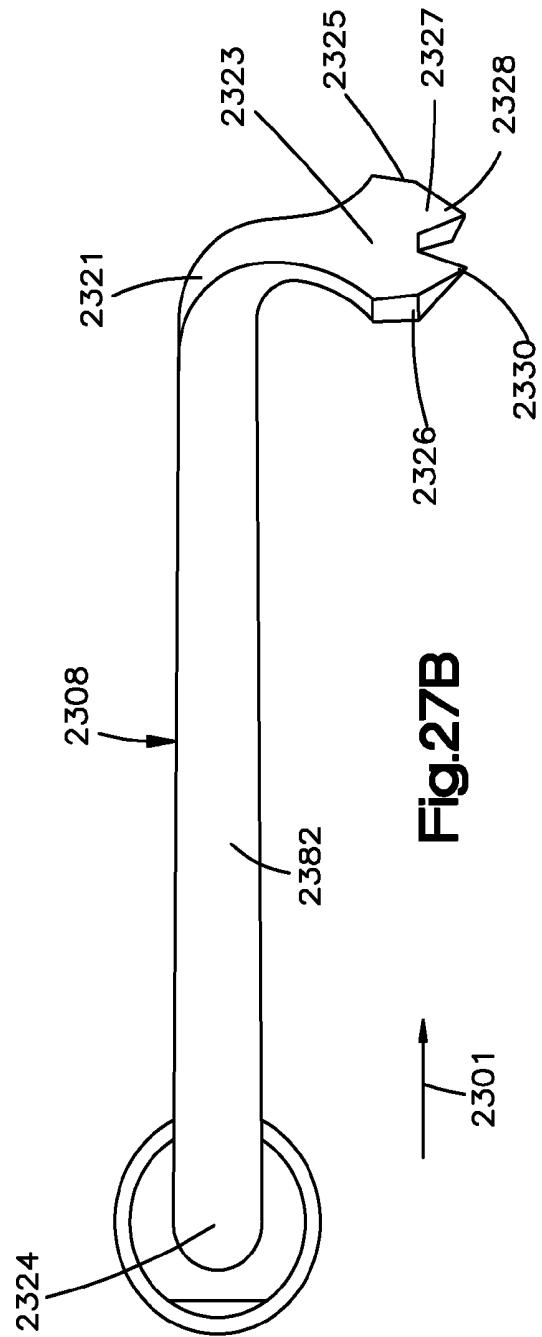
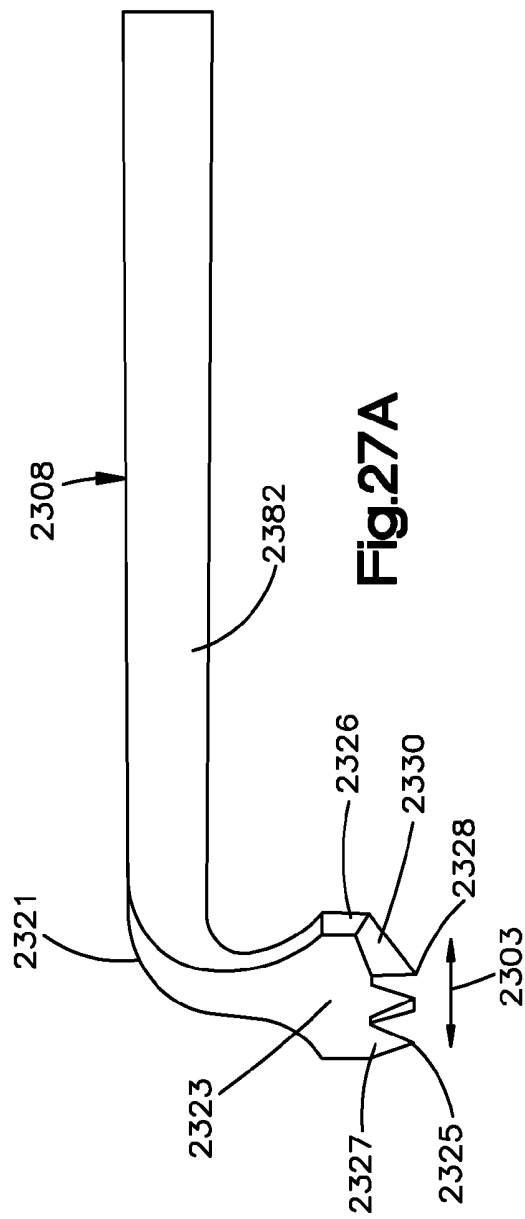
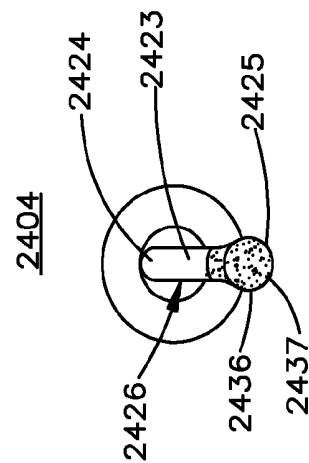
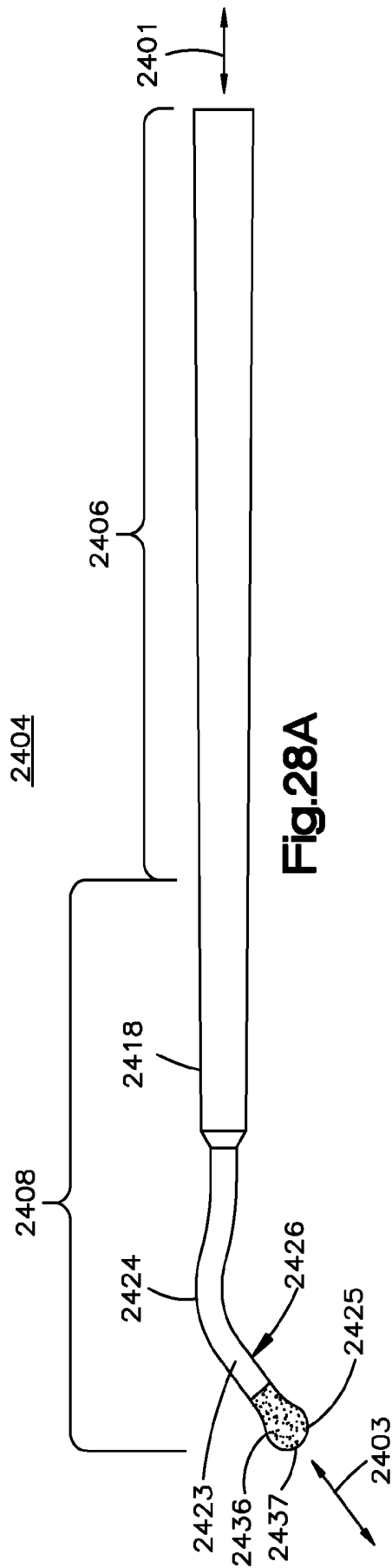
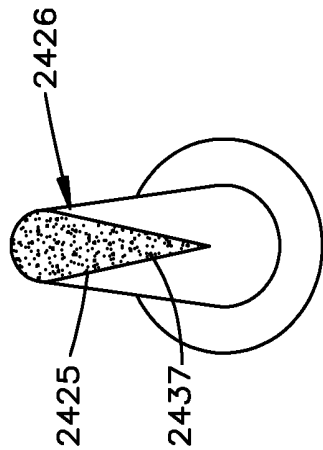
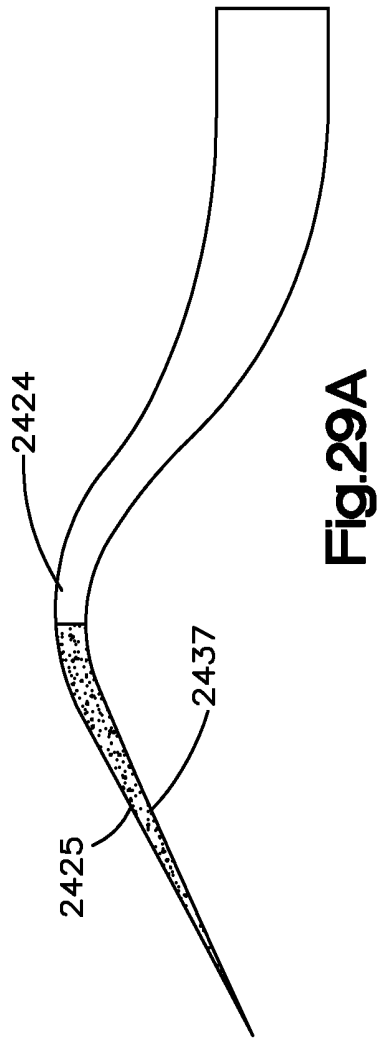


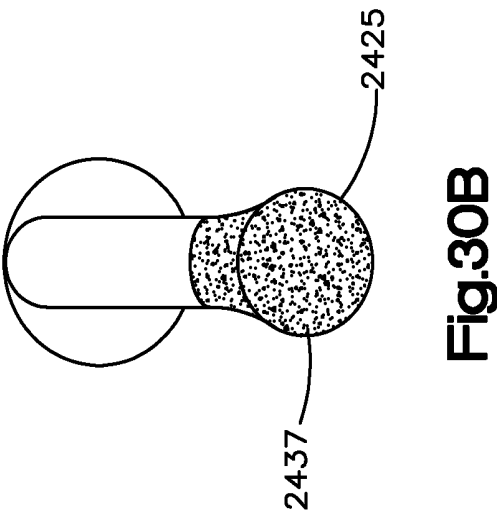
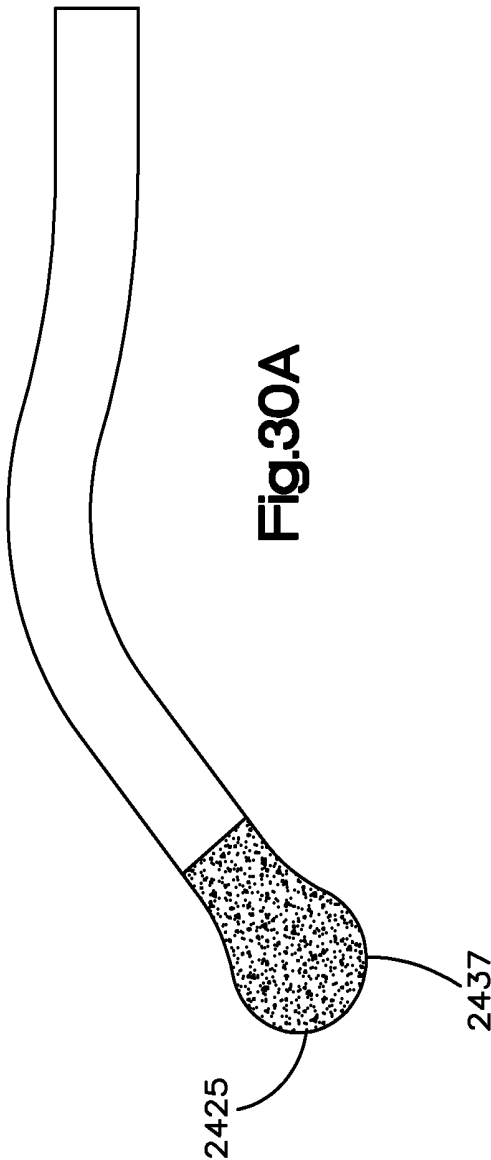
Fig. 25











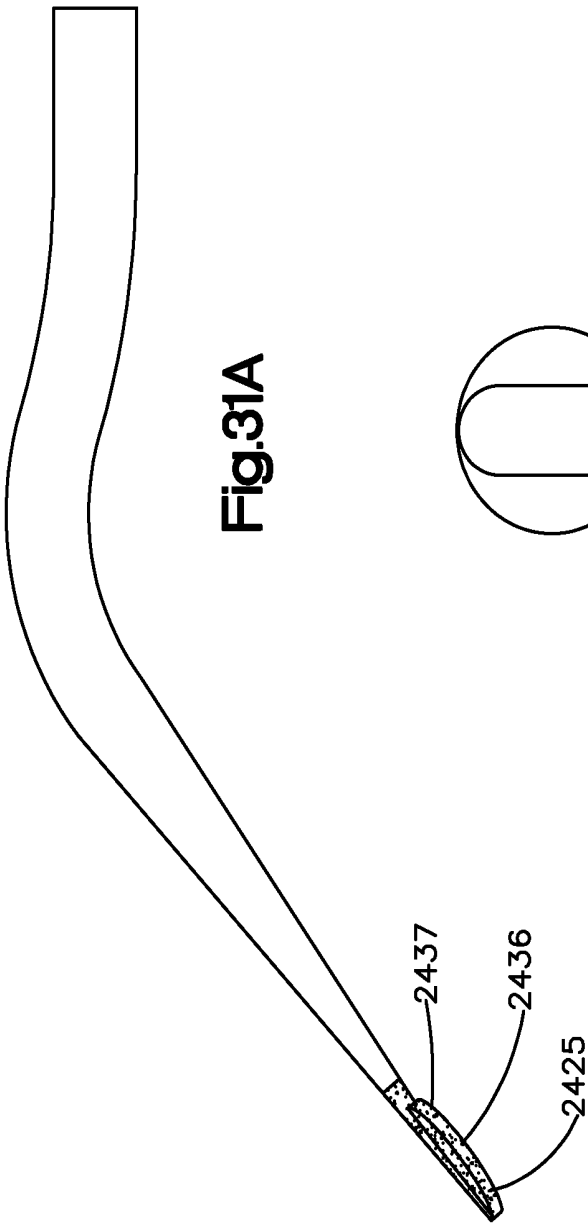


Fig. 31A

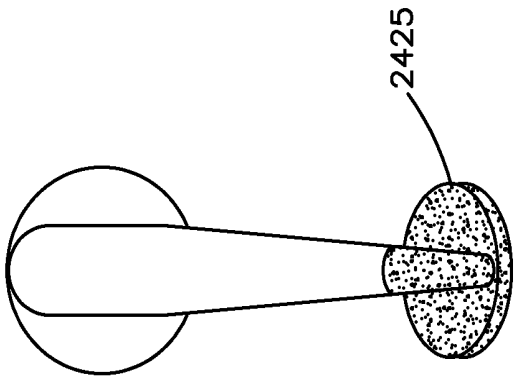


Fig. 31B

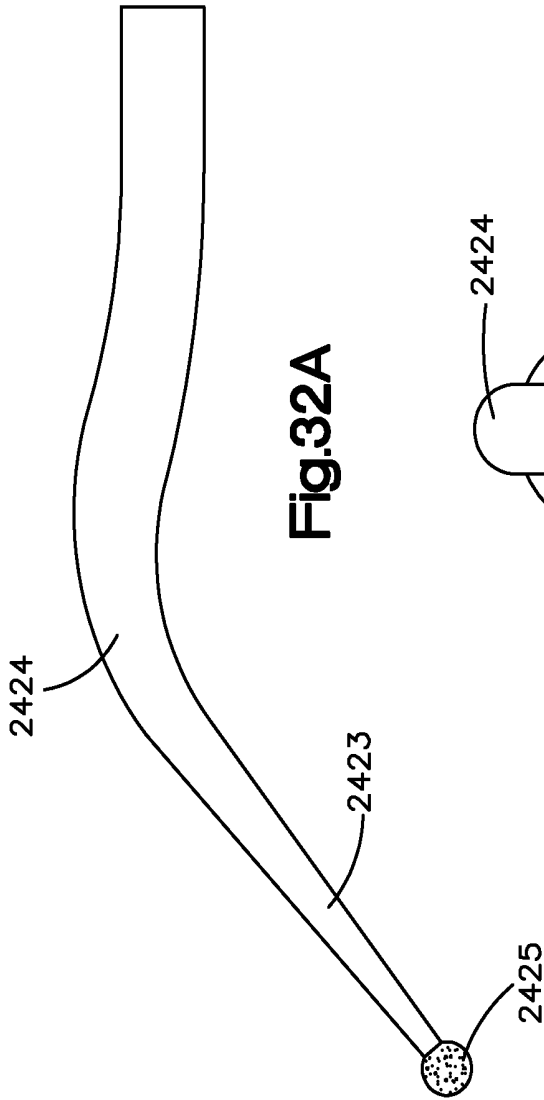


Fig. 32A

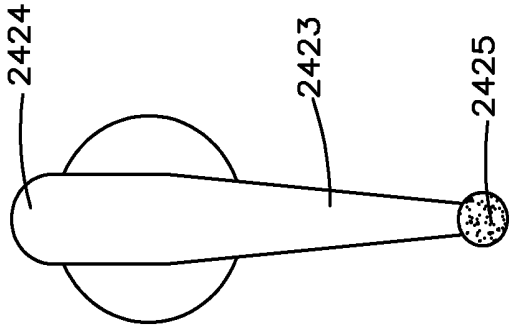
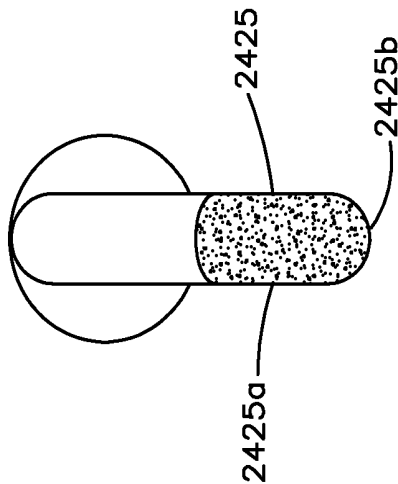
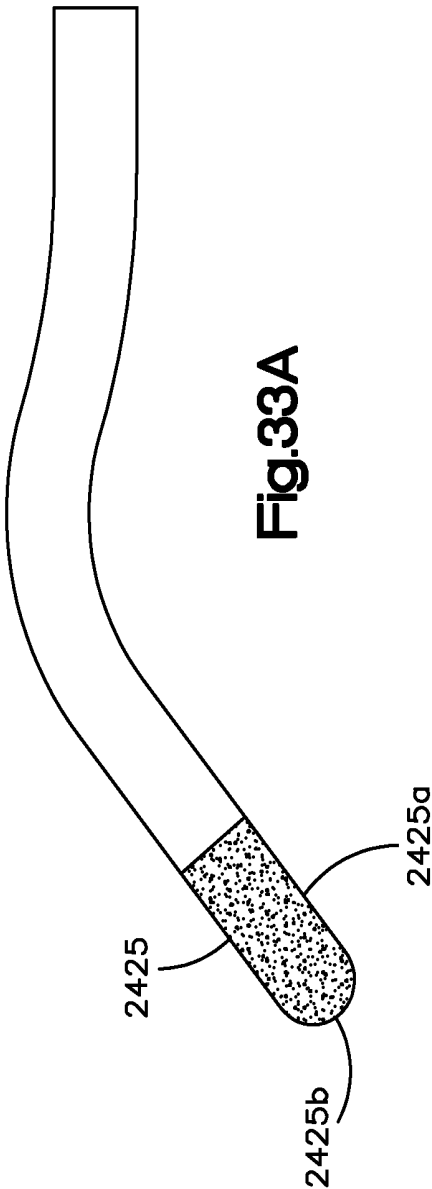


Fig. 32B



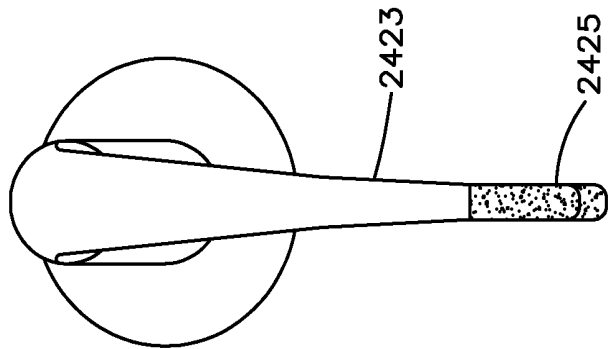


Fig.34A

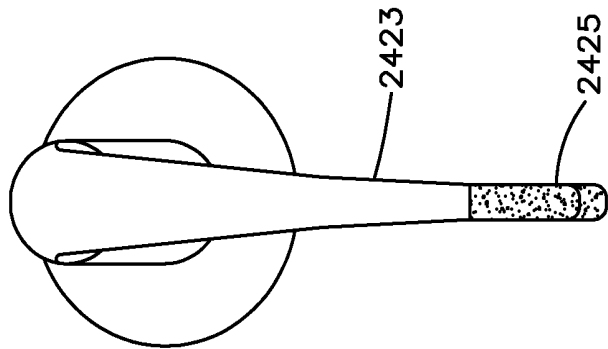


Fig.34B

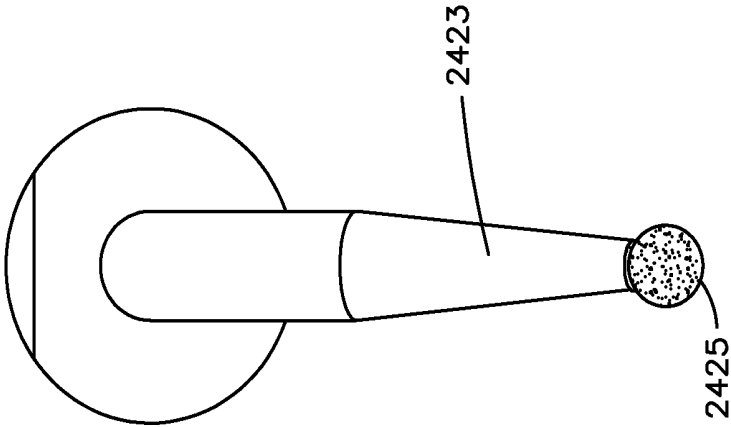


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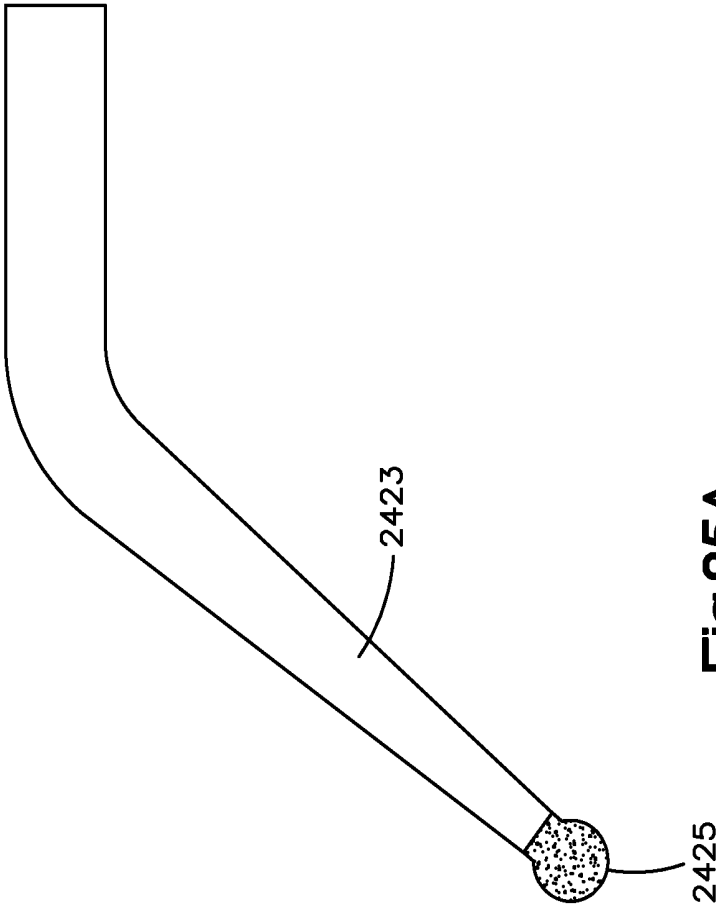


Fig.35A

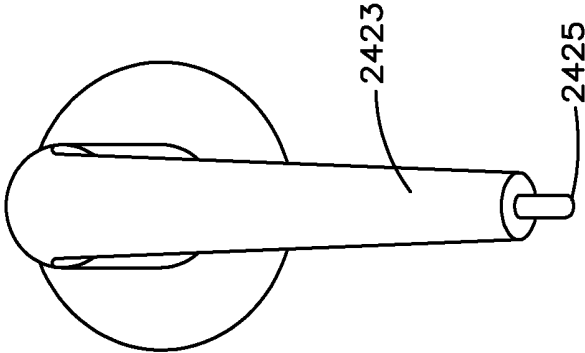


Fig.36B

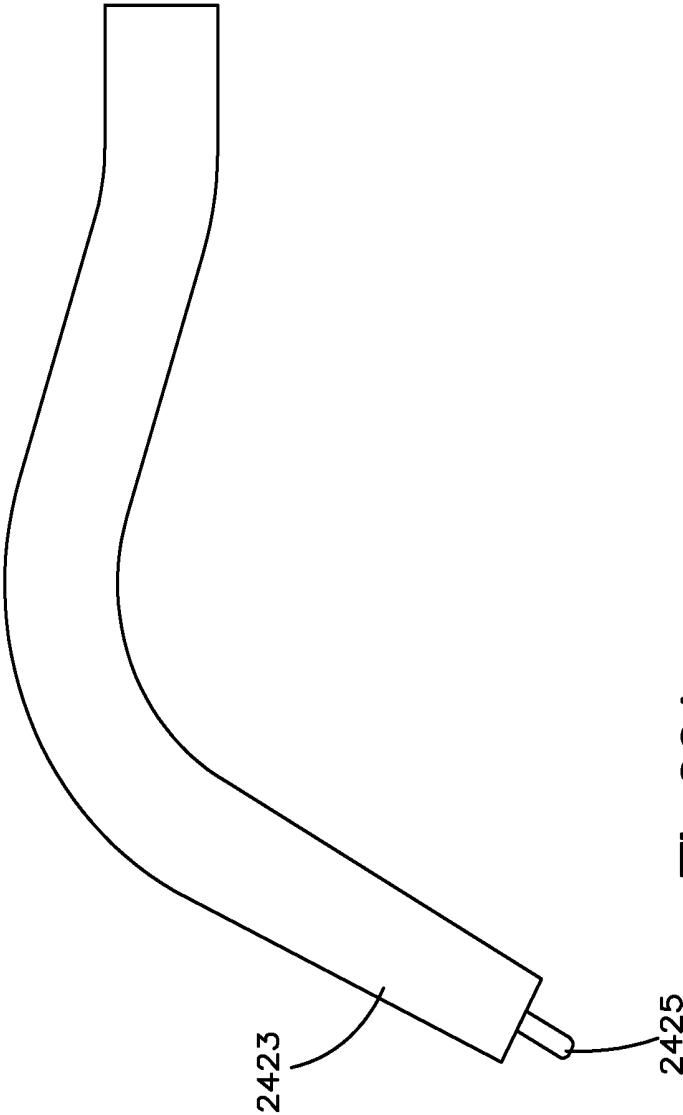


Fig.36A

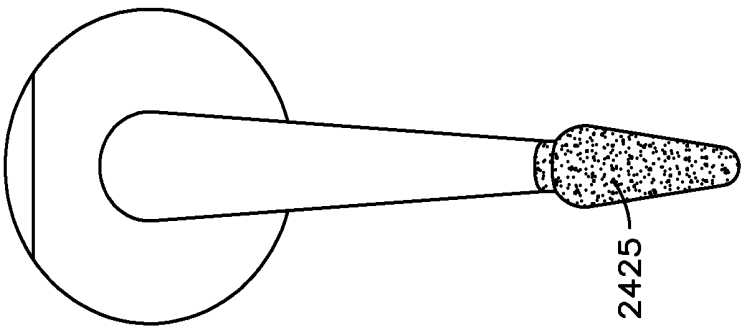


Fig.37B

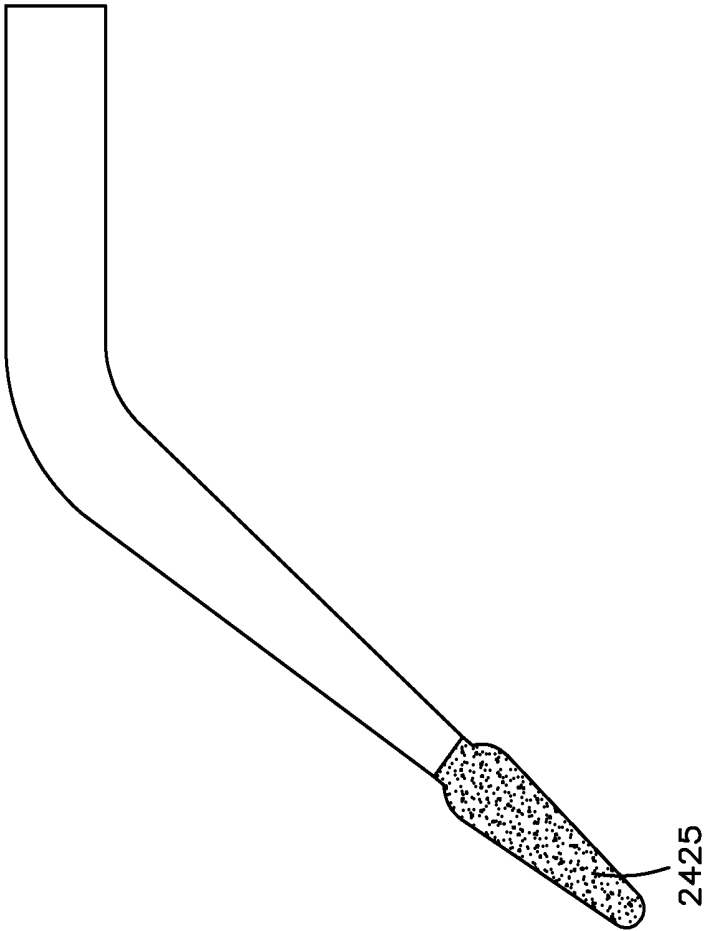


Fig.37A

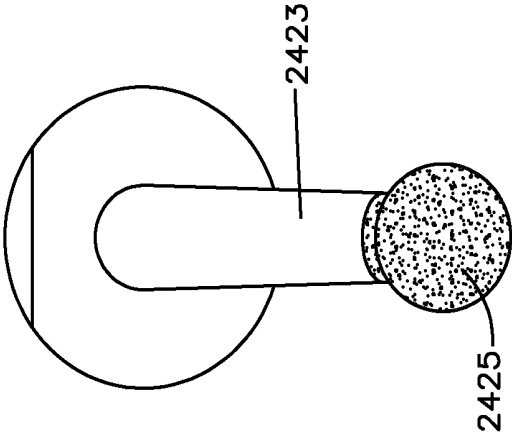


Fig.38B

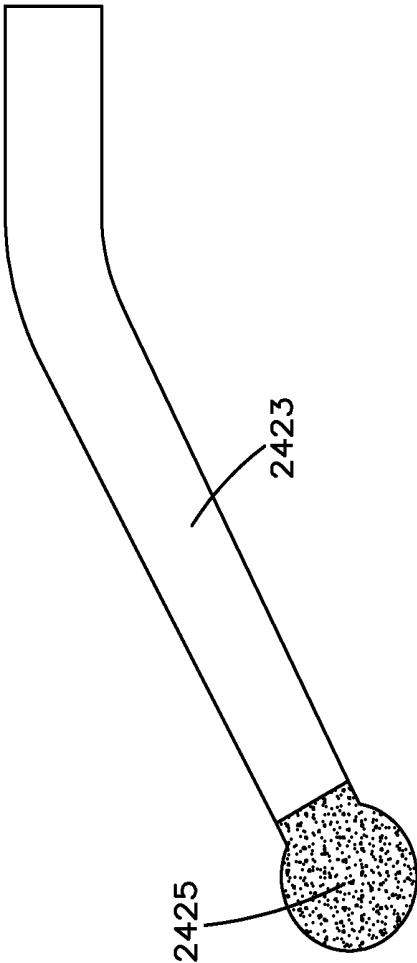


Fig.38A

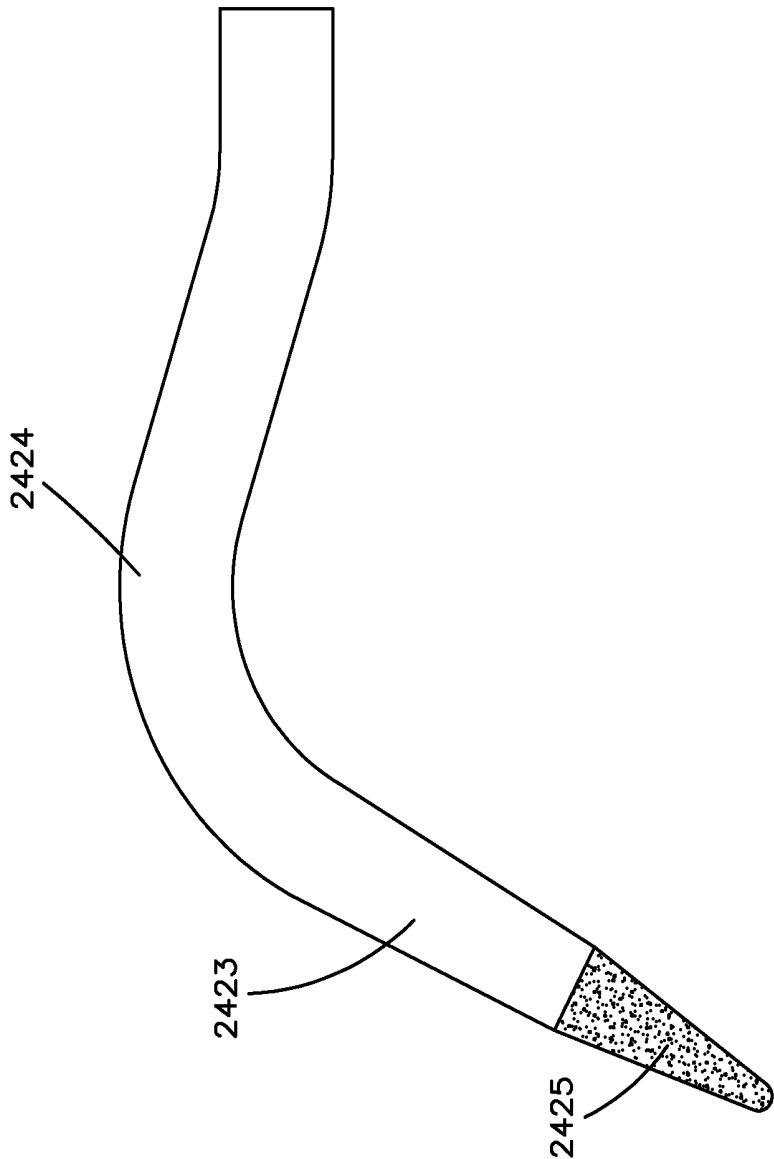


Fig.39A

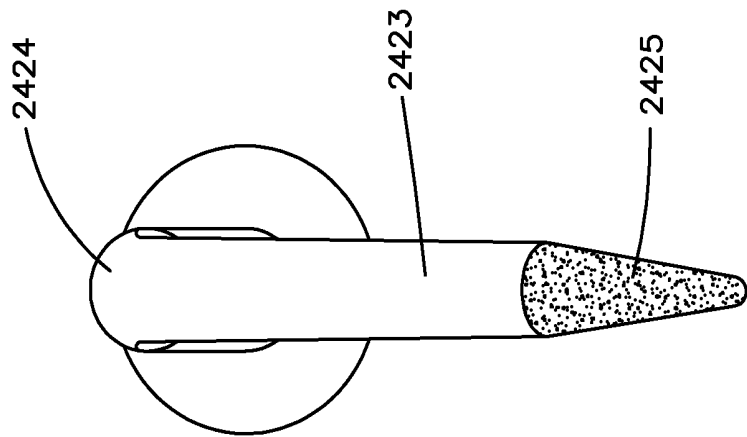


Fig.39B

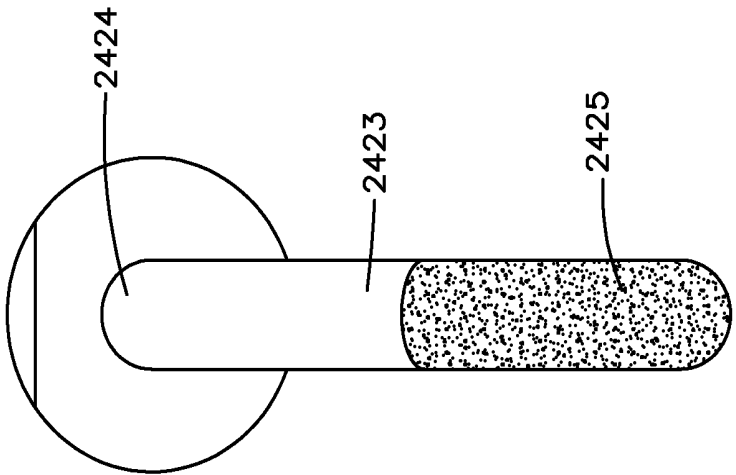


Fig.40B

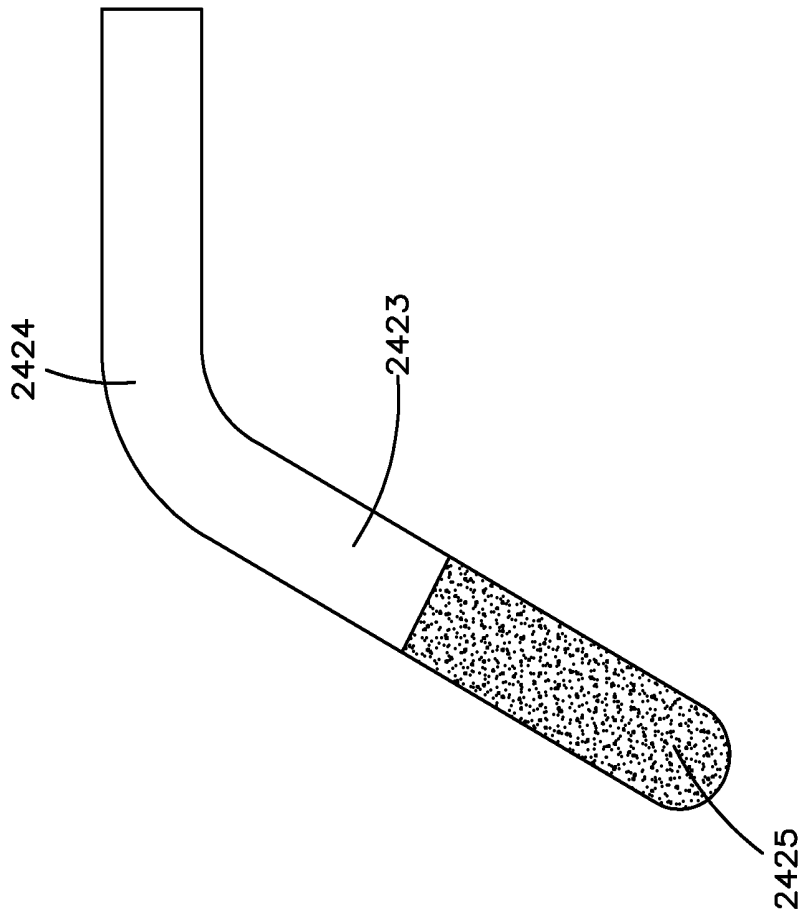


Fig.40A

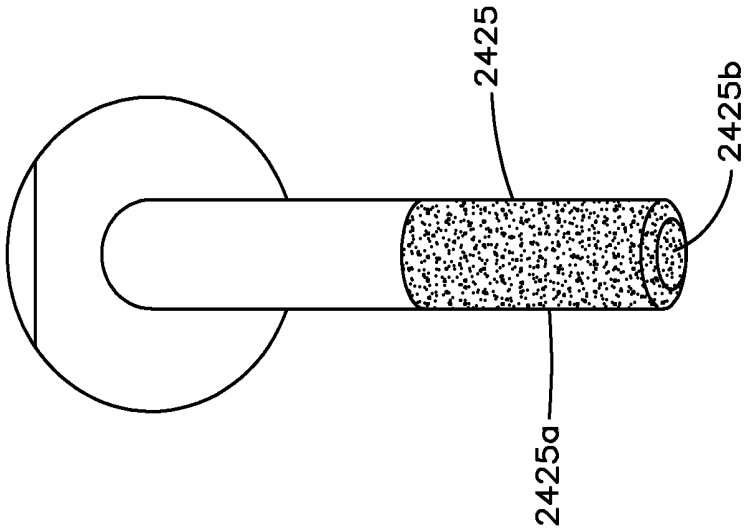


Fig. 41B

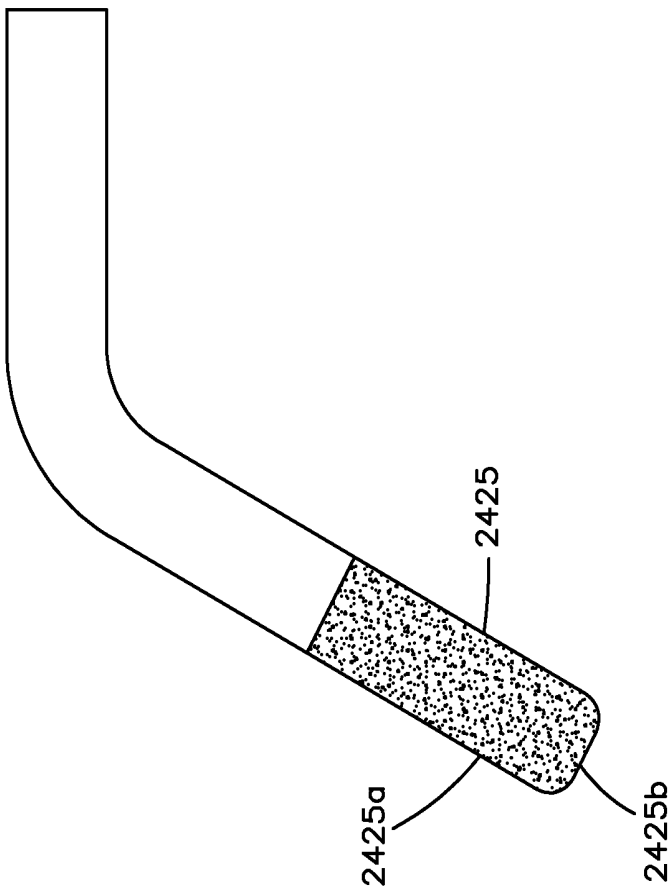


Fig. 41A

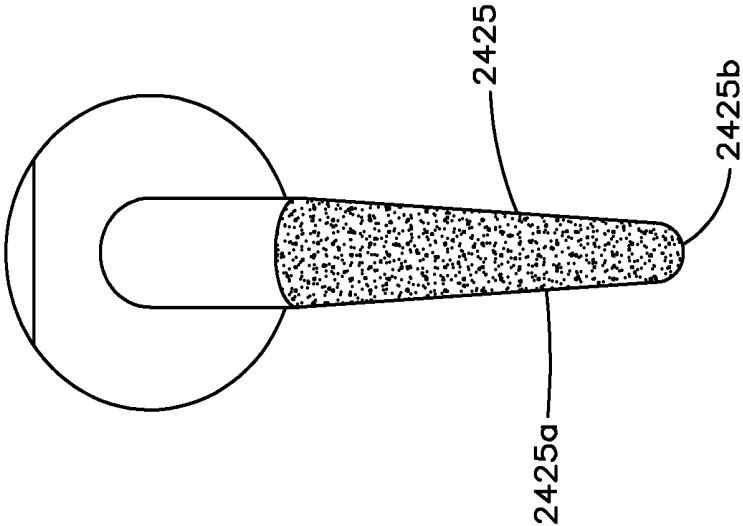


Fig. 42B

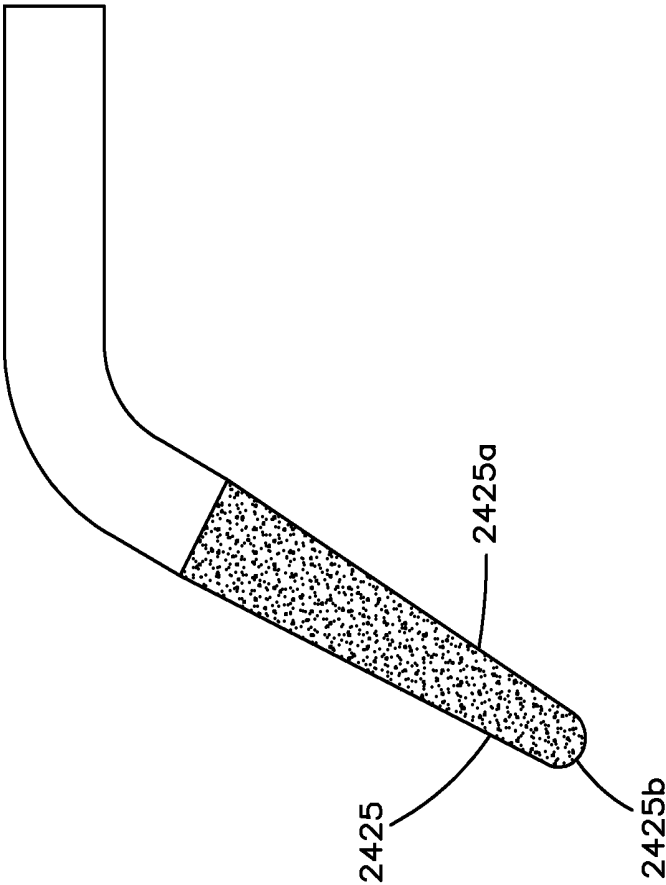


Fig. 42A

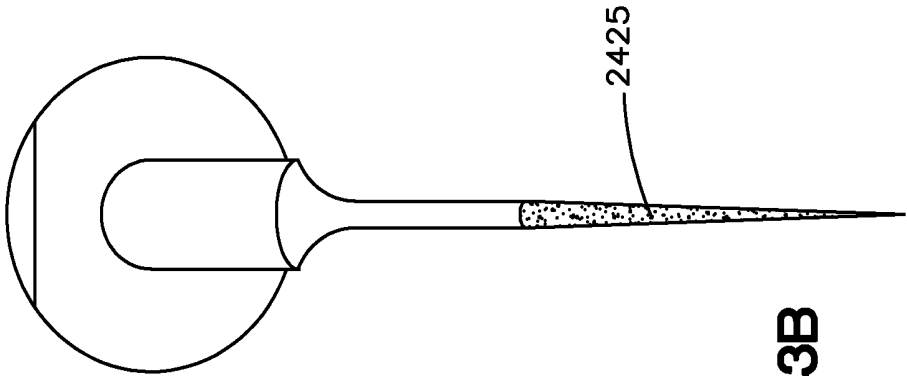


Fig. 43B

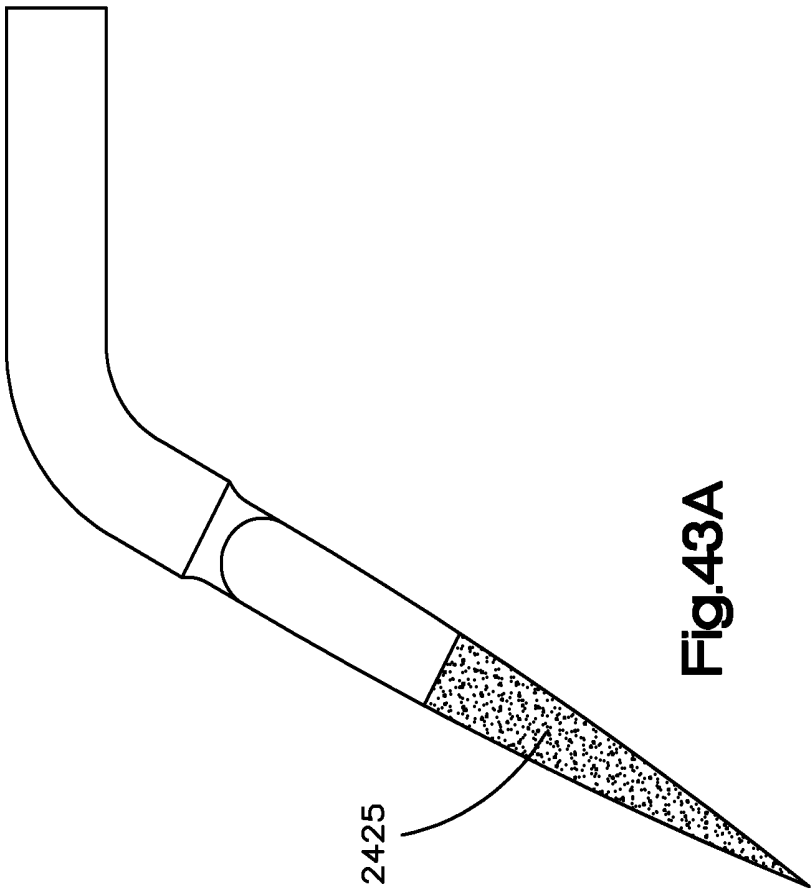


Fig. 43A

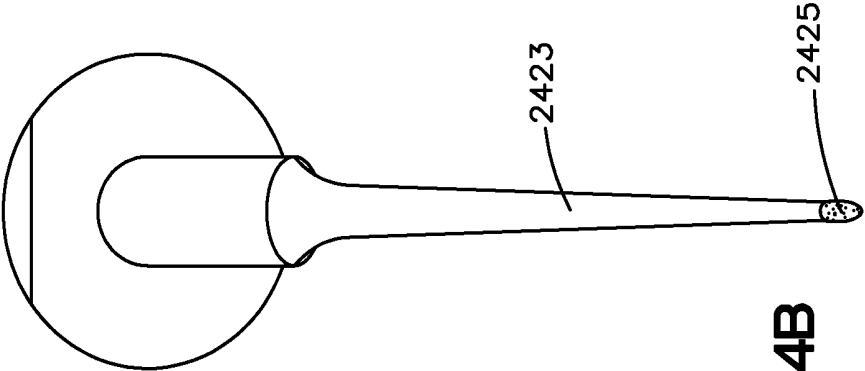


Fig. 44B

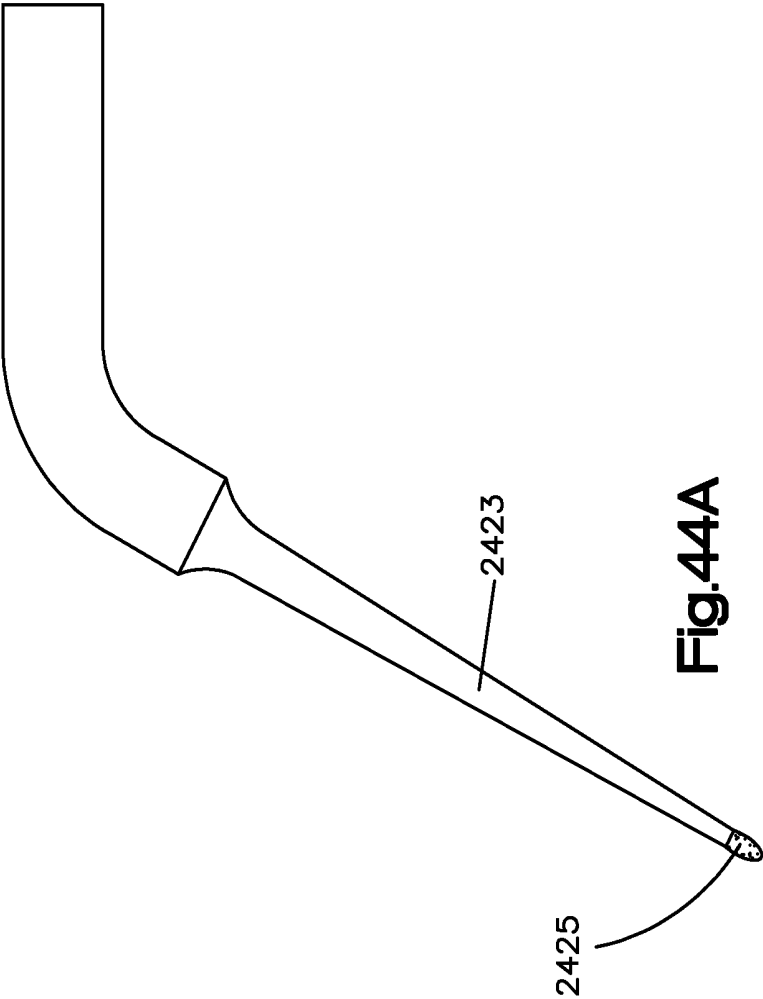


Fig. 44A

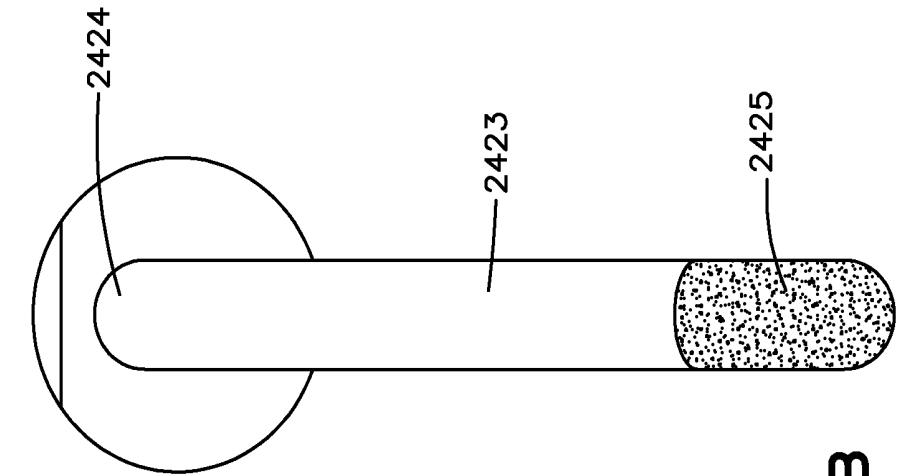


Fig. 45B

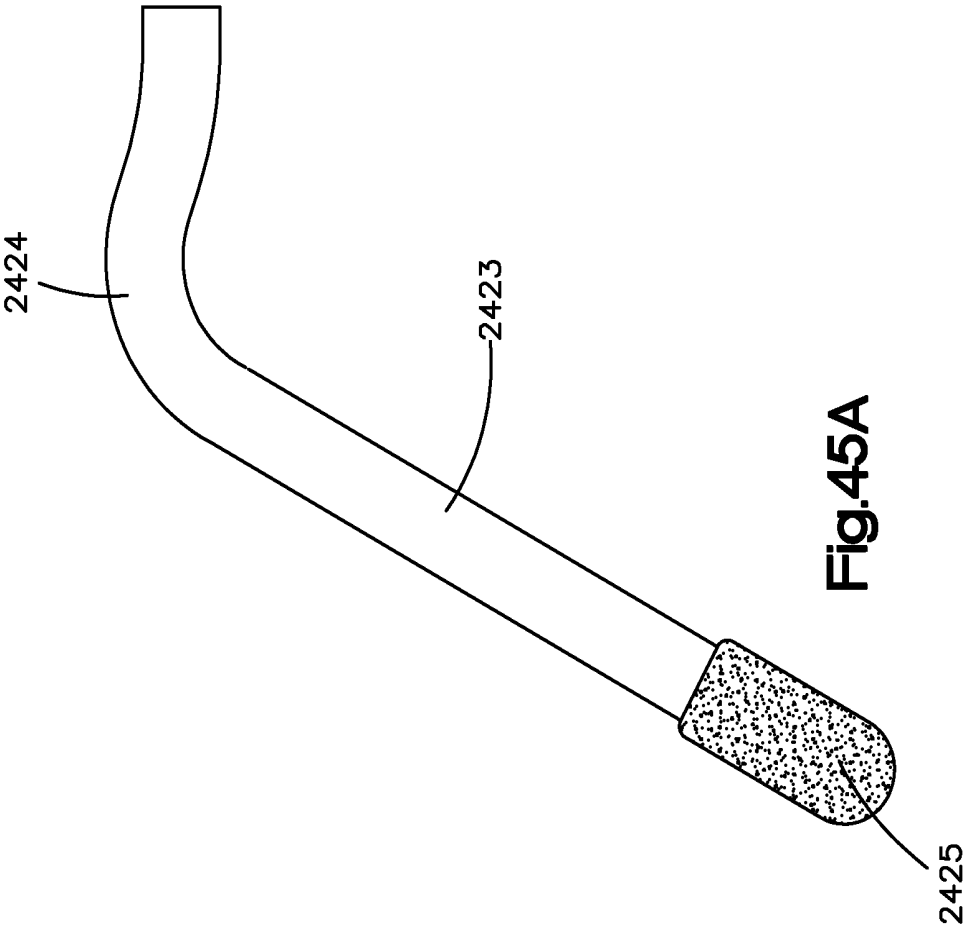


Fig. 45A

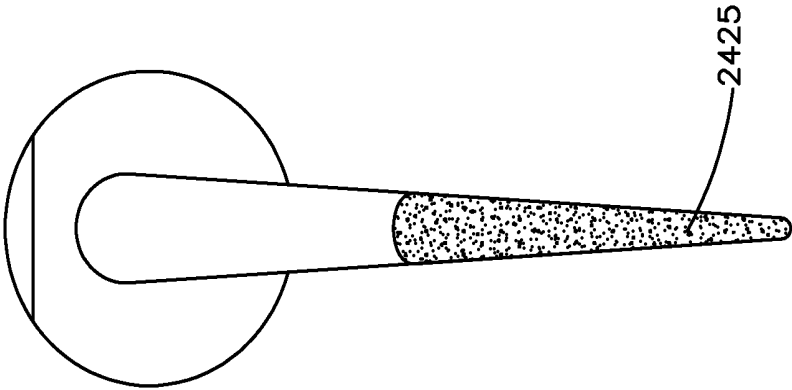


Fig. 46B

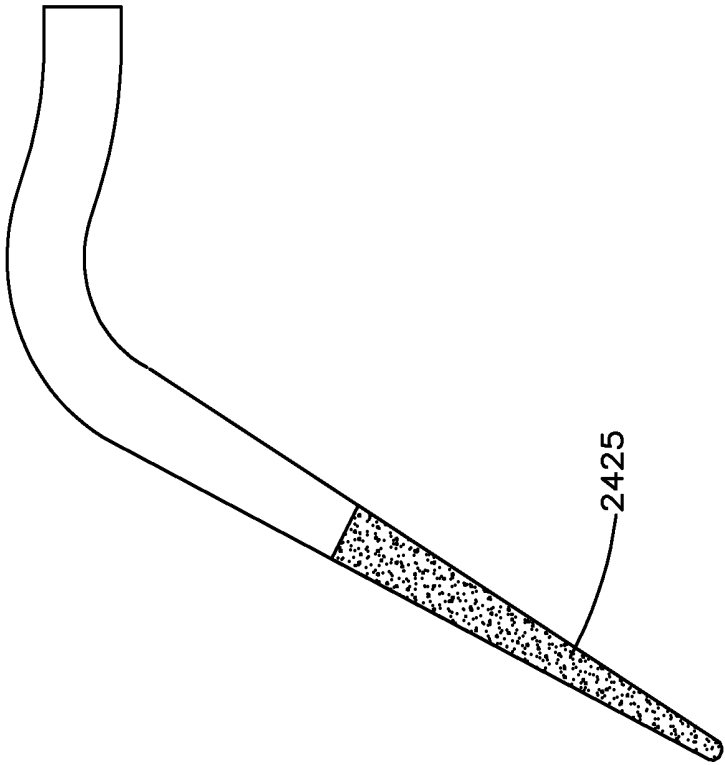


Fig. 46A

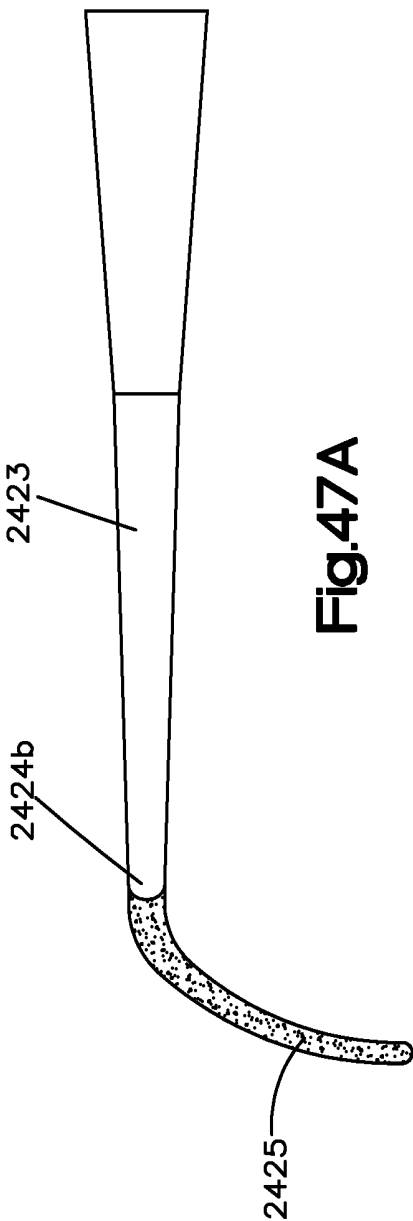


Fig. 47A

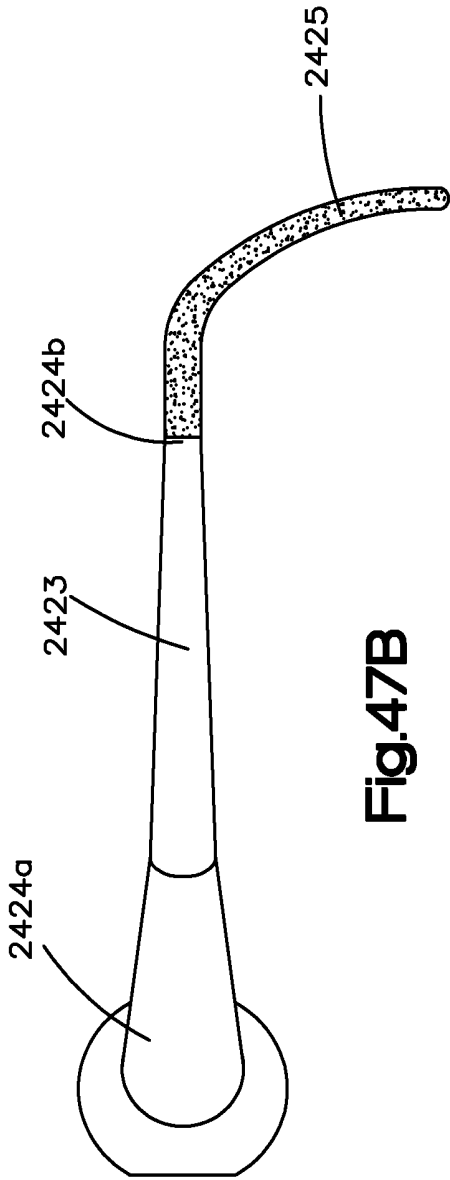


Fig. 47B

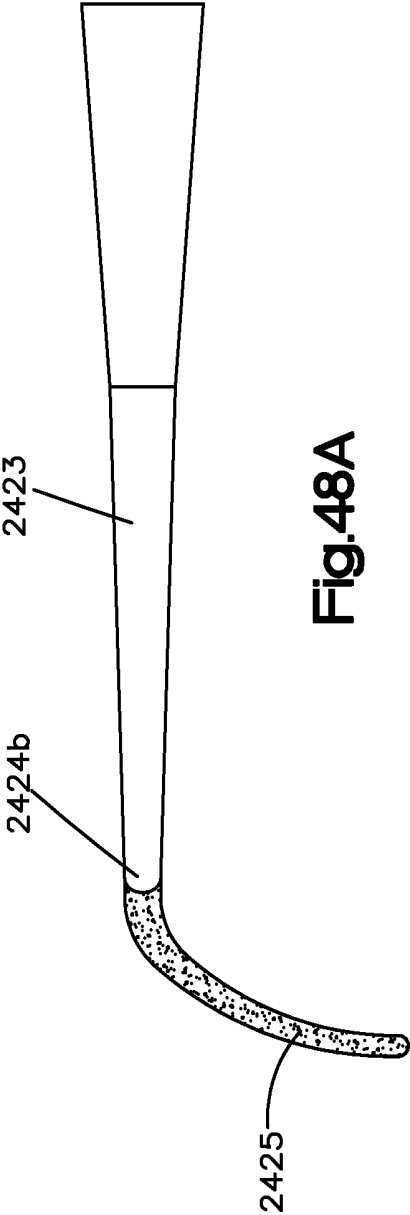


Fig. 48A

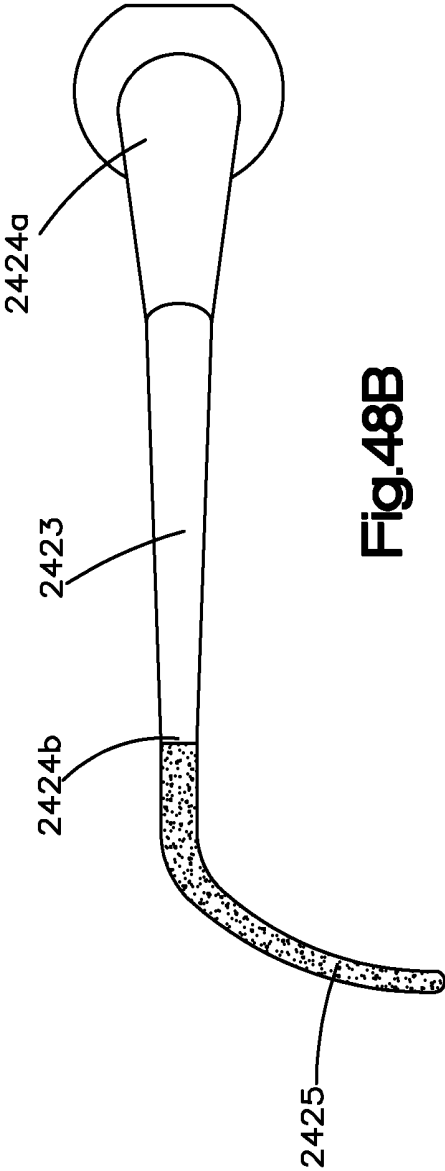


Fig. 48B

CUTTING TIPS FOR ULTRASONIC SURGICAL SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 61/594,616 filed Feb. 3, 2012, the contents of which is hereby incorporated by reference in its entirety herein.

FIELD OF THE INVENTION

The present disclosure relates to apparatus, systems, and methods for cutting tissue, and more particularly, to cutting tips for ultrasonic surgical systems.

BACKGROUND

Surgeons currently use, among other things, ultrasonic surgical systems for cutting, removing or shaping tissue or tissue substitutes during a surgical procedure. Ultrasonic surgical systems typically includes a transducer capable of converting electrical energy into mechanical vibrations and a tool mechanically coupled to the transducer. The transducer is conventionally made of a piezoelectric material, and the tool is typically made of stainless steel. The vibrations generated by the transducer travel along the tool until it reaches its tip. The tip of the tool is configured to cut, for instance shape or remove, tissue when it vibrates. Surgeons can contact the target tissue with the vibrating tip of the tool to cut, for instance shape or remove, said tissue.

Conventional tools of ultrasonic surgical systems have relatively short lengths in order to effectively transmit the mechanical vibrations generated by the transducers. It is desirable, however, to develop tools with relatively long lengths in order to allow the surgeon to employ minimally invasive techniques, to reach areas difficult to access and to increase the chances of a safe surgery. It has been found that simply elongating stainless steel may affect the ability of the tool to transmit vibrations effectively. For instance, elongating a stainless steel tool can increase the weight of the tool, which in turn would require additional power to vibrate. This increase in power can in turn overheat the piezoelectric ceramic elements, causing reduced acoustic performance and reliability.

In view of the drawbacks of the conventional tools described above, it desired to develop a tool for an ultrasonic surgical system capable of effectively transmitting vibrations generated by a transducer without comprising acoustic performance and reliability.

SUMMARY

In accordance with one embodiment, a tool can include a first section configured to be coupled to a transducer assembly, and a second section coupled to the first section. The first section at least partially includes a first material. The second section at least partially includes a second material that is different from the first material and denser than the first material. The second section includes a cutting member that is configured to vibrate at a predetermined frequency so as to cut a tissue body an operative portion.

According to an embodiment, the cutting member of the tool is configured to vibrate at a cutting member amplitude that ranges between about 300 percent to about 500 percent of a transducer assembly amplitude of the vibration pro-

duced by the transducer assembly when the first section is coupled to the transducer assembly and the transducer assembly is activated.

According to an embodiment, the tool includes a first end and a second end, and defines a length that extends from the first end to the second end in a longitudinal direction. The length of the tool is greater than about 80 millimeters.

According to an embodiment, the length of the tool ranges between about 20 millimeters and about 120 millimeters.

According to an embodiment, the length of the tool is about 105.7 millimeters.

According to an embodiment, the first material is a titanium alloy.

According to an embodiment, the second material is stainless steel.

According to an embodiment, the first section is elongated along a first axis, and the second section includes an elbow, such that at least a portion of the second section is elongated along a second axis. The second axis is oriented at an oblique angle with respect to the first axis.

According to an embodiment, the cutting member could include a serrated edge, a scalpel-like end, diamond ball end, or scraper.

According to an embodiment, the second section further comprises a support body, and the cutting member further comprises teeth that protrude outward from the support body.

According to an embodiment, the cutting member has a substantially spherical shape.

According to an embodiment, the cutting member defines at least one cutting surface, and further comprises a coating that covers at least a portion of the at least one cutting surface.

According to an embodiment, the abrasive material could be diamond particles.

According to an embodiment, the abrasive material includes diamond-like carbons.

According to an embodiment, the cutting member has a substantially frusto-conical shape.

According to an embodiment, the cutting member is substantially shaped as a scalpel.

In accordance with an embodiment, a cutting system that is configured to cut a tissue body includes a transducer assembly and a tool. The transducer assembly is configured to receive electrical energy and convert the received electrical energy to mechanical vibration at a predetermined frequency. The tool is coupled to the transducer assembly such that mechanical vibrations produced by the transducer assembly are transmitted to the tool thereby causing the tool to vibrate at the predetermined frequency. The tool includes a first section and a second section. The first section is coupled to the transducer assembly. The first section at least partially includes a first material. The second section is coupled to the first section, and at least partially includes a second material that is different from the first material and denser than the first material. The second section includes an operative portion that includes a cutting member configured to cut the tissue body when the cutting member vibrates.

According to an embodiment, the cutting member of the system is configured to vibrate at a cutting member amplitude that ranges between about 300 percent to about 500 percent of a transducer assembly amplitude of the vibration produced by the transducer assembly when the first section is coupled to the transducer assembly and the transducer assembly is activated.

According to an embodiment, the system further includes a power supply electrically coupled to the transducer assem-

bly. The power supply is configured to supply electrical energy to the transducer assembly.

According to an embodiment, the system further includes a controller electrically coupled to the transducer assembly. The controller is configured to control electrically energy supplied to the transducer assembly.

According to an embodiment, the tool includes a first end and a second end, and defines a length that extends from the first end to the second end in a longitudinal direction. The length of the tool is greater than about 80 millimeters.

According to an embodiment, the length of the tool ranges between about 20 millimeters and about 120 millimeters.

According to an embodiment, the length of the tool is about 105.7 millimeters.

According to an embodiment, the first material is a titanium alloy.

According to an embodiment, the titanium alloy is a Ti6-Al 4-V alloy.

According to an embodiment, the second material is stainless steel.

According to an embodiment, the first section is elongated along a first axis, and the second section includes an elbow, such that at least a portion of the second section is elongated along a second axis. The second axis is oriented at an oblique angle with respect to the first axis.

According to an embodiment, the cutting member defines a serrated edge.

According to an embodiment, the second section includes a support body, and the cutting member includes teeth that protrude outwardly from the support body.

According to an embodiment, the cutting member has a substantially spherical shape.

According to an embodiment, the cutting member defines at least one cutting surface, and further includes an abrasive coating that covers at least a portion of the at least one cutting surface. The abrasive coating is at least made from an abrasive material.

According to an embodiment, the abrasive material includes diamond particles.

According to an embodiment, the abrasive material includes diamond-like carbons.

According to an embodiment, the cutting member has a substantially frusto-conical shape.

According to an embodiment, the cutting member is substantially shaped as a scalpel.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing summary, as well as the following detailed description of a preferred embodiment, are better understood when read in conjunction with the appended diagrammatic drawings. For the purpose of illustrating the present disclosure, reference to the drawings is made. The scope of the disclosure is not limited, however, to the specific instrumentalities disclosed in the drawings. In the drawings:

FIG. 1 is a perspective view of a portion of an ultrasonic surgical system in accordance with an embodiment of the present disclosure;

FIG. 2 is a schematic representation, in block diagram form, of an ultrasonic surgical system in accordance with an embodiment of the present disclosure;

FIG. 3A is a side elevation view of a transducer assembly of the ultrasonic surgical system represented in FIG. 1;

FIG. 3B is a side sectional view of the transducer assembly of FIG. 3A, showing the some internal components;

FIG. 3C is a perspective exploded view of the transducer assembly of FIG. 3A;

FIG. 3D is an enlarged perspective exploded view of region 3D of the transducer assembly as shown in FIG. 3C;

FIG. 4 is a graph illustrating the variations of phase-shift and power as a function of the frequency;

FIG. 5A is a perspective view of a tool in accordance with an embodiment of the present disclosure;

FIG. 5B is a side elevation view of the tool illustrated in FIG. 5A;

FIG. 5C is a front elevation view of the tool illustrated in FIG. 5C;

FIG. 5D is a cross-sectional side view of the tool illustrated in FIG. 5A, taken along section line 5D-5D of FIG. 5C;

FIG. 6 is a side elevation view of a tool in accordance with an embodiment of the present disclosure;

FIG. 7 is a side elevation view of a tool in accordance with an embodiment of the present disclosure;

FIG. 8 is a side elevation view of a tool in accordance with an embodiment of the present disclosure;

FIG. 9A is a perspective view of a tool in accordance with an embodiment of the present disclosure;

FIG. 9B is a side elevation view of the tool illustrated in FIG. 9A;

FIG. 9C is a top view of the tool illustrated in FIG. 9A;

FIGS. 10A-16 illustrate schematics of a tool in accordance with various alternate embodiments of the present disclosure;

FIG. 17A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 17B is a front elevation view of the second section shown in FIG. 17A;

FIG. 18A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 18B is a front elevation view of the second section shown in FIG. 18A;

FIG. 19A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 19B is a front elevation view of the second section shown in FIG. 19A;

FIG. 20A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 20B is a front elevation view of the second section shown in FIG. 20A;

FIG. 21A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 21B is a front elevation view of the second section shown in FIG. 21A;

FIG. 22A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 22B is a front elevation view of the second section shown in FIG. 22A;

FIG. 23A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 23B is a front elevation view of the second section shown in FIG. 23A;

FIG. 24A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 24B is a front elevation view of the second section shown in FIG. 24A;

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FIG. 25 is an enlarged side elevation view of a portion of the second section shown in FIG. 24A;

FIG. 26A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 26B is a front elevation view of the second section shown in FIG. 26A;

FIG. 27A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 27B is a front elevation view of the second section shown in FIG. 27A;

FIG. 28A is a side elevation view of a tool in accordance with an embodiment of the present disclosure;

FIG. 28B is a front elevation view of the tool shown in FIG. 28A;

FIG. 29A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 29B is a front elevation view of the second section shown in FIG. 29A;

FIG. 30A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 30B is a front elevation view of the second section shown in FIG. 30A;

FIG. 31A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 31B is a front elevation view of the second section shown in FIG. 31A;

FIG. 32A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 32B is a front elevation view of the second section shown in FIG. 32A;

FIG. 33A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 33B is a front elevation view of the second section shown in FIG. 33A;

FIG. 34A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 34B is a front elevation view of the second section shown in FIG. 34A;

FIG. 35A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 35B is a front elevation view of the second section shown in FIG. 35A;

FIG. 36A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 36B is a front elevation view of the second section shown in FIG. 36A;

FIG. 37A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 37B is a front elevation view of the second section shown in FIG. 37A;

FIG. 38A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 38B is a front elevation view of the second section shown in FIG. 38B;

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FIG. 39A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 39B is a front elevation view of the second section shown in FIG. 39A;

FIG. 40A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 40B is a front elevation view of the second section shown in FIG. 40A;

FIG. 41A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 41B is a front elevation view of the second section shown in FIG. 41A;

FIG. 42A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 42B is a front elevation view of the second section shown in FIG. 42A;

FIG. 43A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 43B is a front elevation view of the second section shown in FIG. 43A;

FIG. 44A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 44B is a front elevation view of the second section shown in FIG. 44A;

FIG. 45A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 45B is a front elevation view of the second section shown in FIG. 45A;

FIG. 46A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 46B is a front elevation view of the second section shown in FIG. 46A;

FIG. 47A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure;

FIG. 47B is a front elevation view of the second section shown in FIG. 47A;

FIG. 48A is a side elevation view of a second section of a tool in accordance with an embodiment of the present disclosure; and

FIG. 48B is a front elevation view of the second section shown in FIG. 48A.

DETAILED DESCRIPTION

With reference to FIGS. 1 and 2, an ultrasonic surgical system 100 employs mechanical vibrations to cut, for instance to remove or shape, a tissue body, such as anatomical tissue or a tissue substitute T. As used herein, the term tissue includes, but is not limited to, soft tissue and hard tissue. Soft tissue includes, but is not limited to, skin, tendons, ligaments, fascia, fibrous tissues, fat, Synovial membrane, muscle, nerves, and blood vessels. Hard tissue includes, but is not limited to, enamel, dentin, and bone. Tissue substitutes include soft tissue substitute, such as a graft, and hard tissue substitutes, such as calcium-phosphate cement. In one embodiment, the ultrasonic surgical system 100 includes a transducer assembly 102 and a tool 104 mechanically coupled to the transducer assembly 102. The

transducer assembly **102** can convert energy, such as electrical energy, into mechanical vibrations. In an embodiment, the transducer assembly **102** is a piezoelectric transducer assembly capable of converting electrical energy into mechanical vibrations as described in detail below. Given the mechanical connection between the transducer assembly **102** and the tool **104**, the mechanical vibrations generated by the transducer assembly **102** can be propagated through the tool **104**. The tool **104** carries at least one cutting surface **227** that is configured to vibrate at a predetermined frequency while being brought into operative communication with the tissue body, such that the vibration of the cutting tool **104** cut, for instance shaped or remove, tissue body.

As discussed above, the transducer assembly **102** can be a piezoelectric transducer assembly configured to convert electrical energy into mechanical vibrations. A power supply **106** can supply electrical energy to the transducer assembly **102**. In order to supply electrical energy to the transducer assembly **102**, the power supply **106** can be electrically coupled to the transducer assembly **102**. The power assembly **106** can be any suitable power supply capable of supplying the transducer assembly **102** with an electrical energy. In one embodiment, the ultrasonic surgical system **100** includes the power supply described in U.S. Pat. No. 6,765,333, the disclosure of which is hereby incorporated by reference in its entirety. Moreover, the power supply **106** can be part of, or be electrically coupled to, a frequency tracking oscillator circuitry, such as the frequency tracking oscillator circuitry described in U.S. Pat. No. 6,765,333. The frequency tracking oscillator maintains the resonance frequency of the tool **104** during operation regardless of the operating conditions by adjusting the electrical energy supplied to the transducer assembly **102** by the power supply **106**. As such, even if the tool **104** is moved from a position where it contacts hard tissue to another position where it is only in contact with a fluid, such as blood, the frequency tracking oscillator circuitry adjusts the supply voltage provided by the power supply **106** to the transducer assembly **102** in order to maintain the resonance frequency of the tool **104** substantially constant. Alternatively, the power supply **106** can be electrically connected to any other device, apparatus, or circuitry capable of controlling the power supply **106** in order to maintain the resonance frequency of the tool **104** substantially constant regardless of the operating conditions or environment.

In the depicted embodiment, the ultrasonic surgical system **100** can further include an irrigation fluid source **108** disposed in fluid communication with the tool **104**. The irrigation fluid source **108** can be directly coupled to the tool **104**. Alternatively, the water supply **108** can be fluidly coupled to the tool **104** through a controller **110** and/or the transducer assembly **102**. The irrigation fluid source **108** contains any fluid, such as water or a saline solution, suitable for irrigating a target tissue site. As discussed in detail below, tool **104** can define openings for delivering the irrigation fluid to the target site to prevent, or at least minimizes, heat generation and necrosis.

The controller **110** can be electrically coupled to the power supply **106** and fluidly coupled to the irrigation fluid source **108**. In operation, the controller **110** can be configured to control the electrical energy supplied to the transducer assembly **102**. An embodiment of the controller **110** is in the form of a console that includes a user interface that allows a user to adjust the power supplied to the transducer assembly **102**. The user interface can include a touchscreen capable of receiving input commands from a user. In addition or alternatively to the touchscreen, the controller **110**

can include a foot pedal or any other external manual control that allows a user to control the power or electrical energy supplied to the transducer assembly **102**. In one embodiment, the controller **110** includes the frequency tracking oscillator circuitry described above.

The controller **110** can additionally or alternatively be configured to control the delivery of irrigation fluid to the tool **104**. As discussed above, the irrigation fluid source **108** is fluidly coupled to the tool **104** directly or indirectly via the controller **110** and/or the transducer assembly **102**. The ultrasonic surgical system **100** can include one or more pumps for displacing the irrigation fluid from the irrigation fluid source **108** to the tool **104**. The controller **110** can be configured to control the pumps in order to control the delivery of irrigation fluid to the tool **104**. As such, the controller **110** can include circuitry configured to control the pumps.

With reference to FIGS. 3A and 3B, the transducer assembly **102** can be coupled to the controller **110** (FIG. 2). In one embodiment, the transducer assembly **102** includes a housing **112** defining an inner cavity **115**. The housing **112** can be configured as a handle or handpiece to allow a user to easily grasp the transducer assembly **102**. Moreover, the housing **112** defines a first or proximal end **114** and a second or distal end **116** spaced from the first end **114** along a longitudinal axis L. The terms “proximal,” “distal,” and derivatives thereof as used with respect to the transducer assembly **102** and components thereof are made with reference to a direction from distal end **116** toward the proximal end **114**, and a direction from the proximal end **114** toward the distal end **116**, respectively. The proximal end **114** of the housing **112** is configured to be connected to at least one electrical connector **118**, such as an electrical cable. The electrical connector **118** can be any suitable structure, apparatus, or device, capable of electrically coupling the controller **110** (FIG. 2) and the transducer assembly **102**. In one embodiment, the electrical connector **118** can also mechanically connect the transducer assembly **102** to the controller **110**. However, any suitable wireless connection can electrically couple the controller **110** to the transducer assembly **102**.

With continued reference to FIGS. 3A and 3B, the housing **112** defines an outer surface **120** and an inner surface **122**. At least a portion **124** of the outer surface **120** can define a substantially cylindrical shape. Another portion **126** of the outer surface **120** adjacent the distal end **116** can define a substantially frusto-conical shape. The inner surface **122** of the housing defines the inner cavity **115**. The inner cavity **115** extends at least between the proximal end **114** and the distal end **116** of the housing **112**. In one embodiment, the inner cavity **115** is configured and sized to receive at least a portion of the electrical connector **118**.

With continued reference to FIGS. 3A and 3B, in an embodiment, the transducer assembly further includes one or more piezoelectric members or resonators **128** each electrically coupled to the power supply **106** via, for instance, electrical connector **118**. The electrical connector **118** can electrically couple the piezoelectric members **128** to the controller **110** (FIG. 2). The controller **110** (FIG. 2) is in turn electrically connected to the power supply **106**. Irrespective of the specific structure employed to electrically couple the piezoelectric members **128** to the power supply **106**, the power supply **106** can supply electrical energy to the piezoelectric members **128**. In the depicted embodiment, the electrical connector **118** transmits electrical energy supplied by the power supply **106** to the piezoelectric members **128**. Each of the piezoelectric members **128** is configured to

vibrate upon receive of electrical energy from, for example, the power supply 106. In one embodiment, at least one of the piezoelectric members 128 is configured to vibrate at an ultrasonic frequency when it receives electrical energy. At least one piezoelectric member 128 can be a piezo-ceramic plate. In the depicted embodiment, the piezoelectric members 128 include a plurality of stacked piezo-ceramic plates 130. For instance, the piezoelectric members 128 can be six piezo-ceramic plates stacked together. Nevertheless, the piezoelectric members 128 can have other shapes and be made of other piezoelectric materials. For example, the piezoelectric members 128 can be shaped as rings. Alternatively, the piezoelectric member 128 can be constructed as single monolithic (one-piece) structure. Irrespective of its construction, the piezoelectric member 128 defines a proximal or first end 134 and a distal or second end 136.

With continued reference to FIGS. 3A and 3B, in addition to the backing mass structure 132, the transducer assembly 102 can further include vibration transmission member 138, such as an impedance matching member, attached to the distal end 136 of the piezoelectric member 128. In the depicted embodiment, the entire vibration transmission member 138 is disposed within the housing 112. The vibration transmission member 138 is configured to facilitate the propagation of the mechanical vibrations generated by the piezoelectric member 128 into the tool 104. To this end, vibration transmission member 138 can substantially match the output impedance of the source (i.e., the piezoelectric member 128) to the input impedance of the load (i.e., tool 104). In one embodiment, the vibration transmission member 138 is at least partly made from a material that has an acoustic impedance that gradually changes from that of the piezoelectric member 128 to that of the tool 104. In another embodiment, the vibration transmission member 138 is at least partly made of a material that has an acoustic impedance between the that of the piezoelectric member 128 and the acoustic impedance of the tool 104. The vibration transmission member 138 can be made of one or more layers. These layers of the vibration transmission member 138 can each be made of materials having different acoustic impedances. Alternatively, all the layers forming the vibration transmission member 138 can have the substantially the same acoustic impedance. In an embodiment, the vibration transmission member 138 can be a single monolithic ("one-piece") structure capable of facilitating the transmission of the mechanical vibrations stemming from the piezoelectric member 128 into the tool 104.

With continued reference to FIGS. 3A and 3B, the vibration transmission member 138 defines a proximal or first end 140 attached to the piezoelectric member 128 and a distal or second end 142 configured to be attached to the tool 104. Thus, the tool 104 is configured to be attached to the distal end 142 of the vibration transmission member 138. In one embodiment, the tool 104 can vibrate at selected frequency range between 28 and 36 kHz upon actuation of the piezoelectric member 128. At this frequency range, the tool 104 only cuts mineralized tissue, such as teeth and bone, in a very precise way, while limiting the risk of soft tissue lesions. Soft tissues such as nerves, blood vessels, dura or membrane are not altered by the tool 104 because of their ability to oscillate at the same speed and amplitude as the tool 104.

With continued reference to FIGS. 3A and 3B, the ultrasonic surgical system 100 can further include fluid conduit 144 configured to convey irrigation fluid from the irrigation fluid source 108 (FIG. 2) into an inner portion of the tool 104 as described in detail below. The fluid conduit 144 can be

tube defining a channel or any other structure capable of conveying an irrigation fluid from the irrigation fluid source 108 into an inner portion of the tool 104. A portion of the fluid conduit 144 can be disposed within the housing 112 and can extend from a proximal end 114 in a direction toward the distal end 116 of the housing 112. The fluid conduit 144 fluidly interconnects the irrigation fluid source 108 (FIG. 2) and an inner portion of the tool 104. Accordingly, the fluid conduit 144 can be in fluid communication with the fluid source 108 (FIG. 2) and an inner portion of the tool 104.

With continued reference to FIGS. 3A and 3B, the ultrasonic surgical system 100 can further include a light source 146 configured to illuminate a surgical target site. In the depicted embodiment, the light source 146 is supported within the housing 112 and includes a support body 148, such as a support ring, and one or more light emitting diodes (LEDs) 150 supported by the support body 148. The support body 148 is disposed around a portion of the vibration transmission member 138. The LEDs 150 are attached to the support body 148 such that they illuminate in a direction toward the distal end 116 of the housing 112. The distal end 116 of the housing 112 defines an open end 152 that allows light emitted by the light source 146 to travel in a direction toward the surgical target site to enhance visibility of the surgical target site near the tool 104.

With reference to FIGS. 3C-D, the transducer assembly 102 can include a mounting member 149, such as a frame, that is configured to hold the support body 148. In the present disclosure, the mounting member 149 can also be referred to as a mount. The support body 148 can be connected to the mounting member 149. In the depicted embodiment, the mounting member 149 is disposed around the vibration transmission member 138, and is attached to the housing 112. The mounting member 149 supports one or more electrical contacts 151. The electrical contacts 151 are configured to be electrically coupled to the power supply 106 (see FIG. 2) when the transducer assembly 102 is electrically connected to the power supply 106. The support body 148 also supports one or more electrical contacts 153 that are configured to be electrically coupled to the electrical contacts 151. The electrical contacts 153 can be shaped as rods that protrude from the support body 148 in a direction toward the proximal end 114 (see FIG. 3B) of the transducer assembly 102. In operation, the electrical contacts 153 are configured to transmit electrical energy to the light source 146 (e.g., LEDs 150) such that the light source 146 can illuminate in a direction toward the distal end 116 of the housing 112.

With continued reference to FIGS. 3C-D, the transducer assembly 102 includes a light diffuser 147 configured to be disposed over the light source 146. The light diffuser 147 is configured to receive light from the light source 146 and regulate the light such that the regulated light has an intensity distribution suitable for substantially uniform illumination of a target site. In the depicted embodiment, the light diffuser 147 has a substantially frusto-conical shape. However, the light diffuser 147 may have any other suitable shape. The transducer assembly 102 further includes a nose cone 154 configured and sized to be disposed over the light diffuser 147. In the depicted embodiment, the nose cone 154 has a substantially frust-conical shape. However, the nose cone 154 may have other suitable shapes.

With reference to FIGS. 3C-D, the vibration transmission member 138 includes a body 139 and a connecting member 141 that protrudes from the body 139 in a direction toward the distal end 116 of the housing 112. The body 139 can have a cross-sectional dimension, such as a diameter, that is

greater than the cross-sectional dimension, such as a diameter, of the connecting member **141**. The connecting member **141** defines an outer surface **143** and external threads **145** that are formed on the outer surface **143**. The external threads **145** are configured to mate with the inner threads **219** of the tool **204** such that the tool **204** can be connected to the transducer assembly **102**.

With reference to FIGS. **1** and **4**, as discussed in detail above, some of the embodiments of the tools described in the present disclosure are relatively longer and thinner than conventional tools. The length and cross-sectional dimension of conventional tools herein allow the surgeon to employ minimally invasive approaches and to reach areas difficult to access. Moreover, in conventional tools, when the user grabs the handpiece that is connected to the tool, the user's fingers and the handpiece must be positioned very close to the target surgical site. As a consequence, the user's fingers and the handpiece obstruct the user's line of sight to the target surgical site. To enhance visibility, surgeons often cut soft tissue surrounding the target surgical site. Such cuts, however, may cause post-operative inflammation. When using the relatively longer tools described in the present disclosure, the user's fingers and the housing **112** (e.g., handpiece) are positioned farther away from the target surgical site and, consequently, the user has a direct line of sight to the target site and does not need to cut soft tissue surrounding the target bone, thereby reducing post-operative swelling.

Conventional tools cannot simply be elongated to have the longer lengths as some of the tools described in the present disclosure, because such elongation would significantly affect the efficiency of the transducer assembly. Typically, conventional tools are made of stainless steel. Stainless steel is relatively heavy in comparison with other materials. If a conventional stainless steel tool is elongated to reach the relatively longer lengths of some of the tools described in the present disclosure, vibrating such a heavy stainless steel tool would require significant amount of power from a power supply. In turn, this increase in power can overheat the piezoelectric members of the transducer assembly, thereby causing, among other things, inefficiencies in the transducer assembly. In other words, if the piezoelectric members or resonators overheat, the transducer assembly does not operate at its optimal conditions.

With reference to FIGS. **1** and **4**, in an embodiment, the transducer assembly **102** can vibrate in response to a sinusoidal electrical signal having a frequency band between about 27 and about 34 kilohertz (KHz). However, it is envisioned that the transducer assembly **102** can vibrate when it receives any other modulated electrical signal having other frequency bands. As discussed above, the transducer assembly **102** propagates vibrations to the tool **102**. The vibration of the tool **102** depends, among other things, of the power supplied to the transducer assembly **102**. The power supplied to the transducer assembly **102** can be at least partially controlled by the frequency tracking oscillator circuitry, such as the frequency tracking oscillator circuitry described in U.S. Pat. No. 6,765,333, the entire disclosure of which is hereby incorporated by reference. The transducer assembly **102** can receive power ranging between about 0.5 and about 10 Watts (W). This power can be in the form of a sinusoidal signal and is a function of the voltage, the current, and the phase shift of the current relative to the voltage. To determine the optimal operating conditions of the transducer assembly **102**, tests were conducted to determine the power, the phase, and the impedance of the transducer for each frequency in the range between 27 and

34 kilohertz (KHz). The results of these tests are shown in the graph depicted in FIG. **4**. By observing this graph, the resonance frequency and the anti-resonance frequency of the transducer assembly **102** can be obtained. The resonance frequency F_r is the frequency at which the impedance is minimum and the phase shift is zero. The anti-resonance frequency F_a is the frequency at which the impedance is maximum and the phase shift is zero. In this test, it was determined that the resonance frequency F_r is about 30,297 Hz, and the minimum impedance was 509 ohms. When vibrated at the resonance frequency F_r , the transducer assembly **102** most efficiently converts electrical energy input into mechanical vibrations. As the frequency is increased, the transducer assembly **102** can reach its anti-resonance frequency, at which point the impedance reaches its maximum value. Thus, the transducer assembly **102** should be vibrated at or close to the resonance frequency F_r but its vibration frequency should not reach or exceed the anti-resonance frequency F_a while maintain a zero phase shift.

With reference to FIGS. **5A-5C**, an embodiment of a tool **204** that is at least partly made of a titanium alloy, has length L_1 that is greater than the length of conventional tools. The length L_1 is defined by the distance from a first or proximal end **210** and a second or distal end **212** of the tool **204** along a direction defined by the longitudinal axis X_1 . The longitudinal axis X_1 extends along at least a portion of the tool **204** in a longitudinal direction indicated by the arrow **A**. In the depicted embodiment, the length L_1 of the tool **204** is greater than about 80 millimeters. In an embodiment, the length L_1 of the tool **204** ranges between about 20 millimeters and 120 millimeters. In one embodiment, the length L_1 of the tool **204** is about 105.7 millimeters. As discussed above, the length L_1 of the tool **204** is important, because it allows the surgeon to employ minimally invasive approaches and to reach areas difficult to access. The length L_1 of the tool **204** also enhances visibility of the surgical target site and forgoes the need to cut soft tissue surrounding the target bone or soft tissue, thereby reducing post-operative swelling.

With reference to FIGS. **5A-5C**, the tool **204** is configured to be removably attached to the transducer assembly **102** (FIG. **2**). In one embodiment, tool **204** can be removably coupled to the vibration transmission member **138** by any suitable apparatus, device, or mechanism. For instance, the tool **204** can define a threaded bore configured to mate with an external thread formed on outer surface of the vibration transmission member **138**. As discussed above, the vibration transmission member **138** transmits vibrational motion from the piezoelectric members **128** to the tool **204**. Thus, the tool **204** is configured to vibrate when the piezoelectric member **128** vibrate in response to an electrical signal.

With continued reference to FIGS. **5A-5C**, in the depicted embodiment, the tool **204** includes a first or proximal section **206** and a second or distal section **208** that is spaced from the first or proximal section **206** along the longitudinal direction **A**. The first section **206** can extend into the housing **112**, and is configured to be attached to the transducer assembly **102**. The second section **208** carries at least one cutting surface **227** that is configured to operate on a surgical target site so as to cut, for instance shape or remove, tissue from the surgical site. In an embodiment, the first and second sections **206** and **208** are made from different materials. For instance, the first section **206** can be made of a first material, and the second section **208** can be made from a second material that is heavier than the first material. In other words, the density of the second material is greater than the density of the first

material. Thus, the second material is denser than the first material. The combination of the two materials (e.g., alloys) having different densities allows the production of an efficient and effective tool **204** that is longer than the conventional tools made of a single material. Moreover, the use of materials having different densities enhances the vibration transmission from the transducer assembly **102** to the extremity of the tool **204** (e.g., cutting member **225**). Therefore, a tool, such as the tool **204**, that is made of the materials having different densities (as described in the present disclosure) enhances the tissue cutting efficiency in a very precise way. As discussed above, the term "tissue" includes hard tissue, such as bone or tooth, and soft tissue while the term "cutting" includes shaping. In addition, the tool **204**, which is made of materials having different densities, is safer to use relative to conventional tools because the user can select via a controller **110** to vibrate the tool **204** at a vibration that would only cut the desired tissue. For instance, at predetermined frequency range, the tool **204** only cuts hard tissue and does not cut soft tissue, such as nerve, membrane, skin, dura matter etc. The first section **206** can have an elongated configuration and be made of a material that is lighter than the stainless steel used in conventional tools. Thus, the first section **206** can be partly or entirely made of a material that has a density lower than the density of stainless steel. The materials with different densities listed above are important because it allows the cutting member **225** of the tool **204** to vibrate at a cutting member amplitude that ranges between about 300 percent to about 500 percent of a transducer assembly amplitude of the vibration produced by the transducer assembly **102** when the first section **206** is coupled to the transducer assembly **102** and the transducer assembly **102** is activated and is receiving power from the power supply **106**.

With continued reference to FIGS. 5A-5C, in an embodiment, the first section **206** can be partly or wholly made of any suitable biocompatible titanium alloy. For instance, the first section **206** is partly or entirely made from a titanium-aluminum-vanadium alloy. The first section **206** can be sufficiently flexible to transmit the mechanical vibrations generated by the piezoelectric member **128** to tissue or tissue substitute in order to cut, for instance shape or remove, such tissue. To this end, the first section **206** can be partly or entirely made from a material sufficiently flexible to transmit vibrational motion from the piezoelectric member **128** but sufficiently rigid to allow the tool **204** to cut, for instance shape or remove, hard tissue, soft tissue, or tissue substitutes. The moduli of elasticity described above are important because it provides the first section **204** with sufficient flexibility to allow the propagation of mechanical vibrations along the tool **204** and also because it provides the tool **204** with sufficiently rigidity so that it can cut, for instance shape or remove, hard tissue, soft tissue, or tissue substitutes. The use of a titanium alloy for the first section **206** also allows the transducer assembly **102** to generate mechanical vibrations efficiently and minimizes the risk of overheating the transducer assembly **102**.

With continued reference to FIGS. 5A-5C, the first section **206** of tool **204** extends in a direction along a longitudinal axis **X1** and has an outer surface **214**. The outer surface **214** of the first section **206** defines a cross-sectional dimension or diameter **D1**. The first section **206** can be tapered so that the cross-sectional dimension decreases in a direction from the proximal end **210** toward the distal end **212**. The cross-sectional dimension or diameter **D1** is less than cross-sectional dimension or diameter of conventional tools to allow the surgeon to reach difficult areas to access.

With continued reference to FIGS. 5A-5C, the first section **206** can further include one or more recesses **216** on the outer surface **214**. The recesses **216** are configured and sized to allow a holding tool, such as a wrench, to securely hold the tool **204**. During assembly, a user can place portion of the holding tool, such as a wrench, to hold the tool **204**. The user can then turn the holding tool to turn tool **204** and thereby disconnect the tool **204** from the transducer assembly **104**. In this embodiment, the tool **204** can be connected to the transducer assembly via a threading mechanism. In one embodiment, the tool **204** defines two identical recesses **214** disposed in a diametrically-opposed relationship to each other.

With continued reference to FIGS. 5A-5C, the second section **208** of the tool **204** can be directly or indirectly connected to the first section **206**. The second section **208** can be of a different material than the first section **206**. For instance, the second section **208** can be partly or wholly made of a stainless steel. In one embodiment, the stainless steel used for making the second section **208** can be sufficiently strong to allow this second section **208** to cut, for instance shape or remove, even hard tissue. Thus, in one embodiment, the stainless steel of the second section **208** is subjected to thermal treatment to increase its strength and hardness.

In the depicted embodiment, the second section **208** can include a connection or elongated portion **218** coupled to the first section **206**. The connection portion **218** extends along the longitudinal axis **X1** and defines an outer surface **220**. The outer surface **220** of the connection portion **218** defines a cross-sectional dimension or diameter **D2**. The outer surface **220** can be tapered so that the cross-sectional dimension or diameter **D2** decreases in a direction toward the distal end **212**.

With continued reference to FIGS. 5A-5D, the second section **208** can further include a shoulder **222** coupled to the connection portion **218**. The shoulder **222** can be in turn connected to an elbow **224**. The elbow **224** allows the tool **204** to change its direction relative to the longitudinal axis **X1**.

With continued reference to FIGS. 5A-5D, the second section **208** further includes an operative portion **226** coupled to the elbow **224**. The operative portion **226** includes a support body **223** and cutting member **225** that is carried by the support body **223**. For instance, the cutting member **225** can be monolithic with the support body **223**. The cutting member **225**, in turn, carries at least one cutting surface **227** that is configured to vibrate and to contact a tissue body in order to cut, for instance shape or remove, the tissue body. In the depicted embodiment, the operative portion **226** can extend along an axis **Z1** that is oriented at an oblique angle relative to the longitudinal axis **X1**. At least part of the operative portion **226** can have a substantially flat or planar configuration as shown in FIG. 5C. In accordance with one embodiment, the cutting member **225** can define more than one cutting surface **227**, such as at least a pair of cutting surfaces **227**, that define a cutting edge **228** that is configured to cut, for instance shape or remove, a tissue body as it vibrates at a predetermined frequency. The edge **228** can thus be sharp and can be serrated or non-serrated. In the embodiment illustrated in FIGS. 5A-C, the cutting member **225** defines a serrated edge **228** so as to define a plurality of teeth **230** that protrude outward from the support body **223** along a direction away from the elbow **224**, which can be angularly offset with respect to the longitudinal direction **A**. Alternatively, it should be appreciated that the teeth **230** can protrude outward from the support body **223**

along a direction substantially parallel to the longitudinal direction A. The teeth **230** of the cutting member **225** are spaced from each other along a row direction indicated by arrow Y1.

With continued reference to FIGS. 5A-5D, the tool **204** can further define an inner surface **213**. The inner surface **213** defines an irrigation fluid channel **215** that can be disposed in fluid communication with the fluid conduit **144** (FIG. 3B) when the tool **204** is coupled to the transducer assembly **102**. The irrigation fluid channel **215** is sized and configured to receive any suitable irrigation fluid, such as water or saline. Moreover, the irrigation fluid channel **215** can extend at least into or through at least a portion of the tool **204**, such as at least a portion of the first section **206**, along a direction having a directional component along the longitudinal direction A, and can further extend at least into or through at least a portion of the second section **208**, so as to define an outlet **217** of the tool **204**. The irrigation fluid channel **215** can alternatively define more than one outlet **215**. The outlet **217** can be located at the operative portion **226** of the tool **204**, such that irrigation fluid can travel through the irrigation fluid channel **215** and exit the tool **204** at the outlet **217**. The irrigation fluid can thus exit the outlet **215** and be brought into contact with the cutting member **225** so as to cause the physical phenomenon of cavitation effect. For instance, cavitation can occur when the cutting member **225** is in contact irrigation fluid as the cutting member **225** vibrates, such that irrigation fluid creates micro-bubbles that have hemostatic effects on the cutting surface **227**, partially due to the production of nascent oxygen during cavitation. The cavitation phenomenon provides visibility of the operative site, removes bone debris and limits temperature rise due to tissue degradation. The inner surface **213** further defines an inner thread **219** at the proximal end **210** of the tool **210**.

In operation, tool **204** can be used for mandible and skull based procedures, transnasal and transorbital approaches, lateral decompression, and full ramus osteotomy. Thus, the tool **204** can be used in neurosurgery and cranio-maxillofacial (CMF) surgery. For example, in neurosurgery, the tool **204** can be used for decompression of neurovascular structures (i.e., optic nerve), frontal craniotomy, and a transorbital approach. The tool **204** can also be used to gain access the following anatomies, namely: the anterior clinoid process, dorsum sellae, internal acoustic meatus, posterior cranial fossa, middle cranial fossa, groove for sigmoid sinus, super-orbital fissure, optical canal, cribriform plate, crista galli, clinoid process, lesser wing of sphenoid, and greater wing of sphenoid. In CMF surgery, the tool **204** can also be used to gain access the following anatomies, namely coronoid process, condyle, ramus, angle, groove for external maxillary artery, maxillary frontal process, anterior lacrimal crest, lacrimal groove, orbital surface, maxillary tuberosity, zygomatic process, alveolar process, nasal bone, vomer bone, sphenoid, and palatine bones.

In use, the tool **204** can be connected to the transducer assembly **102** using any suitable apparatus or mechanism. The tool **204** can be pre-connected to the transducer assembly **102**. Once the tool **204** is connected to the transducer assembly **102**, the power supply **106** is activated to energize the transducer assembly **102**. When the power supply **106** is activated, electrical energy is supplied to the transducer assembly **102**. The transducer assembly **106** can then convert the electrical energy into mechanical vibrations. In one embodiment, the piezoelectric members or resonators **128** vibrates upon receipt of the electrical energy. The transducer assembly **102** propagates the mechanical vibrations to the

tool **204**. When tool **204** receives the mechanical vibrations generated by the transducer assembly **104**, its first section **206** and at least a part of the section **208** vibrate in a direction back and forth in the direction indicated by arrows A. This back and forth vibration of the first section **206** and at least a part of the section **208** causes the elbow **224** to move in a whipping manner such that the operative portion **226** can vibrate in the direction indicated by arrows Y1. The edge **228** can be placed in contact with the tissue body to be cut, for instance shaped or removed. As the operative portion **226** vibrates in the direction indicated by arrow Y1, the teeth **230** of the edge **228** contact the target tissue body and cut, for instance shape or remove, such tissue body.

With reference to FIG. 6, another embodiment of a tool **304** can be mechanically coupled to the transducer assembly **102** (FIG. 2). The tool **304** is substantially similar to the tool **204** shown in FIGS. 5A-5C, except for the operative portion **326**, and defines a first or proximal end **310** and a second or distal end **312**. The tool **304** can have length L2 defined between the proximal end **310** and the distal end **312** along a longitudinal direction A. The length L2 can be substantially similar or identical to the length L1 described above with respect to FIGS. 5A-5C. In the depicted embodiment, the length L2 of the tool **304** is greater than about 80 millimeters. In an embodiment, the length L2 of the tool **304** ranges between about 20 millimeters and 120 millimeters. In one embodiment, the length L2 of the tool **304** is about 105.7 millimeters. The length L2 of the tool **304** is important, because it allows the surgeon to employ minimally invasive approaches and to reach areas difficult to access. The length L2 of the tool **304** also enhances visibility of the surgical target site and forgoes the need to cut soft tissue surrounding the target bone or soft tissue, thereby reducing post-operative swelling.

With continued reference to FIG. 6, the tool **304** includes a first section **306** and second section **308**. The first section **306** and the second section **308** can be made of different materials. For example, the first section **306** can be made of a titanium alloy, whereas the second section **308** can be made of stainless steel. In one embodiment, the first section **306** can be substantially similar or identical to the first section **206** shown in FIGS. 5A-5C. The second section **308** can be substantially similar or identical to the second section **208** shown in FIGS. 5A-5C except for its operative portion **326**. Like the second section **208** shown in FIGS. 5A-5C, the second section **308** of the tool **304** can include a connection portion **318** that is directly or indirectly connected to the first section **306** and an elbow **324** that is coupled to the connection portion **318**. The operative portion **326** is substantially shaped as a mace. As used herein, the term "mace" refers to a spiked staff or club used especially in the Middle Ages for breaking armor. Thus, the operative portion **326** includes a support body **323** and cutting member **325** that is carried by the support body **323**. For instance, the cutting member **325** can be monolithic with the support body **323**. The cutting member **325**, in turn, carries at least one cutting surface **327** that is configured to vibrate and to contact a tissue body in order to cut, for instance shape or remove, the tissue body. The cutting surface **327** can define a cutting edge **328** so as to define a plurality of spikes **330** that produce radially outward from the support body **323**. The spikes **320** can protrude from the support body **323** in different directions with respect to the longitudinal direction A. For instance, some of the spikes **320** can protrude from the support body **323** along a direction that is angularly offset with respect to the longitudinal direction A. One or more spikes **320** can protrude from the support body **323**

along a direction that is substantially parallel to the longitudinal direction A. The support body **323** can have a substantially ellipsoidal shape. As used herein, the term “ellipsoidal” includes, but is not limited to, the following terms, namely: spherical, oblate spheroidal, prolate spheroidal, and a scalene ellipsoidal. Hence, the body **323** can have a substantially spherical shape, a substantially oblate spheroidal shape, a substantially prolate spheroidal shape, or a substantially scalene ellipsoidal. The spikes **330** can have a substantially pyramidal shape. The tool **304** can additionally include an irrigation channel and inner threads as described above with respect to FIG. 5D.

With continued reference to FIG. 6, the operation of the tool **304** is substantially similar or identical to the operation of the tool **204** described above in connection with FIGS. 5A-5C. Thus, tool **304** can vibrate upon activation of the transducer assembly **102** (FIG. 2). The tool **304** can be used for skull base surgery. For example, in neurosurgery, the tool **304** can be used for decompression of neurovascular structures (i.e., optic nerve), frontal craniotomy, and transorbital approach. The tool **304** can also be employed for accessing or doing work on the following anatomies, namely: anterior clinoid process, dorsum sellae, internal acoustic meatus, posterior cranial fossa, middle cranial fossa, groove for sigmoid sinus, superorbital fissure, optical canal, cribriform plate, crista galli, clinoid process, lesser wing of sphenoid, and greater wing of sphenoid. In CMF surgery, the tool **304** can be used for accessing or doing work on the coronoid process, condyle, ramus, angle, groove for external maxillary artery, maxillary frontal process, anterior lacrimal crest, lacrimal groove, orbital surface, maxillary tuberosity, zygomatic process, alveolar process, nasal bone, vomer bone, Sphenoid, and palatine bones.

With reference to FIG. 7, an embodiment of a tool **404** can be removably coupled to the transducer assembly **102** (FIG. 2). The tool **404** is substantially similar to the tool **204** described above with respect to FIGS. 5A-5C, and defines a first or proximal end **410** and a second or distal end **412**. For instance, the tool **404** can have a length L3 defined between the proximal end **410** and the distal end **412** along the longitudinal direction A. The length L3 can be substantially similar or identical to the length L1 described above with respect to FIGS. 5A-5C. In the depicted embodiment, the length L3 of the tool **404** is greater than about 80 millimeters. In an embodiment, the length L3 of the tool **404** ranges between about 20 millimeters and 120 millimeters. In one embodiment, the length L3 of the tool **404** is about 105.7 millimeters. The length L3 of the tool **404** is important, because it allows the surgeon to employ minimally invasive approaches and to reach areas difficult to access. The length L3 of the tool **404** also enhances visibility of the surgical target site and forgoes the need to cut soft tissue surrounding the target bone or soft tissue, thereby reducing post-operative swelling.

In an embodiment, the tool **404** includes a first section **406** and a second section **408**. The first section **408** is configured to be coupled to the transducer assembly **102** (FIG. 2), whereas the second section **408** has a free end and is connected to the first section **406**. The first and second sections **406** and **408** can be made of different materials. In one embodiment, the first section **406** can be substantially similar or identical to the first section **206** shown in FIGS. 5A-5C. Hence, the first section **406** can be partly or entirely made from a titanium alloy, such as the titanium alloys described above with respect to the tool **204**. The second section **408** can be substantially similar or identical to the second section **208** shown in FIGS. 5A-5C, except for its

operative portion **426**. For example, the second section **408** can be partly or wholly made from any suitable stainless steel, such as the stainless steel grades listed above in connection with the tool **204**. Like the second section **208** shown in FIGS. 5A-5C, the second section **408** of the tool **404** can include a connection portion **418** that is directly or indirectly connected to the first section **406** and an elbow **424** that is coupled to the connection portion **418**. At least part of the operative portion **426** can have an abrasive coating.

The operative portion **426** has a proximal end section **430** that is coupled to the elbow **424**, and a distal end section **428**. The distal end section **428** is partly or entirely coated with a suitable abrasive material. The operative portion **426** includes a support body **423** and a cutting member **425** that is carried by the support body **423**. For instance, the cutting member **425** can be monolithic with the support body **423**. The cutting member **425**, in turn, carries at least one cutting surface **436** that is configured to vibrate and to contact a tissue body in order to cut, for instance shape or remove, the tissue body. The cutting surface **436** can be partly or entirely covered with an abrasive coating **437**. The abrasive coating **437** can be made from any suitable abrasive material that is configured to cut, for instance shape or remove, a tissue body when the cutting surface **436** vibrates. Suitable abrasive materials include, but are not limited to, diamond and diamond-like carbons (DLC), such as tetrahedral amorphous carbon (ta-C). The abrasive material can have a nanocrystalline or micro-crystalline structure. In one embodiment the cutting surface **436** is coated with diamond or diamond particles. The distal end section **428** has a first end **432** that is coupled to the proximal end section **430** and a second free end **434**. The second free end **434** of the distal end section **428** can coincide with the distal end **412** of the tool **404**. Further, the cutting surface **436** defines a cross-sectional dimension or diameter D2. In one embodiment, the distal end section **432** has a substantially frusto-conical shape. In one embodiment, the distal end section **432** is tapered so that the cross-sectional dimension or diameter D2 decreases in a direction from the first end **432** toward the second free end **434**. The tool **404** can have an irrigation fluid channel and inner threads as described above with respect to FIG. 5D.

The operation of the tool **404** is substantially similar or identical to the operation of the tool **202** described above with respect to FIGS. 5A-D. In operation, tool **404** can be used for mandible and skull based procedures, transnasal and transorbital approaches, lateral decompression, and full ramus osteotomy. Thus, the tool **404** can be used in neurosurgery and cranio-maxillofacial (CMF) surgery. For example, in neurosurgery, the tool **404** can be used for decompression of neurovascular structures (i.e., optic nerve), frontal craniotomy, and a transorbital approach. The tool **404** can also be used to gain access the following anatomies, namely: the anterior clinoid process, dorsum sellae, internal acoustic meatus, posterior cranial fossa, middle cranial fossa, groove for sigmoid sinus, superorbital fissure, optical canal, cribriform plate, crista galli, clinoid process, lesser wing of sphenoid, and greater wing of sphenoid. In CMF surgery, the tool **404** can also be used to gain access the following anatomies, namely coronoid process, condyle, ramus, angle, groove for external maxillary artery, maxillary frontal process, anterior lacrimal crest, lacrimal groove, orbital surface, maxillary tuberosity, zygomatic process, alveolar process, nasal bone, vomer bone, sphenoid, and palatine bones.

With reference to FIG. 8, an embodiment of a tool **504** can be removably coupled to the transducer assembly **102** (FIG. 2). The tool **504** is substantially similar to the tool **204** described above with respect to FIGS. 5A-C, and defines a first or proximal end **510** and a second or distal end **512**. For instance, the tool **504** can have a length **L4** defined between the proximal end **510** and the distal end **512**. The length **L4** can be substantially similar or identical to the length **L1** described above with respect to FIGS. 5A-5C. In the depicted embodiment, the length **L4** of the tool **504** is greater than about 80 millimeters. In an embodiment, the length **L4** of the tool **504** ranges between about 20 millimeters and 120 millimeters. In one embodiment, the length **L4** of the tool **504** is about 105.7 millimeters. The length **L4** of the tool **504** is important, because it allows the surgeon to employ minimally invasive approaches and to reach areas difficult to access. The length **L3** of the tool **404** also enhances visibility of the surgical target site and forgoes the need to cut soft tissue surrounding the target bone or soft tissue, thereby reducing post-operative swelling.

In an embodiment, the tool **504** includes a first section **506** and a second section **508**. The first section **508** is configured to be coupled to the transducer assembly **102** (FIG. 2), whereas the second section **508** is connected to the first section **506**. The first and second sections **506** and **506** can be made of different materials. In one embodiment, the first section **506** can be substantially similar or identical to the first section **206** shown in FIGS. 5A-5C. Thus, the first section **506** can be partly or wholly made from a titanium alloy, such as the titanium alloys described above in connection with the tool **204**. The second section **508** can be substantially similar or identical to the second section **208** shown in FIGS. 5A-5C, except for its operative portion **526**. For example, the second section **508** can be partly or wholly made from any suitable stainless steel, such as the stainless steel described above in connection with the tool **204**. Like the second section **208** shown in FIGS. 5A-5C, the second section **408** of the tool **404** can include a connection portion **518** that is directly or indirectly connected to the first section **506**. Although the operative portion **526** of the depicted embodiment does not include an elbow, it is envisioned that the operative portion **524** can include an elbow, such as the elbow **224** described above in connection with FIGS. 5A-5C.

The operative portion **526** includes a support body **523** and a cutting member **528** that is carried by the support body **523**. For instance, the cutting member **528** can be monolithic with the support body **523**. The cutting member **528**, in turn, carries at least one cutting surface **525** that is configured to vibrate and to contact a tissue body in order to cut, for instance shape or remove, the tissue body. The cutting member **528** can be located at the distal end **512** of the tool **504**. In an embodiment, the cutting member **528** can have a substantially ellipsoidal shape. As used herein, the term "ellipsoidal" includes, but is not limited to, the following terms, namely: spherical, oblate spheroidal, prolate spheroidal, and a scalene ellipsoidal. Hence, the cutting member **528** can have a substantially spherical shape, a substantially oblate spheroidal shape, a substantially prolate spheroidal shape, or a substantially scalene ellipsoidal. The cutting surface **525** is partly or entirely coated with a suitable abrasive material. At least a portion of the cutting member **528** can be coated with an abrasive coating **530**. The abrasive coating **530** can be partly or entirely made from an abrasive material suitable to cut, for instance shape or remove, a tissue body when the cutting surface **525** vibrates at a predetermined frequency. Suitable abrasive materials

include, but are not limited to, diamond and diamond-like carbons (DLC), such as tetrahedral amorphous carbon (ta-C). The abrasive material can have a nano-crystalline or micro-crystalline structure. The abrasive coating **530** can be about 107 micrometers (μm) thick. The tool **504** can include an irrigation fluid channel and inner threads as described above with respect to FIGS. 5D.

The operation of the tool **504** can be substantially similar or identical to the operation of the tool **204** described above with respect to FIGS. 5A-C. In operation, tool **504** can be used for mandible and skull based procedures, transnasal and transorbital approaches, lateral decompression, and full ramus osteotomy. Thus, the tool **504** can be used in neurosurgery and cranio-maxillofacial (CMF) surgery. For example, in neurosurgery, the tool **504** can be used for decompression of neurovascular structures (i.e., optic nerve), frontal craniotomy, and a transorbital approach. The tool **504** can also be used to gain access the following anatomies, namely: the anterior clinoid process, dorsum sellae, internal acoustic meatus, posterior cranial fossa, middle cranial fossa, groove for sigmoid sinus, superorbital fissure, optical canal, cribriform plate, crista galli, clinoid process, lesser wing of sphenoid, and greater wing of sphenoid. In CMF surgery, the tool **504** can also be used to gain access the following anatomies, namely coronoid process, condyle, ramus, angle, groove for external maxillary artery, maxillary frontal process, anterior lacrimal crest, lacrimal groove, orbital surface, maxillary tuberosity, zygomatic process, alveolar process, nasal bone, vomer bone, sphenoid, and palatine bones.

With reference to FIGS. 9A-9C, an embodiment of a tool **604** is configured to be removably coupled to the transducer assembly **102**, and defines a first or proximal end **610** and a second or distal end **612**. The tool **604** has a length **L5** defined between the proximal end **610** and the distal end **612** along a longitudinal direction indicated by arrows B. The tool **604** is substantially similar to the tool **204** described with respect to FIGS. 5A-5C, except for the operative portion **626**. In the depicted embodiment, the length **L5** of the tool **604** is greater than about 80 millimeters. In an embodiment, the length **L5** of the tool **604** ranges between about 20 millimeters and about 120 millimeters. In one embodiment, the length **L5** of the tool **604** is about 105.7 millimeters. The length **L5** of the tool **604** is important, because it allows the surgeon to employ minimally invasive approaches and to reach areas difficult to access. The length **L5** of the tool **604** also enhances visibility of the surgical target site and forgoes the need to cut soft tissue surrounding the target bone or soft tissue, thereby reducing post-operative swelling.

With continued reference to FIGS. 9A-9C, in an embodiment, the tool **604** includes a first section **606** and a second section **608**. The first section **606** is configured to be coupled to the transducer assembly **102** (FIG. 2), whereas the second section **608** is connected to the first section **606**. The first and second sections **606** and **608** can be made from different materials. In an embodiment, the first section **606** can be substantially similar or identical to the first section **206** shown in FIGS. 5A-5C. The first section **606** can be partly or wholly made from a titanium alloy, such as the titanium alloys described above in connection with the tool **204**. The first section **606** of the tool **604** extends in a direction along a longitudinal axis X2 and has an outer surface **614**. The outer surface **614** of the first section **606** defines a cross-sectional dimension or diameter D3. The first section **606** can be tapered so that the cross-sectional dimension or diameter D3 decreases in a direction from the proximal end

610 toward the distal end 612. Thus, the first section 606 can have a substantially frusto-conical shape. The cross-sectional dimension or diameter D3 is less than cross-sectional dimension or diameter of conventional tools to allow the surgeon to reach difficult areas to access. For example, the first section 206 can have a maximum diameter of about 5.8 millimeters.

With continued reference to FIGS. 9A-9C, the first section 606 can define one or more recesses 616 that extend into the outer surface 614. The recesses 616 are configured and sized to allow a holding tool, such as a wrench, to securely hold the tool 604. During assembly, a user can place a portion of the holding tool, such as a wrench, in the recesses 616 to hold the tool 604. The user can also use the holding tool to turn the tool 604 and thereby disconnect the tool 604 from the transducer assembly 104. In an embodiment, the tool 604 defines two identical recesses 614 disposed in a diametrically-opposed relationship to each other.

With continued reference to FIGS. 9A-9C, the second section 608 can be substantially similar or identical to the section 208 shown in FIGS. 5A-5C, except for its operative operation 626. For example, the second section 608 can be partly or entirely made from any suitable stainless steel, such as the stainless steel described above in connection with the tool 204. The second section 608 can include a connection portion 618 coupled to the first section 606. The connection portion 618 is elongate along the longitudinal direction B and defines an outer surface 620. The outer surface 620 of the connection portion 618 defines a cross-sectional dimension or diameter D4. The outer surface 620 can be tapered so that the cross-sectional dimension or diameter decreases in a direction toward the distal end 612. Thus, the connection portion 618 can have a substantially frusto-conical shape.

With continued reference to FIGS. 9A-9C, the second section 608 can further include a shoulder 622 coupled to the connection portion 618. The shoulder 622 can be connected to an elbow 624. The second section 608 can further include an operative section 626 directly or indirectly coupled to the elbow 624. The operative portion 626 is configured to contact a tissue body in order to cut, for instance shape or remove, such tissue body. In the depicted embodiment, the operative portion 626 is elongate along an axis Z2 that is oriented at an oblique angle relative to the longitudinal axis X2. At least part of the operative portion 626 can have a substantially flat or planar configuration. In one embodiment, the operative portion 626 can be substantially shaped as a scalpel.

With continued reference to FIGS. 9A-9C, the operative portion 626 includes a support body 623 and a cutting member 625 that is carried by the support body 623. For instance, the cutting member 625 can be monolithic with the support body 623. The cutting member 625, in turn, carries at least one cutting surface 627 that is configured to vibrate and to contact a tissue body in order to cut, for instance shape or remove, the tissue body. In accordance with one embodiment, the cutting member 625 can define a first top cutting surface 628 and a second top cutting surface 630. The first top surface 628 can contact the second top surface 630 so that the first top surface 628 and the second top surface 630 cooperate to define a first cutting edge 631. The first top surface 628 can be directly or indirectly connected to the second top surface 630. The cutting member 625 can further define a first side cutting surface 632, a second side cutting surface 634, and a bottom cutting surface 636. The first side cutting surface 632 can extend from the second top surface 630 in a direction toward the bottom surface 636. Moreover, the first side cutting surface 632 can contact the

second top cutting surface 630 such that the first side cutting surface 632 and the second top cutting surface 630 cooperate to define a cutting edge 633. The second side cutting surface 634 can extend from the second top cutting surface 630 toward the bottom surface 636. The second side cutting surface 634 can contact the second top cutting surface 630 such that the second side cutting surface 634 and the second top cutting surface 630 cooperate to define a cutting edge 635. The cutting member 625 can further define a front cutting surface 638 that can extend from the second top cutting surface 630 toward the bottom surface 636. The front cutting surface 638 can contact the second top cutting surface 630 such that the front cutting surface 638 and the second top cutting surface 630 cooperate to define a cutting edge 637. The front cutting surface 638 can contact the bottom cutting surface 636 such that the front cutting surface 638 and the bottom cutting surface 636 cooperate to define a cutting edge 639. The cutting member 625 can have a width W2 defined between the first side surface 632 and the second side surface 634 along a direction that is substantially perpendicular to the longitudinal direction B. In one embodiment, the width W2 ranges between approximately 2 millimeters and approximately 5 millimeters. In an embodiment, the width W2 is approximately 3 millimeters. The width W2 described above are important because they allow the surgeon to perform minimally invasive procedures. The tool 604 can include an irrigation fluid channel and inner threads as described above with respect to FIG. 5D.

With continued reference to FIGS. 9A-9C, the operation of the tool 604 is substantially similar or identical to the operation of the tool 204 described above with respect to FIGS. 5A-D. In operation, the tool 604 can be used for mandible and skull based procedures, transnasal and transorbital approaches, lateral decompression, contouring, osteotomy, and bone harvesting. When the tool 604 is connected to the transducer assembly 102, the transducer assembly 102 can propagate mechanical vibrations along tool 604. Specifically, when the transducer assembly 102 receives electrical energy, it converts the electrical energy into mechanical vibrations. Then, the transducer assembly 102 transmits the mechanical vibrations to the tool 604, causing at least the first section 606 to vibrate in the direction indicated by arrows B. The vibration of the first section 606 causes the operative portion 626 to vibrate in the direction indicated by arrows Y2. The operative portion 626 can then be placed in contact with a tissue body in order to cut, for instance shape or remove, such tissue body.

With continued reference to FIGS. 9A-9C, the tool 604 can be used in neurosurgery. For example, the tool 604 can be used for decompression of neurovascular structures (i.e., optic nerve), frontal craniotomy, and transorbital approach. In addition, the tool 604 can be used to access the following anatomical structures: anterior clinoid process, dorsum sellae, Internal acoustic meatus, Posterior cranial fossa, Middle cranial fossa, groove for sigmoid sinus, superorbital fissure, optical canal, cribriform plate, crista galli, clinoid process, lesser wing of sphenoid and greater wing of sphenoid. In CMF surgery, the tool 604 can be used to access the following anatomical structures: coronoid process, condyle, ramus, angle, groove for external maxillary artery, maxillary frontal process, anterior lacrimal crest, lacrimal groove, orbital surface, maxillary tuberosity, zygomatic process, alveolar process, nasal bone, vomer bone, sphenoid, and palatine bones.

With reference to FIGS. 17A and 17B, a second section 1408 can entirely or partly replace the second section of any

of the tools described in the present disclosure. The second section **1408** includes an elbow **1424** and an operative portion **1426** connected to the elbow **1424**. The operative portion **1426** includes a support body **1423** and a cutting member **1425** carried by the support body **1423**. The support body **1423** can be monolithically formed with the cutting member **1425**. Alternatively, the support body **1423** can be a discrete component connected to the cutting member **1425**. The cutting member **1425** can have a substantially flat configuration (e.g., planar configuration) and defines one or more cutting surfaces **1427**. In turn, the cutting surfaces **1427** define one or more cutting edges **1428** that are configured to cut, for instance, shape or remove, a tissue body as it vibrates at a predetermined frequency range. The cutting edges **1428** can thus be sharp. The cutting member **1425** further defines a pointed free tip **1429** that is configured to cut tissue. The pointed free end **1429** can have a substantially flat configuration (e.g., planar configuration) and can be tapered.

With reference to FIGS. **18A** and **18B**, a second section **1508** can entirely or partly replace the second section of any of the tools described in the present disclosure. The second section **1508** includes an elbow **1524** and an operative portion **1526** connected to the elbow **1524**. The operative portion **1526** includes a support body **1523** and a cutting member **1525** carried by the support body **1523**. The support body **1523** can be monolithically formed with the cutting member **1525**, and can have a substantially flat configuration (e.g., planar configuration). The cutting member **1525** defines one or more cutting surfaces **1527**. In turn, the cutting surfaces **1527** define a pair of cutting serrated edges **1528** that are configured to cut, for instance, shape or remove, a tissue body as it vibrates at a predetermined frequency range. The cutting serrated edges **1528** can be formed by a plurality of teeth **1530** that protrude outward from the support body **1523**. The cutting surfaces **1527** can further define a free pointed end **1529** that protrudes outward from the support body **1523**. The free pointed end **1529** can be sharp and can have a substantially planar configuration (e.g., flat configuration). Further, the free pointed end **1529** can have a substantially tapered configuration.

With reference to FIGS. **19A** and **19B**, a second section **1608** can entirely or partially replace the second section of any of the tools described in the present disclosure. The second section **1608** includes an elbow **1624** and an operative portion **1626**. The operation portion **1626** is identical or at least substantially similar to the operative portion **926** illustrated in FIGS. **12A-12C**. Thus, the description regarding the operative portion **926** applies to the operative portion **1626**.

With reference to FIGS. **20A** and **20B**, a second portion **1708** can entirely or partially replace the second section of any of the tools described in the present disclosure. The second section **1708** includes an elbow **1724** and an operative portion **1726** connected to the elbow **1724**. The operative portion **1726** includes a support body **1723** and a cutting member **1725** that is carried by the support body **1723**. The cutting member **1725** carries at least one cutting surface **1727** that is configured to vibrate and to contact a tissue body in order to cut, for instance shape or remove, the tissue body. In an embodiment, the cutting member **1727** can define a substantially flat top surface **1730** and a substantially flat bottom surface **1732** opposite to the substantially flat top surface **1730**. The top surface **1730** and the bottom surface **1732** cooperate to define first side cutting edge **1734** and a second side cutting edge **1736**. The cutting member **1725** further defines a front upper cutting surface **1738** and

a front lower cutting surface **1740**. The front upper cutting surface **1738** and the front lower cutting surface **1740** can be substantially flat and can cooperate to define a front cutting edge **1742**.

With reference to FIGS. **21A** and **21B**, a second section **1808** can entirely or partially replace the second section of any of the tools described in the present disclosure. The second section **1808** includes an elbow **1824** and an operative portion **1826** connected to the elbow **1824**. The operative portion **1826** includes a support body **1823** and a cutting member **1825** that is carried by the support body **1823**. The cutting member **1825** can have a substantially flat configuration (e.g., planar configuration) and includes one or more cutting surfaces **1827** that are configured to vibrate and to contact a tissue body in order to cut, for instance shape or remove, the tissue body. In an embodiment, the cutting member **1825** includes a top cutting surface **1828**, a bottom cutting surface **1830** opposite to the top cutting surface **1828**, and an outer cutting surface **1832** that interconnects the top cutting surface **1828** and the bottom cutting surface **1830**. The top cutting surface **1828** and the bottom cutting surface **1830** can have a substantially flat configuration (e.g., planar configuration). The outer cutting surface **1832** can also have a substantially flat configuration (e.g., planar configuration), and can be oriented at an oblique angle relative to the top cutting surface **1828** and/or the bottom cutting surface **1830**. In an embodiment, the outer cutting surface **1832** can be disposed in rounded manner around an axis **1834** that extends substantially perpendicular to the top cutting surface **1828** and/or the bottom cutting surface **1830**. As used herein, the term “rounded” includes, but is not limited to, a circular, elliptical, arched, semi-circular, curved, and elliptical arch. The top cutting surface **1828** and the outer cutting surface **1832** cooperate to define a top cutting edge **1836**. The top cutting edge **1836** can be disposed in a rounded manner about the axis **1834**. The bottom cutting surface **1830** and the outer cutting surface **1832** cooperate to define a bottom cutting edge **1838**. The bottom cutting edge **1838** can be disposed in a rounded manner about the axis **1834**.

With reference to FIGS. **22A** and **22B**, a second section **1908** can entirely or partly replace the second section of any of the tools described in the present disclosure. The second section **1908** includes an elbow **1924** and an operative portion **1926** connected to the elbow **1924**. The operative portion **1926** includes a support body **1923** and a cutting member **1925** that is carried by the support body **1923**. The support body **1923** can have a substantially flat configuration (e.g., planar configuration). The cutting member **1925** can carry at least one cutting surface **1927** that is configured to vibrate and to contact a tissue body in order to cut, for example shape or remove, the tissue body. The cutting member **1925** can define more than one cutting surface **1927**, such as a pair of cutting surfaces **1927**, that define a cutting edge **1928**. In one embodiment, the cutting member **1925** defines a serrated edge **1928** so as to define a plurality of teeth **1930** that protrude outward from the support body **1923** along a direction away from the support body **1923**, which can be angularly offset with respect to a longitudinal direction **1901**. In an embodiment, the teeth **1930** are spaced apart from one another along a longitudinal row in an angled direction **1903**. The angled direction **1903** can be oriented at an oblique angle relative to the longitudinal direction **1901**.

With reference to FIGS. **23A** and **23B**, a second section **2008** can entirely or partly replace the second section of any of the tools described in the present disclosure. The second section **2008** includes an elbow **2024** and an operative

portion **2026** connected to the elbow **2024**. The operative portion **2026** includes a support body **2023** and a cutting member **2025**. The cutting member **2025** carries one or more cutting surfaces **2027** that are configured to vibrate and to contact a tissue body in order to cut, for example shape or remove, the tissue body. In an embodiment, the cutting member **2025** defines an upper cutting surface **2028**, a lower cutting surface **2029** opposite to the upper cutting surface **2028**, a first side cutting surface **2030**, and a second cutting side surface **2031**. Each of the first and second side cutting surfaces **2030** and **2031** can interconnect the upper cutting surface **2028** and the lower cutting surface **2029**. The distance defined from the first side cutting surface **2030** to the second side cutting surfaces **2031** increases in a direction from the cutting member **2025** toward the elbow **2024** so as to define a tapered cutting member **2025**. The first and second side cutting surfaces **2030** and **2031** cooperate to define a front sharp edge **2032**.

With reference to FIGS. **24A**, **24B**, and **25** a second section **2108** can entirely or partially replace the second section of any of the tools described in the present disclosure. The second section **2108** includes an elbow **2124** and an operative portion **2126** directly or indirectly connected to the elbow **2124**. The operative portion **2126** includes a support body **2123** and a cutting member **2125** that is carried by the support body **2125**. The cutting member **2125** carries at least one cutting surface **2127** that is configured to vibrate and to contact a tissue body in order to cut (e.g., shape or remove) the tissue body. The cutting member can define more than one cutting surface **2127**, such as a pair of cutting surfaces **2127**, that define a cutting edge **2128**. The cutting edge **2128** can be sharp and can be serrated or non-serrated. In one embodiment, the cutting member **2125** can include a serrated edge **2128** so as to define a plurality of teeth **2130** that protrude outward from the support body **2125** as shown in FIG. **25**. The serrated edge **2128** can define a plurality of teeth **2130** that are spaced apart from each other along or around a perimeter. This perimeter may, for example, have a round shape. As used herein, the term “round” includes, but is not limited to, the following shapes: curved, elliptical, circular, semi-circular, and oval. In an embodiment, the teeth **2130** are spaced apart from each other around a circumference. Thus, the teeth **2130** can be arranged, for example, along an annular row. Regardless of its shape or arrangement, the serrated edge **2128** is configured to cut (e.g., shape or remove) a tissue body as it vibrates.

With reference to FIGS. **25A** and **25B**, a second section **2208** can entirely or partially replace the second section of any of the tools described in the present disclosure. The second section **2208** includes a first elbow **2224**, a second elbow **2221**, and a connecting member **2282**, such as a rod, connected between the first elbow **2224** and the second elbow **2221**. The first elbow **2224** changes the direction of the second section **2208** from a first direction to a second direction as indicated by arrow **2201**. The second section **2208** further includes an operative portion **2226** directly or indirectly connected to the second elbow **2221**. The operative portion **2226** includes a support body **2223** and a cutting member **2225** that is carried by the support body **2223**. For instance, the cutting member **2225** can be monolithic with the support body **2223**. The cutting member **2225**, in turn, carries at least one cutting surface **2227** that is configured to vibrate and to contact tissue body in order to cut, for instance, shape or remove, the tissue body. The cutting surfaces **2227** can define at least one cutting edge **2228** that is configured to cut, for instance shape or remove, a tissue body as it vibrates at a predetermined frequency. The cutting

edge **2228** can be sharp and can be serrated or non-serrated. In the depicted embodiment, the cutting member **2225** defines a serrated cutting edge **2228** so as to define a plurality of teeth **2230** that protrude outward from the support body **2223** along a direction away from the second elbow **2221**. The teeth **2230** of the cutting member **2225** are spaced from each other along a row direction indicated by arrow **2203**.

With reference to FIGS. **26A** and **26B**, a second section **2308** can entirely or partially replace the second section of any of the tools described in the present disclosure. The second section **2308** includes a first elbow **2324**, a second elbow, **2321**, and a connection member **2382**, such as a rod, connected between the first elbow **2324** and the second elbow **2321**. The second section **2308** is substantially similar to the second section **2208** illustrated in FIGS. **25A** and **25B**. However, the first elbow **2324** changes the direction of the second section **2308** from a first direction to a second direction as indicated by arrow **2301**. The direction indicated by arrow **2301** is opposite to the direction indicated by arrow **2201** in FIG. **26B**. The second section **2308** further includes an operative portion **2326** directly or indirectly connected to the second elbow **2321**. The operative portion **2326** includes a support body **2323** and a cutting member **2325** that is carried by the support body **2323**. For instance, the cutting member **2325** can be monolithic with the support body **2323**. The cutting member **2325**, in turn, carries at least one cutting surface **2327** that is configured to vibrate and to contact tissue body in order to cut, for instance, shape or remove, the tissue body. The cutting surfaces **2327** can define at least one cutting edge **2328** that is configured to cut, for instance shape or remove, a tissue body as it vibrates at a predetermined frequency. The cutting edge **2328** can be sharp and can be serrated or non-serrated. In the depicted embodiment, the cutting member **2325** defines a serrated cutting edge **2328** so as to define a plurality of teeth **2330** that protrude outward from the support body **2323** along a direction away from the second elbow **2321**. The teeth **2330** of the cutting member **2325** are spaced from each other along a row direction indicated by arrow **2303**.

With reference to FIGS. **28A** and **29B**, an embodiment of a tool **2404** can be removably coupled to the transducer assembly **102** (FIG. **2**). The tool **2404** is similar to the tool **404** described above with respect to FIG. **7**. Like the tool **404**, the tool **2404** includes a first section **2406** configured to be coupled to the transducer assembly **102** (FIG. **2**) and a second section **2408** that is connected to the first section **2406**. The first section **2406** and the second section **2408** can be made of different materials as discussed above with respect to the embodiment illustrated in FIG. **7**. The first section **2406** is elongate along a longitudinal direction **2401**. The second section **2408** includes a connection portion **2418**, such as a rod, that is connected to the first section **2406**, an elbow **2424** that is coupled to the connection portion **2418**, and an operative portion **2426** that is connected to the elbow **2424**. A portion of the second section **2408** can be elongate along the longitudinal direction **2401**; however, the elbow **2424** changes the direction of the second section **2408** such that the operative portion **2426** is elongate along an angled direction **2403**. The angled direction **2403** is oriented at an oblique angle relative to the longitudinal direction **2401**. The elbow **2424** can define a predetermined curvature or even a substantially right angle. The operative portion **2426** includes a support body **2423** that is connected to the elbow **2424**, and a cutting member **2425** that is carried by the support body **2423**. The cutting member **2425** defines at least one cutting surface **2436**. The cutting surface **2436**

is configured to vibrate and to contact a tissue body in order to cut (e.g., shape or remove) the tissue body. The cutting surface **2436** can be entirely or partly covered with an abrasive coating **2437**. The abrasive coating **2437** can be made of any suitable abrasive material such as diamond particles. The cutting member **2425** can have a substantially spherical shape or any other ellipsoidal shape. As used herein, the term “ellipsoidal” includes, but is not limited to, the following terms, namely: spherical, oblate spheroidal, prolate spheroidal, and a scalene ellipsoidal. Hence, the body **328** can have a substantially spherical shape, a substantially oblate spheroidal shape, a substantially prolate spheroidal shape, or a substantially scalene ellipsoidal.

The second section **2408** can have different shapes and features as illustrated in FIGS. **29A-48B**. The embodiments shown in FIGS. **29A-48B** include the abrasive coating **2437**. For example, the cutting member **2425** can have an arched-shape and the abrasive coating **2437** can cover the cutting member **2425** and at least a portion of the elbow **2424** as shown in FIGS. **29A** and **29B**. As seen in FIGS. **30A** and **30B**, the cutting member **2425** can be substantially spherical but have a different size as the size of the cutting member shown in FIGS. **28A** and **28B**. As illustrated in FIGS. **31A** and **31B**, the cutting member **2425** can be spoon-shaped, and the abrasive coating **2437** can partly cover the cutting surface **2436**. As depicted in FIGS. **32A** and **32B**, the support body **2423** can be tapered so that its cross-section dimension (e.g., diameter) can decrease in a direction from the cutting member **2425** toward the elbow **2424**. As shown in FIGS. **33A** and **33B**, the cutting member **2425** can have substantially cylindrical portion **2425a** and a substantially hemispherical end **2425b**. As seen in FIGS. **34A** and **34B**, the support body **2423** and the cutting member **2425** can have a substantially flat configuration (e.g., planar configuration).

As shown in FIGS. **35A** and **35B**, the support body **2423** and the cutting member **2425** can have different sizes as the sizes of the embodiments described above. As shown in FIGS. **36A** and **36B**, the cutting member **2425** can be a projection that protrudes from the support body **2423**, and that is significantly smaller than the support body **2423**. As seen in FIGS. **37A** and **37B**, the cutting member **2425** can have a substantially oblong shape. As shown in FIGS. **38A** and **38B**, the cross-sectional dimension (e.g., diameter) of the cutting member **2425** can be greater than the cross-sectional dimension (e.g. diameter) of the support body **2423**. As seen in FIGS. **39A** and **39B**, both the cutting member **2425** and the support body **2423** can be tapered such that the cross-sectional dimensions (e.g., diameters) of the cutting member **2425** and the support member **2423** decreases in a direction from the cutting member **2425** toward the elbow **2424**.

As depicted in FIGS. **40A** and **40B**, the curvature of the elbow **2424** can be different than in other embodiments. In addition, the cross-sectional dimension (e.g., diameter) of at least a portion of the cutting member **2425** can be identical or substantially similar to the cross-sectional dimension (e.g., diameter) of at least a portion of the support body **2423**. As seen in FIGS. **41A** and **41B**, the cutting member **2425** can have substantially cylindrical portion **2425a** and a substantially flat end **2425b**. As illustrated in FIGS. **42A** and **42B**, the cutting member **2425** can have substantially frusto-conical portion **2425a** and a substantially hemispherical end **2425b**. As shown in FIGS. **43A** and **43B**, the cutting member **2425** can have a substantially flat and triangular shape. As seen in FIGS. **44A** and **44B**, the cutting member **2425** can be significantly smaller than the support body **2423**. As seen in

FIGS. **45A** and **45B**, the support body **2423** can have a different length in comparison with the embodiment described above. In addition, the elbow **2424** can have a different curvature than other embodiments. As depicted in FIGS. **46A** and **46B**, the cutting member **2425** can have a frusto-conical shape, and can have a cross-sectional dimension that is less than the cross-sectional dimension of other embodiments. As shown in FIGS. **47A**, **47B**, **48A**, and **48B**, the support body **2423** can have more than one elbow **2424**, and the cutting member **2425** can be arched-shape. Specifically, the support body **2423** can have a first elbow **2424a** and a second elbow **2424b**. The elbows **2424** can curve along different directions.

FIGS. **10A-16** illustrate various schematics of different embodiments of a tool in accordance with the present disclosure.

It should be noted that the illustrations and discussions of the embodiments shown in the figures are for exemplary purposes only, and should not be construed limiting the disclosure. One skilled in the art will appreciate that the present disclosure contemplates various embodiments. It should be further appreciated that the features and structures described and illustrated in accordance one embodiment can apply to all embodiments as described herein, unless otherwise indicated. Additionally, it should be understood that the concepts described above with the above-described embodiments may be employed alone or in combination with any of the other embodiments described above.

What is claimed:

1. A cutting system configured to cut a tissue body, the cutting system comprising:

a transducer assembly configured to receive electrical energy and convert the received electrical energy to mechanical vibration at a predetermined frequency in a range of about 28 kHz to about 36 kHz; and

a tool including a first end and a second end spaced from the first end along a longitudinal direction, the tool configured to be coupled to and located distally from the transducer assembly such that mechanical vibrations produced by the transducer assembly are transmitted to the tool thereby causing the tool to vibrate at the predetermined frequency, wherein the tool consists essentially of:

a first section coupled to and distally adjacent to the transducer assembly, the first section elongate along a first axis that extends along the longitudinal direction, the first section having a proximal end defining the first end, and the first section constructed from a titanium alloy; and

a second section coupled to and distally adjacent to the first section, the second section constructed from stainless steel having a density greater than the titanium alloy, the second section comprising an operative portion elongate along a second axis coplanar with the first axis, the second axis oriented at an oblique angle relative to the first axis, the operative portion including a support body and a cutting member located distally of the support body, the cutting member configured to cut the tissue body when the cutting member vibrates at the predetermined frequency, the cutting member having a distal tip extending from the support body and defining the second end, the cutting member defining a serrated edge at the distal tip, the serrated edge defining teeth that protrude outwardly from the support body, each

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of the teeth tapering linearly and distally to a pointed tip in a plane coextensive with the first and second axes;

wherein when the tool receives the mechanical vibrations generated by the transducer assembly, the first section and at least a part of the second section vibrates back and forth along the longitudinal direction at the predetermined frequency;

wherein the tool has a length extending from the first end to the second end along the longitudinal direction between about 80 to about 120 millimeters;

wherein the cutting member is configured to vibrate at a cutting member amplitude range that is between about 300 percent to about 500 percent of a transducer assembly amplitude of the mechanical vibration produced by the transducer assembly when the first section is coupled to the transducer assembly and the transducer assembly is activated; and

wherein, at the predetermined frequency and the cutting member amplitude range, the cutting member is configured to cut mineralized tissue while not cutting soft tissue.

2. The cutting system according to claim 1, further comprising a power supply electrically coupled to the trans-

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ducer assembly, wherein the power supply is configured to supply electrical energy to the transducer assembly.

3. The cutting system according to claim 1, further comprising a controller electrically coupled to the transducer assembly, wherein the controller is configured to control electrically energy supplied to the transducer assembly.

4. The cutting system according to claim 1, wherein the length is about 105.7 millimeters.

5. The cutting system according to claim 1, wherein the titanium alloy is a Ti 6-Al 4-V alloy.

6. The cutting system according to claim 1, wherein the second section includes an elbow, such that at least a portion of the second section is elongated along the second axis.

7. The cutting system according to claim 1, wherein the cutting member defines at least one cutting surface, and further comprises an abrasive coating that covers at least a portion of the at least one cutting surface, and the abrasive coating is at least made from an abrasive material.

8. The cutting system according to claim 7, wherein the abrasive material comprises diamond particles.

9. The cutting system according to claim 7, wherein the abrasive material comprise diamond-like carbons.

* * * * *

专利名称(译)	超声波手术系统的切割技巧		
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摘要(译)

工具被配置为切割组织体。该工具包括第一部分和第二部分，第一部分构造成连接到换能器组件，第二部分连接到第一部分。第一部分至少部分地包括第一材料。第二部分至少部分地包括第二材料，该第二材料与第一材料不同并且比第一材料更密集。第二种包括切割构件，该切割构件构造成以预定频率振动，以便将组织体切割成操作部分。

