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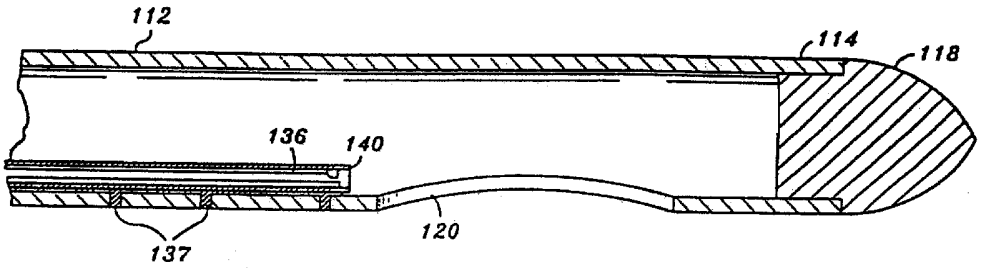
(54) Title: TISSUE REMOVER AND METHOD



(57) Abstract: An electromagnetically induced cutting mechanism provides accurate cutting operations on hard or soft tissues. The electromagnetically induced cutter is adapted to interact with atomized fluid particles. A tissue remover comprises an aspiration cannula housing a fluid and energy guide for conducting electromagnetically induced cutting forces to the site within a patient's body for aspiration of hard or soft tissue. The cannula is provided with a cannula distal end. The proximal end of the cannula is provided with fluid flow connection to an aspiration source. Separated hard or soft tissue and fluid are aspirated through the cannula distal end and the cannula by an aspiration source at the proximal end of the cannula. Methods of using such a cutter for hard or soft tissue removal are also disclosed.

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TISSUE REMOVER AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/535,182, filed January 8, 2004 and entitled TISSUE REMOVE AND METHOD, the contents of which are expressly incorporated herein by reference. This application is a continuation-in-part of co-pending U.S. Application No. 10/667,921 filed September 22, 2003 and entitled TISSUE REMOVER AND METHOD, which is a continuation of co-pending U.S. Application No. 09/714,479 filed November 15, 2000 and entitled TISSUE REMOVER AND METHOD, which is a continuation-in-part of U.S. Application No. 09/188,072, filed November 6, 1998, now U.S. Patent No. 6,254,597 and entitled TISSUE REMOVER AND METHOD, the contents of all of the above which are expressly incorporated herein by reference. U.S. Application No. 09/188,072 claims the benefit of U.S. Provisional Application No. 60/064,465 filed November 6, 1997 and entitled ELECTROMAGNETICALLY INDUCED MECHANICAL CUTTER FOR LYPOSUCTION the contents of which are expressly incorporated herein by reference. U.S. Application No. 09/188,072 is also a continuation-in-part of U.S. Application No. 08/985,513 filed December 5, 1997 and entitled USER PROGRAMMABLE COMBINATION OF ATOMIZED PARTICLES FOR ELECTROMAGNETICALLY INDUCED CUTTING, which is a continuation of U.S. Application No. 08/522,503 filed August 31, 1995 and entitled USER PROGRAMMABLE COMBINATION OF ATOMIZED PARTICLES FOR ELECTROMAGNETICALLY INDUCED CUTTING which issued into U.S. Pat. No. 5,741,247, both of which are commonly assigned and the contents of which are expressly incorporated herein by reference. U.S. Application No. 09/188,072 is also a continuation-in-part of co-pending U.S. Application No. 08/995,241, filed December 17, 1997 and entitled FLUID CONDITIONING SYSTEM, which is a continuation of U.S. Application No. 08/575,775, filed December 20, 1995 and entitled FLUID CONDITIONING SYSTEM which issued into U.S. Pat. No. 5,785,521, both of which are commonly assigned and the contents of which are expressly incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to medical apparatus and, more particularly, to methods and apparatus for cutting and removing soft or hard tissue from patients.

2. Description of Related Art

Turning to FIG. 1, an example of one of many varying types of prior art optical cutters includes a fiber guide tube 5, a water line 7, an air line 9, and an air knife line 11 for supplying pressurized air. A cap 15 fits onto the hand-held apparatus 13 and is secured via threads 17. The fiber guide tube 5 abuts within a cylindrical metal piece 19. Another cylindrical metal piece 21 is a part of the cap 15. The pressurized air from the air knife line 11 surrounds and cools the laser as the laser bridges the gap between the two metal cylindrical objects 19 and 21. Air from the air knife line 11 flows out of the two exhausts 25 and 27 after cooling the interface between elements 19 and 21.

The laser energy exits from the fiber guide tube 23 and is applied to a target surface of the patient. Water from the water line 7 and pressurized air from the air line 9 are forced into the mixing chamber 29. The air and water mixture is very turbulent in the mixing chamber 29, and exits this chamber through a mesh screen with small holes 31. The air and water mixture travels along the outside of the fiber guide tube 23, and then leaves the tube and contacts the area of surgery.

Other examples of a wide array of prior art devices and methods include U.S. Patent No. 5,199,870 to Steiner et al. and U.S. Patent No. 5,267,856 to Wolbarsht et al. Other devices have existed in the prior art for utilizing laser energy to perform soft tissue procedures, wherein for example laser energy facilitates the separation or manipulation of soft tissue in vivo. U.S. Patent No. 4,985,027 to Dressel discloses one example of many various types of devices in the field. According to this one example of a prior art device, the contents of which are expressly incorporated herein by reference, a tissue remover utilizes laser energy from a Nd:YAG to separate tissue held within a cannula. Use of the Nd:YAG laser for in vivo tissue removal may in some ways be inefficient,

since the energy from the Nd:YAG laser may not be highly absorbed by water. Further, the Nd:YAG laser and other lasers, such as an Er:YAG laser, may in some configurations use thermal heating as the sole cutting mechanism. Adjacent tissue may in certain implementations be charred or thermally damaged and, further, noxious and potentially toxic smoke may in some instances be generated during the thermal cutting operations.

Many devices also have existed in the prior art for performing endoscopic surgical procedures, wherein for example one or more catheters or cannulas are inserted through a small opening in a patient's skin to provide various working passageways through which small surgical instruments can be advanced into the patient during surgery. Specific endoscopic applications include arthroscopic surgery, neuroendoscopic surgery, laparoscopic surgery, and liposuction. Arthroscopic surgery refers to surgery related to, for example, joints such as the shoulders and knees. One example of a prior-art device, which has been used during the implementation of an arthroscopic surgical procedure, is an arthroscopic shaver. The arthroscopic shaver entails the application of a spinning tube-within-a-tube that concurrently resects tissue while aspirating debris and saline from within the operative site. One such arthroscopy system is the DYONICS.RTM. Model EP-1 available from Smith & Nephew Endoscopy, Inc., of Andover, Mass. Cutting with such an instrument is obtained by driving the inner tube at a high speed using a motor. Surrounding the tubular blade is an outer tubular membrane having a hub at its proximal end adapted to meet with the handle. Performing an arthroscopic procedure with a high-speed rotary shaver such as the one mentioned may in certain instances result in extensive trauma to the tissue and blood vessel laceration.

SUMMARY OF THE INVENTION

The present invention discloses an electromagnetically induced cutting mechanism, which can provide accurate cutting operations on hard and soft tissues, and other materials as well. Soft tissues may include fat, skin, mucosa, gingiva, muscle, heart, liver, kidney, brain, eye, and vessels, and hard tissue may include tooth enamel,

tooth dentin, tooth cementum, tooth decay, amalgam, composites materials, tarter and calculus, bone and cartilage.

In accordance with the present invention, an electromagnetically induced cutter is used to perform surgical procedures, using cannulas and catheters, also known as endoscopic surgical procedures. Endoscopic surgical applications for the electromagnetic cutter of the present invention include arthroscopic surgery, neuroendoscopic surgery, laparoscopic surgery, liposuction and other endoscopic surgical procedures. The electromagnetically induced cutter is suitable to be used for arthroscopic surgical procedures in the treatment of, for example: (i) torn menisci, anterior cruciate, posterior cruciate, patella malalignment, synovial diseases, loose bodies, osteal defects, osteophytes, and damaged articular cartilage (chondromalacia) of the knee; (ii) synovial disorders, labial tears, loose bodies, rotator cuff tears, anterior impingement and degenerative joint disease of the acromioclavicular joint and diseased articular cartilage of the shoulder joint; (iii) synovial disorders, loose bodies, osteophytes, and diseased articular cartilage of the elbow joint; (iv) synovial disorder, loose bodies, ligament tears and diseased articular cartilage of the wrist; (v) synovial disorders, loose bodies, labrum tears and diseased articular cartilage in the hip; and (vi) synovial disorders, loose bodies, osteophytes, fractures, and diseased articular cartilage in the ankle.

The electromagnetically induced cutter of the present invention is disposed within a cannula or catheter and positioned therein near the surgical site where the treatment is to be performed. In accordance with one aspect of the present invention, a diameter of the cannula or catheter is minimized to reduce the overall cross-sectional area of the cannula or catheter for the performance of minimally invasive procedures. In accordance with another aspect of the present invention, a plurality of catheters may be formed together for various purposes. For example, in arthroscopic knee surgery, one cannula can be configured to incorporate the cutting device and suction, and a separate cannula can be configured to incorporate the imaging system that monitors the treatment site during the procedure. In accordance with yet another aspect of the present invention, the suction, cutting device and imaging device may all be incorporated within the same cannula. Another aspect of the present invention may provide for an additional third cannula for supplying air to the treatment site.

The electromagnetically induced cutter of the present invention may be capable of providing extremely fine and smooth incisions, irrespective of the cutting surface. Additionally, a user programmable combination of atomized particles may allow for user control of various cutting parameters. The various cutting parameters may also be controlled by changing spray nozzles and electromagnetic energy source parameters. Applications for the present invention include medical procedures, such as arthroscopic surgery, neuroendoscopic surgery, laparoscopic surgery, liposuction and dental, and other environments where an objective may be to precisely remove surface materials with attenuation or elimination or one or more of thermal damage, uncontrolled cutting parameters, and/or rough surfaces inappropriate for ideal bonding. Certain implementations of the present invention further may not require films of water or particularly porous surfaces to obtain accurate and controlled cutting. Since in certain embodiments thermal heating may not be used, or may not be used exclusively, as the cutting mechanism, thermal damage may be attenuated or substantially eliminated. Moreover, in certain implementations, adjacent tissue may not be charred or thermally damaged, or charred or thermally damaged less, and, further, noxious and potentially toxic smoke may be attenuated or completely eliminated.

The electromagnetically induced cutter of the present invention includes an electromagnetic energy source, which focuses electromagnetic energy into a volume of air adjacent to a target surface. The target surface may comprise tissue within a cannula, for example. A user input device specifies a type of cut to be performed, and an atomizer responsive to the user input device places a combination of atomized fluid particles into the volume of air. The electromagnetic energy is focused into the volume of air, and the wavelength of the electromagnetic energy is selected to be substantially absorbed by the atomized fluid particles in the volume of air. Upon absorption of the electromagnetic energy the atomized fluid particles expand and impart cutting forces onto the target surface.

The electromagnetically induced cutter of the present invention can provide an improvement over prior-art high-speed rotary shavers, such as the above-mentioned arthroscopic shaver, since the electromagnetically induced cutter of the present invention may not directly contact the tissue to cause trauma and blood vessel laceration. Instead, cutting forces may remove small portions of the tissue through a process of fine or gross

erosion depending on the precision required. This process can be applied to precisely and cleanly shave, reshape, cut through or remove, for example, cartilage, fibrous cartilage, or bone without the heat, vibration, and pressure associated with rotary shaving instruments. The system can be used without air and/or water, in order to coagulate bleeding tissue. In accordance with another application of the electromagnetic cutter, a spray of water can be the carrier of an anti-coagulant medication that may also contribute to tissue coagulation.

Other endoscopic applications for the electromagnetically induced cutter may include neurosurgical and abdominal surgical applications. In neurosurgery, the electromagnetically induced cutter may be suited for removing brain tissue lesions, as well as for the cutting of various layers of tissue to reach the locations of the lesions. The entire method of creating an access through the scalp into the bone and through the various layers of tissue that protect the brain tissue may be accomplished with the electromagnetically induced cutter of the present invention.

The invention, together with additional features and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying illustrative drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an example of one of many types of conventional optical cutter apparatuses;

FIG. 2 is a schematic block diagram illustrating an example of an electromagnetically induced cutter of the present invention;

FIG. 3 illustrates an example of one embodiment of the electromagnetically induced cutter of the present invention;

FIGS. 4a and 4b illustrate examples of other embodiments of electromagnetically induced cutters;

FIG. 5 illustrates an example of a control panel for programming the combination of atomized fluid particles according to the present invention;

FIG. 6 is a plot of particle size versus fluid pressure in accordance with one implementation of the present invention;

FIG. 7 is a plot of particle velocity versus fluid pressure in accordance with one implementation of the present invention;

FIG. 8 is a schematic diagram illustrating examples of a fluid particle, a source of electromagnetic energy, and a target surface according to an aspect of the present invention;

FIG. 9a is a side cut-away elevation view of a tissue remover of an embodiment of the present invention with a cannula tip;

FIG. 9b is a side cut-away elevation view of a tissue remover of an embodiment of the present invention with an open cannula end;

FIG. 10a is an exploded longitudinal section view of the distal end of the cannula with a cannula tip;

FIG. 10b is an exploded longitudinal section view of the distal end of the cannula with an open cannula end;

FIG. 11a is an exploded view similar to FIG. 10a, showing an embodiment of an electromagnetically induced cutter disposed adjacent the soft tissue aspiration inlet port;

FIG. 11b is an exploded view similar to FIG. 10b, showing an electromagnetically induced cutter disposed within the open cannula;

FIG. 11c is a block diagram illustrating an implementation of an imaging tube and imaging device disposed within the cannula;

FIG. 12 is a partial exploded longitudinal section view of the handle and proximal end cap showing the laser fiber and sources of fluids within the fluid and laser guide tube;

FIG. 13 is a partial exploded longitudinal section of an embodiment of a guide tube transmission coupler positioned within the handle; and

FIG. 14 is a cut-away detail of an implementation of an embodiment of the laser soft tissue device of the present invention illustrated in position for performing liposuction within a fatty deposit of a body intermediate overlying epidermal layer and underlying muscle layer.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 2 is a block diagram illustrating an electromagnetically induced cutter in accordance with an embodiment of the present invention. An electromagnetic energy source 51 is coupled to both a controller 53 and a delivery system 55. The delivery system 55 imparts forces onto the target surface 57. As presently embodied, the delivery system 55 comprises a fiber optic guide for routing the laser 51 into an interaction zone 59, located above the target surface 57. The delivery system 55 further comprises an atomizer for delivering user-specified combinations of atomized fluid particles into the interaction zone 59. The controller 53 controls various operating parameters of the laser 51, and further controls specific characteristics of the user-specified combination of atomized fluid particles output from the delivery system 55.

FIG. 3 shows a simple embodiment of the electromagnetically induced cutter of the present invention, in which a fiber optic guide 61, an air tube 63, and a water tube 65 are placed within a hand-held housing 67. As used herein, the term "water" is intended to encompass various modified embodiments of liquids such as distilled water, deionized water, sterile water, tap water or water that has a controlled number of colony forming units (CFU) for the bacterial count, etc. For instance, drinking water is often chemically treated to a level where there are no more than 500 CFU/ml and in some cases between 100 – 200 CFU/ml. The water tube 65 is operated under a relatively low pressure, and the air tube 63 is operated under a relatively high pressure. The laser energy from the fiber optic guide 61 focuses onto a combination of air and water, from the air tube 63 and the water tube 65, at the interaction zone 59. As used herein, mentions of air and/or water are intended to encompass various modified embodiments of the invention, including various biocompatible fluids used with or without the air and/or water, and including equivalents, substitutions, additives, or permutations thereof. For instance, in certain modified embodiments other biocompatable fluids may be used instead of air and/or water. Atomized fluid particles in the air and water mixture absorb energy from the laser energy of the fiber optic tube 61, and explode. The explosive forces from these atomized fluid particles impart cutting forces onto the target surface 57.

Turning back to FIG. 1, the prior art optical cutter focuses laser energy onto a target surface at an area A, for example, and the electromagnetically induced cutter of

the present invention can in certain embodiments be configured to focus laser energy into an interaction zone B, for example. The prior art optical cutter may use the laser energy directly to cut tissue, and the electromagnetically induced cutter of the present invention in certain configurations uses the laser energy to expand atomized fluid particles to thus impart at least partial cutting forces onto or into the target surface. The example of a prior art optical cutter may use a large amount of laser energy to cut the area of interest, and also may use a large amount of water to both cool this area of interest and remove cut tissue.

In contrast, the electromagnetically induced cutter of the present invention may in some implementations use a relatively small amount of water and, further, may be configured to use only a small amount of laser energy to expand atomized fluid particles generated from the water. According to the electromagnetically induced cutter of the present invention, water may not be needed to cool the area of surgery, since the exploded atomized fluid particles bay be cooled by exothermic reactions before they contact the target surface. Thus, atomized fluid particles of certain embodiments of the present invention can be heated, expanded, and cooled before contacting the target surface. The electromagnetically induced cutter of certain embodiments of the present invention may thus be capable of cutting without charring or discoloration.

FIG. 4a illustrates an embodiment of the electromagnetically induced cutter. The atomizer for generating atomized fluid particles comprises a nozzle 71, which may be interchanged with other nozzles (not shown) for obtaining various spatial distributions of the atomized fluid particles, according to the type of cut desired. A second nozzle 72, shown in phantom lines, may also be used. The cutting power of the electromagnetically induced cutter is further controlled by a user control 75 (FIG. 4b). In a simple embodiment, the user control 75 controls the air and water pressure entering into the nozzle 71. The nozzle 71 is thus capable of generating many different user-specified combinations of atomized fluid particles and aerosolized sprays.

Intense energy is emitted from the fiber optic guide 23. This intense energy can be generated from a coherent source, such as a laser. In an illustrated embodiment, the laser comprises either an erbium, chromium, yttrium, scandium, gallium garnet (Er, Cr:YSGG) solid state laser, which generates electromagnetic energy having a wavelength in a range of 2.70 to 2.80 microns, or an erbium, yttrium, aluminum garnet

(Er:YAG) solid state laser, which generates electromagnetic energy having a wavelength of 2.94 microns. The Er, Cr:YSGG solid state laser can have a wavelength of approximately 2.78 microns and the Er:YAG solid state laser has a wavelength of approximately 2.94 microns.

While comprising water in an illustrated embodiment, the fluid emitted from the nozzle 71 may comprise other fluids with appropriate wavelengths of the electromagnetic energy source being selected to allow for high absorption by the fluid. Other possible laser systems include an erbium, yttrium, scandium, gallium garnet (Er:YSGG) solid state laser, which generates electromagnetic energy having a wavelength in a range of 2.70 to 2.80 microns; an erbium, yttrium, aluminum garnet (Er:YAG) solid state laser, which generates electromagnetic energy having a wavelength of 2.94 microns; chromium, thulium, erbium, yttrium, aluminum garnet (CTE:YAG) solid state laser, which generates electromagnetic energy having a wavelength of 2.69 microns; erbium, yttrium orthoaluminate (Er:YALO3) solid state laser, which generates electromagnetic energy having a wavelength in a range of 2.71 to 2.86 microns; holmium, yttrium, aluminum garnet (Ho:YAG) solid state laser, which generates electromagnetic energy having a wavelength of 2.10 microns; quadrupled neodymium, yttrium, aluminum garnet (quadrupled Nd:YAG) solid state laser, which generates electromagnetic energy having a wavelength of 266 nanometers; argon fluoride (ArF) excimer laser, which generates electromagnetic energy having a wavelength of 193 nanometers; xenon chloride (XeCl) excimer laser, which generates electromagnetic energy having a wavelength of 308 nanometers; krypton fluoride (KrF) excimer laser, which generates electromagnetic energy having a wavelength of 248 nanometers; and carbon dioxide (CO2), which generates electromagnetic energy having a wavelength in a range of 9.0 to 10.6 microns. Water may be chosen as the preferred fluid because of its biocompatibility, abundance, and low cost. The actual fluid used may vary as long as it is properly matched (meaning it is highly absorbed) to the selected electromagnetic energy source (i.e. laser) wavelength.

The electromagnetic energy source can be configured with the repetition rate greater than 1 Hz, the pulse duration range between 1 picosecond and 1000 microseconds, and the energy greater than 1 milliJoule per pulse. According to one operating mode of the present invention, the electromagnetic energy source has a

wavelength of approximately 2.78 microns, a repetition rate of 20 Hz, a pulse duration of 140 microseconds, and an energy between 1 and 300 milliJoules per pulse.

In one embodiment the electromagnetic energy source has a pulse duration on the order of nanoseconds, which is obtained by Q-switching the electromagnetic energy source, and in another embodiment the electromagnetic energy source has a pulse duration on the order of picoseconds, which is obtained by mode locking the electromagnetic energy source. Q-switching is a conventional mode of laser operation which is extensively employed for the generation of high pulse power. The textbook, Solid-State Laser Engineering, Fourth Extensively Revised and Updated Edition, by Walter Koechner and published in 1996, the entire contents of which are expressly incorporated herein by reference, discloses Q-switching laser theory and various Q-switching devices. Q-switching devices generally inhibit laser action during the pump cycle by either blocking the light path, causing a mirror misalignment, or reducing the reflectivity of one of the resonator mirrors. Near the end of the flashlamp pulse, when maximum energy has been stored in the laser rod, a high Q-condition is established and a giant pulse is emitted from the laser. Very fast electronically controlled optical shutters can be made by using the electro-optic effect in crystals or liquids. An acousto-optic Q-switch launches an ultrasonic wave into a block of transparent optical material, usually fused silica. Chapter eight of the textbook, Solid-State Laser Engineering, Fourth Extensively Revised and Updated Edition, discloses the above-mentioned and other various Q-switching devices. Mode locking is a conventional procedure which phase-locks the longitudinal modes of the laser and which uses a pulse width that is inversely related to the bandwidth of the laser emission. Mode locking is discussed on pages 500-561 of the above-mentioned textbook entitled, Solid-State Laser Engineering, Fourth Extensively Revised and Updated Edition.

The atomized fluid particles can in certain implementations provide at least a part of the cutting forces when they absorb the electromagnetic energy within the interaction zone. In other implementations, part or all of the cutting forces may stem from other effects or mechanisms, such as thermal affects. The atomized fluid particles, however, can provide a second function of cleaning and cooling the fiber optic guide from which the electromagnetic energy is output. The delivery system 55 (FIG. 2) for delivering the electromagnetic energy includes a fiber optic energy guide or equivalent which attaches

to the laser system and travels to the desired work site. Fiber optics or waveguides are typically long, thin and lightweight, and are easily manipulated. Fiber optics can be made of calcium fluoride (CaF), calcium oxide (CaO2), zirconium oxide (ZrO2), zirconium fluoride (ZrF), sapphire, hollow waveguide, liquid core, TeX glass, quartz silica, germanium sulfide, arsenic sulfide, germanium oxide (GeO2), and other materials. Other delivery systems include devices comprising mirrors, lenses and other optical components where the energy travels through a cavity, is directed by various mirrors, and is focused onto the targeted cutting site with specific lenses. An embodiment of light delivery for medical applications of the present invention can be through a fiber optic conductor, because of its light weight, lower cost, and ability to be packaged inside of a handpiece of familiar size and weight to the surgeon, dentist, or clinician. In industrial applications, non-fiber optic systems may be used.

The nozzle 71 is employed to create an engineered combination of small particles of the chosen fluid. The nozzle 71 may comprise several different designs including liquid only, air blast, air assist, swirl, solid cone, etc. When fluid exits the nozzle 71 at a given pressure and rate, it is transformed into particles of user-controllable sizes, velocities, and spatial distributions. The nozzle may have spherical, oval, or other shaped openings of any of a variety of different sizes, according to design parameters.

FIG. 5 illustrates a control panel 77 for allowing user-programmability of the atomized fluid particles. By changing the pressure and flow rates of the fluid, for example, the user can control the atomized fluid particle characteristics. These characteristics may determine absorption efficiency of the laser energy, and the subsequent cutting effectiveness of the electromagnetically induced cutter. This control panel may comprise, for example, a fluid particle size control 78, a fluid particle velocity control 79, a cone angle control 80, an average power control 81, a repetition rate 82 and a fiber selector 83.

The cone angle may be controlled, for example, by changing the physical structure of the nozzle 71. Various nozzles 71 may be interchangeably placed on the electromagnetically induced cutter. Alternatively, the physical structure of a single nozzle 71 may be changed.

FIG. 6 illustrates a plot 85 of mean fluid particle size versus pressure. According to this figure, when the pressure through the nozzle 71 is increased, the mean fluid

particle size of the atomized fluid particles decreases. The plot 87 of FIG. 7 shows that the mean fluid particle velocity of these atomized fluid particles increases with increasing pressure.

According to one implementation of the present invention, materials are removed from a target surface at least in part by disruptive (e.g., mechanical) cutting forces, instead of by conventional cutting forces which in some instances may comprise purely thermal cutting forces. Laser energy may be used only to induce forces onto the targeted material. Thus, the atomized fluid particles can act as the medium for transforming the electromagnetic energy of the laser into the energy required to achieve the cutting effect of such an implementation of the present invention. The laser energy itself in such embodiments may not be directly absorbed by the targeted material. The interaction of the present invention may in certain instances be safer, faster, and/or eliminate the negative thermal side-effects typically associated with certain conventional laser cutting systems.

The fiber optic guide 23 (FIG. 4a) can be placed into close proximity of the target surface. This fiber optic guide 23, however, does not actually contact the target surface. Since the atomized fluid particles from the nozzle 71 are placed into the interaction zone 59, the purpose of the fiber optic guide 23 is for placing laser energy into this interaction zone, as well. One feature of the present invention is the formation of the fiber optic guide 23 of straight or bent sapphire. Regardless of the composition of the fiber optic guide 23, however, another feature of the present invention is the cleaning effect of the air and water, from the nozzle 71, on the fiber optic guide 23.

The present inventors have found that this cleaning effect is optimal when the nozzle 71 is pointed somewhat directly at the target surface. For example, debris from the cutting are removed by the spray from the nozzle 71.

Additionally, the present inventors have found that this orientation of the nozzle 71, pointed toward the target surface, enhances the cutting efficiency of the present invention. Each atomized fluid particle contains a small amount of initial kinetic energy in the direction of the target surface. When electromagnetic energy from the fiber optic guide 23 contacts an atomized fluid particle, the exterior surface of the fluid particle acts as a focusing lens to focus the energy into the water particle's interior. As shown in FIG. 8, the water particle 101 has an illuminated side 103, a shaded side 105, and a

particle velocity 107. The focused electromagnetic energy is absorbed by the water particle 101, causing the interior of the water particle to heat and explode rapidly. This exothermic explosion cools the remaining portions of the exploded water particle 101. The surrounding atomized fluid particles further enhance cooling of the portions of the exploded water particle 101. A pressure-wave is generated from this explosion. This pressure-wave, and the portions of the exploded water particle 101 of increased kinetic energy, are directed toward the target surface 107. The incident portions from the original exploded water particle 101, which are now traveling at high velocities with high kinetic energies, and the pressure-wave, may in certain implementations to impart strong, concentrated, forces onto the target surface 107.

These forces may cause the target surface 107 to break apart from the material surface through a "chipping away" action. The target surface 107 may not undergo, or may undergo a reduced amount of, vaporization, disintegration, or charring. The chipping away process can be repeated by the present invention until the desired amount of material has been removed from the target surface 107.

The nozzle 71 can be configured to produce atomized sprays with a range of fluid particle sizes narrowly distributed about a mean value. The user input device for controlling cutting efficiency may comprise a simple pressure and flow rate gauge 75 (FIG. 4b) or may comprise a control panel as shown in FIG. 5, for example. Upon a user input for a high resolution cut, relatively small fluid particles are generated by the nozzle 71. Relatively large fluid particles are generated for a user input specifying a low resolution cut. A user input specifying a deep penetration cut causes the nozzle 71 to generate a relatively low density distribution of fluid particles, and a user input specifying a shallow penetration cut causes the nozzle 71 to generate a relatively high density distribution of fluid particles. If the user input device comprises the simple pressure and flow rate gauge 75 of FIG. 4b, then a relatively low density distribution of relatively small fluid particles can be generated in response to a user input specifying a high cutting efficiency. Similarly, a relatively high density distribution of relatively large fluid particles can be generated in response to a user input specifying a low cutting efficiency.

Soft tissues may include fat, skin, mucosa, gingiva, muscle, heart, liver, kidney, brain, eye, and vessels, and hard tissue may include tooth enamel, tooth dentin, tooth

cementum, tooth decay, amalgam, composites materials, tarter and calculus, bone, and cartilage. The term "fat" refers to animal tissue consisting of cells distended with greasy or oily matter. Other soft tissues such as breast tissue, lymphangiomas, and hemangiomas are also contemplated. The hard and soft tissues may comprise human tissue or other animal tissue. Other materials may include glass and semiconductor chip surfaces, for example. The electromagnetically induced cutting mechanism can be further used to cut or ablate biological materials, ceramics, cements, polymers, porcelain, and implantable materials and devices including metals, ceramics, and polymers. The electromagnetically induced cutting mechanism can also be used to cut or ablate surfaces of metals, plastics, polymers, rubber, glass and crystalline materials, concrete, wood, cloth, paper, leather, plants, and other man-made and naturally occurring materials. Biological materials can include plaque, tartar, a biological layer or film of organic consistency, a smear layer, a polysaccharide layer, and a plaque layer. A smear layer may comprise fragmented biological material, including proteins, and may include living or decayed items, or combinations thereof. A polysaccharide layer will often comprise a colloidal suspension of food residue and saliva. Plaque refers to a film including food and saliva, which often traps and harbors bacteria therein. These layers or films may be disposed on teeth, other biological surfaces, and nonbiological surfaces. Metals can include, for example, aluminum, copper, and iron.

A user may adjust the combination of atomized fluid particles exiting the nozzle 71 to efficiently implement cooling and cleaning of the fiber optic guide 23 (FIG. 4a), as well. According to an implementation of the present invention, the combination of atomized fluid particles may comprise a distribution, velocity, and mean diameter to effectively cool the fiber optic guide 23, while simultaneously keeping the fiber optic guide 23 clean of particular debris which may be introduced thereon by the surgical site.

Looking again at FIG. 8, electromagnetic energy contacts each atomized fluid particle 101 on its illuminated side 103 and penetrates the atomized fluid particle to a certain depth. The focused electromagnetic energy is absorbed by the fluid, inducing explosive vaporization of the atomized fluid particle 101.

The diameters of the atomized fluid particles can be less than, almost equal to, or greater than the wavelength of the incident electromagnetic energy. In each of these three cases, a different interaction occurs between the electromagnetic energy and the

atomized fluid particle. When the atomized fluid particle diameter is less than the wavelength of the electromagnetic energy ($d<\lambda$), the complete volume of fluid inside of the fluid particle 101 absorbs the laser energy, inducing explosive vaporization. The fluid particle 101 explodes, ejecting its contents radially. As a result of this interaction, radial pressure-waves from the explosion are created and projected in the direction of propagation. The resulting portions from the explosion of the water particle 101, and the pressure-wave, may in some embodiments operate at least in part to produce the "chipping away" effect of cutting and removing of materials from the target surface 107. When the fluid particle 101 has a diameter, which is approximately equal to the wavelength of the electromagnetic energy ($d\blacktriangleleft\lambda$), the laser energy travels through the fluid particle 101 before becoming absorbed by the fluid therein. Once absorbed, the distal side (laser energy exit side) of the fluid particle heats up, and explosive vaporization occurs. In this case, internal particle fluid is violently ejected through the fluid particle's distal side, and moves rapidly with the explosive pressure-wave toward the target surface. The laser energy is able to penetrate the fluid particle 101 and to be absorbed within a depth close to the size of the particle's diameter. When the diameter of the fluid particle is larger than the wavelength of the electromagnetic energy ($d>\lambda$), the laser energy penetrates the fluid particle 101 only a small distance through the illuminated surface 103 and causes this illuminated surface 103 to vaporize. The vaporization of the illuminated surface 103 tends to propel the remaining portion of the fluid particle 101 toward the targeted material surface 107. Thus, a portion of the mass of the initial fluid particle 101 is converted into kinetic energy, to thereby propel the remaining portion of the fluid particle 101 toward the target surface with a high kinetic energy. This high kinetic energy is additive to the initial kinetic energy of the fluid particle 101. The effects can be visualized as a micro-hydro rocket with a jet tail, which helps propel the particle with high velocity toward the target surface 107. The electromagnetically induced cutter of the present invention can generate a high resolution cut. Unlike the cut of some prior art devices, the cut of the present invention can be clean and precise. Among other advantages, this cut can provide an ideal bonding surface, can be accurate, and may not stress remaining materials surrounding the cut.

FIGS. 9 and 14 illustrate an embodiment of a tissue remover 110 which utilizes an electromagnetically induced cutter in accordance with the present invention. The tissue remover 110 includes an aspiration cannula 112 having soft tissue aspiration inlet port 120 adjacent to the distal end 114 and cannula tip 118 in the configuration presented in FIGS. 9a and 10a. As illustrated in FIGS. 9a and 10a the cannula tip 118 can advantageously be a generally rounded, blunt or bullet shaped tip attached to the cannula 112 by welding or soldering. In FIGS. 9b and 10b, the tissue remover 110 is configured to have an open cannula configuration. As illustrated in FIG. 9, the cannula proximal end 116 is retained within the distal handle end cap 124, the aspirated soft tissue outlet port 128 is retained within the proximal handle end cap 126, and the distal handle end cap 124 and proximal handle end cap 126 are retained within the handle 122. The soft tissue outlet port 128 is connected to an aspiration source by a plastic tubing (not shown).

As illustrated in FIGS. 9-13, a fluid and laser fiber guide tube extends longitudinally within the tissue remover 110 from the proximal handle end cap 126, at the laser and fluid source port 141, terminating at a point 140 (FIG. 10) immediately proximal to the soft tissue aspiration inlet port 120 in the embodiment shown in FIG. 10a. In FIG. 10b, the laser and fluid source port 161 terminates at point 140 adjacent to the interaction zone 159. The fluid and laser fiber guide tube 136 resides partially within a coaxial fluid channel 130 (FIG. 12) drilled in the proximal handle end cap 126, and comprises a large fluid and laser fiber guide tube 132, a guide tube transition coupler 134, and a small fluid and laser fiber guide tube 136. The guide tube transition coupler 134 is positioned within the handle 122 proximal to the proximal end of the cannula 116 and is drilled to accommodate the external diameters of the large 132 and small guide tubes 136. The guide tube components are joined together and to the proximal handle end cap 126 and within the aspiration cannula inner wall utilizing a means such as soldering or welding. The fluid and laser guide tube can be provided with an O-ring seal 146 (FIG. 12) at its retention within the proximal handle end cap 126 at the laser energy source port 141. The optional guide tube transition coupler 134 can be used to provide for a small fluid and laser fiber guide tube 136 having a relatively small diameter. The optional guide tube transition coupler 134 also allows for more space within the aspiration cannula 112.

Housed within the fluid and laser fiber guide tube is the laser fiber optic delivery system. As shown in FIG. 11, the laser fiber optic delivery system comprises a fiber optic guide 123, an air tube 163 and a water tube 165. The fiber optic guide 123, air tube 163 and water tube 165 may be similar to the fiber optic guide 23, air tube 63 and water tube 65 described above with reference to FIG. 4a. The water tube 165 can be connected to a saline fluid source and pump, and the air tube can be connected to a pressurized source of air. The air tube 163 and the water tube 165 are terminated with a nozzle 171 which may be similar to the nozzle 171 described above with reference to FIG. 4a. In one embodiment, the fiber optic guide 123, air tube 163, and water tube 165 operate together to generate electromagnetically induced cutting forces. In another embodiment, there is only a water tube 165, and no air tube, connected to the nozzle 171. In this case, the nozzle 171 is a water-only type of nozzle. Any of the above-described configurations may be implemented to generate such forces, in modified embodiments.

In an embodiment wherein the fluid emitted from the water tube is water-based and the electromagnetic energy from the fiber optic guide 123 is highly absorbed by the water, it may in some instances be desirable to have a relatively non-aqueous environment (wherein body fluids are minimized) between the output end of the fiber optic guide 123 and the target surface. It may also be desirable in certain embodiments to maintain a non-aqueous environment between the nozzle 171 and the interaction zone 159 (FIG. 11) for generation of the atomized distributions of fluid particles. An aspect of the present invention involves keeping body fluids clear from the nozzle 171 and the interaction zone 159 enhances performance. Accordingly, means for reducing bleeding may be desired in certain implementations. In this connection, the distal blade of the cannula tip 118 can comprise a radio frequency (RF) cutting wire. Electrosurgery procedures using RF cutting wires implement high frequency (radio frequency) energy for implementing cutting of soft tissue and various forms of coagulation.

In electrosurgery, the high density of the RF current applied by the active electrosurgical electrode causes a cutting action, provided the electrode has a small surface (wire, needle, lancet, scalpel). Additionally the current waveform is a significant factor in the cutting performance. A smooth, non-modulated current is more suitable for scalpel-like cutting, whereas the modulated current gives cuts with predetermined

coagulation. The output *intensity* selected, as well as the output *impedance* of the generator, are also important with respect to cutting performance. The electrosurgical cutting electrode can be a fine micro-needle, a lancet, a knife, a wire or band loop, a snare, or even an energized scalpel or scissors. Depending on (1) the shape of the electrode, (2) the frequency and wave modulation, (3) the peak-to-peak voltage, and (4) the current and output impedance of the generator, the cut can be smooth, with absolutely no arcing, or it can be charring and burn the tissue. Electrosurgical coagulation may be carried out, for example, by implementing light charring and burning in a spray coagulation mode. The biological effect, accordingly, can significantly differ from gentle tissue dehydration to burning, charring and even carbonization. The temperature differences during the various coagulation process may vary between 100 degrees Celsius to well over 500 degrees Celsius. The means should be chosen in accordance with the amount of cutting and/or coagulation that is desired, which will be a function of various parameters such as the type of tissue being cut. In accordance with an object of the present invention of reducing smoke, bipolar applications or cutting with no-modulated current may be implemented.

Pressurized air, N_2 or O_2 can be output from the air tube 163 at various flow rates and various intervals, either during cutting or between cutting, in order to provide a relatively non-aqueous working environment for the electromagnetically induced cutting forces. Insufflation procedures, for example, for generating air cavities in the vicinity of the target tissue to be cut and removed can be used to attenuate the introduction of unwanted body liquids in the interaction zone 159.

The negative pressure generated and transmitted by the flexible suction tubing may serve to evacuate from the interaction zone 159 body fluids, removed tissue, and air and water from the nozzle 171. As presently embodied, the large fluid and laser fiber guide tube 132 is connected to a source of air and the negative pressure generated and transmitted by the flexible suction tubing serves to draw the air through the large fluid and laser fiber guide tube 132 and the small fluid and laser fiber guide tube 136. The source of air coupled to the large fluid and laser fiber guide tube 132 may comprise moist air. The flow of air out of the small fluid and laser fiber guide tube 136 serves to keep the nozzle 171, the output end 140 of the fiber optic guide 123, and the interaction zone159 relatively free of body fluids. If additional removal of body fluids is desired,

one or more pressurized air lines can be routed to distal end 114 of the cannula 114 adjacent to the cannula tip 118. The pressurized air line or lines can be activated to introduce air into the lumen of the cannula at the distal end of the cannula to thereby facilitate the removal of body fluids and water from the lumen. Effective removal of body fluids and water from the distal end of the cannula, including the interaction zone 159 and the portion of the lumen distal of the aspiration inlet port, occurs when fatty tissue within the aspiration inlet port forms a seal within the lumen of the cannula so any body fluids are drawn out to the cannula lumen by the negative pressure. The pressurized air line of lines provide displacement for the fluids as they are removed. If the body fluids are viscous, then water from the water tube 165 can be introduced to attenuate the viscosity of and accelerate the removal of the body fluids.

In accordance with certain embodiments only water or saline is delivered to the nozzle 171 during cutting. In other embodiments, the liquid delivered to the nozzle 171 carries different medications such as anesthetics, epinephrines, etc. The anesthetic may comprise, for example, lydocaine. The use of anesthetics and vessel constrictors, such as epinephrines, may help to provide anesthesia during and after surgery, and to reduce blood loss. One or more controls disposed proximally of the aspirated soft tissue outlet port 120 can allow the user to adjust the percent of air and/or water that is directed to the nozzle 171 at any given time. A control panel, having one or more of the features of the control panel 77 shown in FIG. 5, can be used to control, among other things, whether water alone, air alone, a combination of air and water, or a combination of air and medicated liquid is supplied to the nozzle 171.

The large guide tube 132 is maintained in position within cannula 112, for example, by silver solder through holes 137, as illustrated in FIGS. 10 and 11. The retention of the laser fiber optic delivery system is accomplished by a retaining screw 142 at the fluid, air and laser energy source port 141. As will be apparent to those skilled in this art, a shorter and thinner soft tissue aspiration cannula 112 will be useful in more restricted areas of the body, as under the chin, and a longer and larger diameter cannula will be useful in areas such as the thighs and buttocks where the cannula may be extended into soft tissue over a more extensive area. The cannula can be either rigid or flexible depending on the type of access necessary to reach the surgical site.

To perform the method of the present invention as illustrated in FIG. 14, the surgeon determines the location and extent of soft tissue to be removed. The appropriate size tissue remover 110 is selected. A short incision is made and the cannula tip 118 and the distal end of the cannula 114 are passed into the soft tissue to be removed. Air and sterile water/saline are delivered through the air and water tubes 163 and 165. The saline may help to facilitate the removal of fatty tissues. The aspiration pump is then activated. The resultant negative pressure thus generated is transmitted to the tissue remover 110 via a flexible suction tubing, to the soft tissue outlet port 128, through the handle 122, through the cannula 112, to the soft tissue aspiration inlet port 120. The resultant negative pressure at the inlet port draws a small portion of the soft tissue into the lumen of the cannula 112, into close proximity with the interaction zone 159 (FIG. 11a), or into the interaction zone 159 only when the cannula does not include an inlet port 120 such as the cannulas shown in FIGS. 9b, 10b and 11b. In the embodiment of FIGS. 9b, 10b and 11b, negative pressure may not be required, wherein the cannula 112 is advanced to close proximity of the target surface to be cut. The edges of the cannula 112 distal end can be generally rounded or bullet-shaped to facilitate insertion into the patient's tissue with a minimum of localized tissue trauma. The nozzle 171 and the output end of the fiber optic guide 123 may be disposed in a slightly proximal location, relative to the configuration shown in FIG. 11b, so that the output end of the fiber optic guide 123 is proximal of the distal end of the small fluid and laser fiber guide tube 136. Once the target tissue is positioned just distally of the interaction zone 159, the laser is activated and electromagnetically induced cutting forces are imparted onto the soft tissue within the cannula lumen, cleaving the soft tissue. Additional soft tissue enters the soft tissue aspiration inlet port 120 by virtue of a reciprocating longitudinal motion of the tissue remover 110 within the soft tissue. This reciprocating motion is applied by the surgeon's hand on the handle 122. The reciprocating motion of the tissue remover 110, with respect to the surrounding soft tissue, is facilitated by the stabilization of the soft tissue by the surgeon's other hand placed on the skin overlying the cannula soft tissue aspiration inlet port 120. Soft tissue that is cut or ablated near the interaction zone 159 is drawn and removed to the more proximal portion of the lumen of the cannula, and eventually out the cannula to the soft tissue outlet port 128 by the negative pressure generated by the aspiration pump.

Depending on the type of cannula or catheter used for the procedure, endoscopes for providing an image of the surgical site can be classified in three categories. Category 1 endoscopes include rigid scopes using a series of rigid rods coupled to the objective to capture the image of the targeted tissue. The rigid scopes provide the best image quality with limited maneuverability. Category 2 endoscopes include flexible scopes using optical fiber bundles of up to ten thousand fibers in a bundle to capture the image from the objective lens to the camera. Their final image is a mosaic of the images gathered by each fiber in the bundle, and this image has lower resolution than the image resulted from the rigid scope. Surgical procedures inside tiny ducts, capillaries or locations within the body that do not allow for direct/straight access are examples of applications where flexible scopes are needed. Category 3 endoscopes include semi-rigid scopes that use optical fibers with limited flexibility. Through technological advancements of the imaging devices, new technologies have emerged, and some of them are still under development. An example of such an advancement is infrared imaging technology. The infrared imaging technology is based on a process of mapping temperature differences at the surgical site by detecting electromagnetic radiation from tissue that is at different temperatures from its surroundings. Based on this type of information, this imaging technology can provide the surgeon with more than just image information and data. For example, a medical condition of the treatment site can be established through such advanced imaging technology. All of the above imaging technologies can be implemented with the electromagnetic cutting device in accordance with the present invention in helping the clinician to monitor and visualize the surgical site during the procedure of cutting or removing tissue with electromagnetically induced cutter.

The soft tissue aspiration cannula 112, cannula tip 118, handle 122, distal handle end cap 124, proximal handle end cap 126, aspirated soft tissue outlet port 128, large fluid and laser fiber guide tube 132, guide transition coupler 134, small fluid and laser fiber guide tube 136, and retaining screw 142 can be formed, for example, of stainless steel. In modified embodiments, some or all of the components can comprise medical grade plastics. In a flexible cannula design, the cannula 112 is made out of a biocompatible or medical grade flexible plastic. In a modified embodiment, a disposable cannula, flexible or rigid, is constructed from a medical grade disposable plastic. As will be apparent to those of skill in this art, a shorter and thinner diameter aspiration cannula

will be useful in more restricted areas of the body, as around small appendages, and a longer and larger diameter cannula will be useful in areas, such as the thighs and buttocks, where the cannula may be extended into fatty tissue over a more extensive area. The cannula tip 118 is in sizes of the same diameter as the aspiration cannula O.D., machined to a blunt tip and to fit the cannula inside diameter. The handle 122 can be formed of tubing. The distal handle end cap 124 can be machined to fit the handle inside diameter and drilled to accommodate the aspiration cannula outside diameter. The proximal handle end cap 126 can be machined to fit the handle inside diameter, drilled to accommodate the aspiration outlet port, fluid and laser guide channel, and large guide tube, and drilled and tapped to accommodate the retaining screw. The aspirated soft tissue outlet port 128 is preferably machined to fit the proximal handle end cap and tapered to accommodate appropriate suction tubing. The guide tube transition coupler 134 is preferably drilled to accommodate large and small guide tubes 132 and 136. The small fluid and laser fiber guide tube is determined by the length of the cannula 112.

By utilizing the present tissue remover 110 according to the method described above, a variety of advantages are achieved. By enabling the cutting of the soft tissue in a straight line, the scooping, ripping and tearing action characteristic of prior-art devices, is attenuated, resulting in fewer contour irregularities and enhanced satisfaction. With the addition of the cutting action of the present invention the rate of removal of unwanted soft tissue can be enhanced over that of previous devices and techniques thus decreasing operative time. Benefits may be obtained without fear of peripheral laser thermal damage.

In a method in which the tissue remover is used to remove hard tissue, such as bone or cartilage, the tissue remover may be able to facilitate removal of the tissue with attenuated or eliminated thermal damage. For example, in reference to knee arthroscopy, a surgeon will typically create one or more incisions near the knee in an anesthetized patient in need of arthroscopic surgery. The patient may either be under general anesthesia or may have been administered a local anesthetic or analgesic. The surgeon then may insert a needle through the capsule of the knee joint and fill the joint space with a fluid, such as normal saline, to help facilitate distension of the knee to provide improved passage of instruments and visualization of anatomical structures. A camera may then be inserted into the existing incision, or into another incision created

by the surgeon, to permit camera-assisted visualization of the knee anatomy. The tissue remover, as disclosed herein, may then be inserted into one of the existing incisions, or into a third incision created by the surgeon. The tissue remover is used to remove bone, cartilage, or other hard tissue in connection with the corrective surgery.

The knee replacement surgery may be performed by removing the damaged tissue from the knee, and inserting prosthetic devices where the damage tissue has been removed. In one particular embodiment, the surgeon may use the tissue remover to remove part of the damaged femur and the meniscus to expose the top surface of the tibia. The tissue remover may then be used to remove damaged tibia bone. A void is created within the tibia bone to receive an adhesive that will provide adhesion between the tibia and the tibia prosthetic implant. In the embodiment disclosed herein, the void may be about 3 mm deep and about 2-3 cm in radius; however, other dimensions may be used depending on the type of implant being used, and the extent of the damage to the knee. Adhesive, such as bone cement, is added to the void, and the tibia prosthetic is placed in contact with the adhesive in a position complementary to the femur. The prosthetic can be made from any suitable material as understood by persons skilled in the art, examples of some materials include polyethylene plastics or metals including metal alloys. Damaged tissue from the femur, such as the femur condyle, is then removed with the tissue cutter to create an opening to provide an attachment site for the femoral prosthetic. Adhesive is applied to the femur, and the femur prosthetic is attached. After the procedure, the surgical site is flushed with saline to remove any unwanted debris that may cause damage or irritation to the knee. The instruments are removed, and the incisions are closed. The knee is then tested by extending and flexing the joint. The tissue removal can be performed by scanning the laser of the tissue remover either manually or automatically using computer-assisted devices.

Thus, the hard tissue removal using the tissue remover described herein may be accomplished by removing the tissue without directly contacting the tissue. This methodology thus may provide the advantage of reducing one or more of thermal destruction and secondary necrotic effects caused by thermal destruction to the tissue. The tissue remover may in some embodiments causes a least parts of the target surface to break apart, which may then be aspirated from the surgical site. In one specific embodiment, the tissue remover removes the hard tissue with the energy transferred

from the electromagnetic energy interacting with the spray from the tissue remover, as herein disclosed. Although the procedure described hereinabove is for knee replacement surgery, other surgeries using the tissue remover disclosed herein include, and are not limited to, removal and repair of torn cartilage, ligament reconstruction, removal of loose debris.

In an arthroscopic procedure such as a menisectomy, for example, the cannula 112 has no cannula tip 118 and the tip of the fiber optic guide 123 is placed adjacent to the interaction zone 159 in the vicinity of the tissue target. The nozzle spray 171 delivers sterile water or saline to the interaction zone 159 and the process of cutting the miniscule cartilage in the knee is the same as described above and in the summary of the invention. Specifically, upon absorption of the electromagnetic energy, the atomized fluid particles within the interaction zone expand and impart cutting forces onto the minuscule cartilage tissue. The cartilage is then removed through this process and any tissue debris, together with the residual fluid, is quickly aspirated through the suction tube within the cannula. The same cannula device described for this procedure and presented in FIGS. 9b, 10b and 11b is used for neuroendoscopic and laparoscopic procedures. The procedures related to these applications follow the same steps as the procedure described for the removal of fatty tissues with the electromagnetic tissue remover, or the steps regarding the knee replacement surgery. In all of these applications, the cannula 112 can include an additional tube that contains an imaging device required to visualize the surgical site during the procedure. FIG. 11c is a block diagram illustrating such an additional tube 136a and imaging device 136b within the cannula 112. The imager can also be provided through a separate cannula inserted through a different opening into the patient's treatment surgical site.

In accordance with the present invention, water from the water tube 165 can be conditioned with various additives. These additives may include procoagulants and anesthetics, for example. Other additives may be used, such as other medications. Co-pending U.S. Application Serial Number 08/995,241 filed on December 17, 1997 and entitled FLUID CONDITIONING SYSTEM, which is a continuation of U.S. Application Serial Number 08/575,775, filed on December 20, 1995 and entitled FLUID CONDITIONING SYSTEM which issued into U.S. Patent No. 5,785,521, discloses various types of conditioned fluids that can be used with the electromagnetically induced

cutter of the present invention in the context of soft tissue removal. Other additives can include solubilizing and emulsifying agents in modified embodiments when an object to be pursued is to solubilize and emulsify the fatty tissue being removed. All of the additives should preferably be biocompatible.

Although an exemplary embodiment of the invention has been shown and described, many changes, modifications and substitutions may be made by one having ordinary skill in the art without necessarily departing from the spirit and scope of this invention.

CLAIMS

What is claimed is:

1. A method for removing hard tissue from a patient comprising:

providing a tissue remover having a proximal end and a distal end, and a fluid guide and an energy guide extending from the proximal end towards the distal end;

inserting the tissue remover through an incision in the patient so that the distal end of the tissue remover is in proximity to hard tissue;

transmitting gas and fluid through the fluid guide of the tissue remover;

generating atomized fluid particles in an interaction zone located in close proximity to the distal end of the tissue remover by using the air and fluid transmitted through the fluid and energy guide;

providing electromagnetic energy from an energy source to an electromagnetic energy transmitter operatively mounted within the fluid and energy guide; and

transmitting the electromagnetic energy from an output end of the energy transmitter into the interaction zone, the electromagnetic energy having a wavelength which is substantially absorbed by a portion of atomized fluid particles in the interaction zone, the absorption of the electromagnetic energy by the portion of atomized fluid particles causing the portion of atomized fluid particles to expand and impart disruptive cutting forces onto the tissue in close proximity to the distal end of the tissue remover.

2. The method of claim 1, further comprising a step of aspirating the hard tissue removed by the tissue remover.

3. The method of claim 1, wherein the hard tissue is removed by eroding the hard tissue with the forces generated by the electromagnetic energy and the atomized fluid particles.

4. The method of claim 1, wherein the hard tissue comprises bone.

5. The method of claim 1, wherein the hard tissue is removed in an arthroscopic procedure of the patient's knee.

6. The method of claim 1, wherein the hard tissue is removed without inducing thermal damage to the surrounding tissue.

7. The method of claim 1, wherein the energy source comprises an erbium, chromium, yttrium, scandium, gallium garnet (Er, Cr:YSGG) solid state laser.

8. The method of claim 1, wherein the energy source comprises a CO_2 laser.

9. The method of claim 1, wherein the fluid comprises water.

10. The method of claim 1, wherein the fluid comprises an anesthetic.

11. The method of claim 1, wherein the fluid comprises a saline solution.

12. The method of claim 1, wherein the fluid comprises epinephrine.

13. A system for removing hard tissue from a knee of a patient, comprising:

a tissue remover disposed in a cannula having a proximal end and a distal end that is structured to be inserted into a patient's knee joint, the tissue remover having a fluid guide and an energy guide extending towards the distal end of the cannula, wherein the fluid guide is structured to guide fluid and gas toward the distal end of the cannula to create atomized fluid particles; and

an energy source to provide electromagnetic energy through the energy guide to an energy transmitter that transmits the electromagnetic energy to an interaction zone located in close proximity to the distal end of the cannula where the electromagnetic energy is absorbed by atomized fluid particles in the interaction zone to impart erosive forces to cause removal of hard tissue from the patient's knee.

14. The system of claim 13 further comprising an aspirator attached to the cannula to aspirate hard tissue removed by the tissue cutter.

15. The system of claim 14, wherein the aspirator is disposed in a lumen of the cannula to cause the hard tissue to be aspirated through the cannula.

16. The system of claim 13, wherein the fluid guide and energy transmitter are positioned so that the interaction zone is in proximity to the hard tissue to be removed from the knee without inducing thermal damage to the surrounding knee tissue.

17. The system of claim 13, wherein the energy source comprises an erbium, chromium, yttrium, scandium, gallium garnet (Er, Cr:YSGG) solid state laser.

18. The system of claim 13, wherein the energy source comprises a CO_2 laser.

19. The system of claim 13, wherein the cannula is formed of a medical grade plastic.

20. The system of claim 13, wherein the cannula is formed of a stainless steel.

21. The system of claim 13, wherein the energy transmitter is a fiber optic delivery system.

22. The system of claim 13, wherein the fluid comprises water.

23. The system of claim 13, wherein the fluid comprises an anesthetic.

24. The system of claim 13, wherein the fluid comprises a saline solution.

25. The system of claim 13, wherein the fluid comprises epinephrine.

26. The system of claim 13, wherein the energy source comprises an ER:YAG laser.

27. The system of claim 13, wherein the fluid comprises epinephrine and an anesthetic.

28. The system of claim 13, further comprising a camera attached to the cannula to provide images of the knee joint to a user of the system.

29. A method for removing hard tissue from a knee of a patient comprising:

providing a tissue remover having a proximal end and a distal end, and a fluid and energy guide extending from the proximal end towards the distal end;

inserting the tissue remover through an incision so that the distal end of the tissue remover is in proximity to the patient's femur;

transmitting gas and fluid through the fluid guide of the tissue remover;

generating atomized fluid particles in an interaction zone located in close proximity to the distal end of the tissue remover by using the air and fluid transmitted through the fluid and energy guide;

providing electromagnetic energy from an energy source to an electromagnetic energy transmitter operatively mounted within the fluid and energy guide;

transmitting the electromagnetic energy from an output end of the energy transmitter into the interaction zone, the electromagnetic energy having a wavelength which is substantially absorbed by a portion of atomized fluid particles in the interaction zone, the absorption of the electromagnetic energy by the portion of atomized fluid particles causing the portion of atomized fluid particles to expand and impart disruptive cutting forces that erode the patient's femur to expose a surface of the patient's tibia;

removing a portion of the meniscus overlying the surface of the tibia by transmitting the electromagnetic energy to the energy transmitter to create cutting forces to erode the patient's meniscus; and

removing a portion of the patient's tibia to create a receptacle for a prosthetic implant.

30. The method of claim 29, further comprising a step of removing damaged tissue from the patient's femur to create an opening for a femoral prosthetic implant.

31. The method of claim 29, further comprising a step of applying an adhesive to the receptacle in the tibia to provide adhesion of the prosthetic implant to the tibia.

32. The method of claim 28, further comprising a step of applying adhesive to the receptacle in the tibia and the opening in the femur to provide adhesion of the prosthetic implants and the bones.

33. The method of claim 32, further comprising a step of securing prosthetic implants to the adhesive disposed in the femur and the tibia of the patient.

34. The method of claim 27, wherein the tissue is removed by scanning the distal end of the tissue remover along the surface of the tissue without directly contacting the tissue.

35. The method of claim 27, wherein the method is performed for knee replacement surgery.

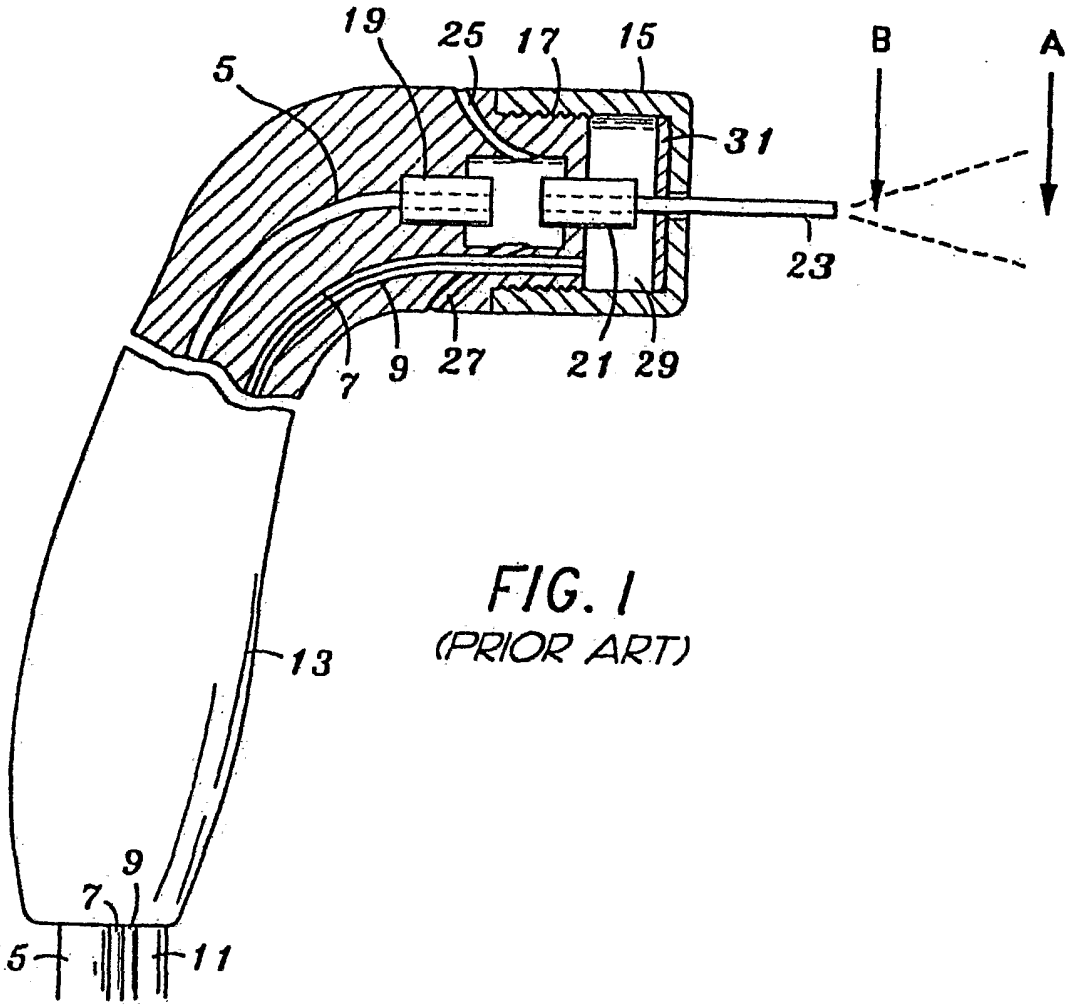

FIG. 1
(PRIOR ART)

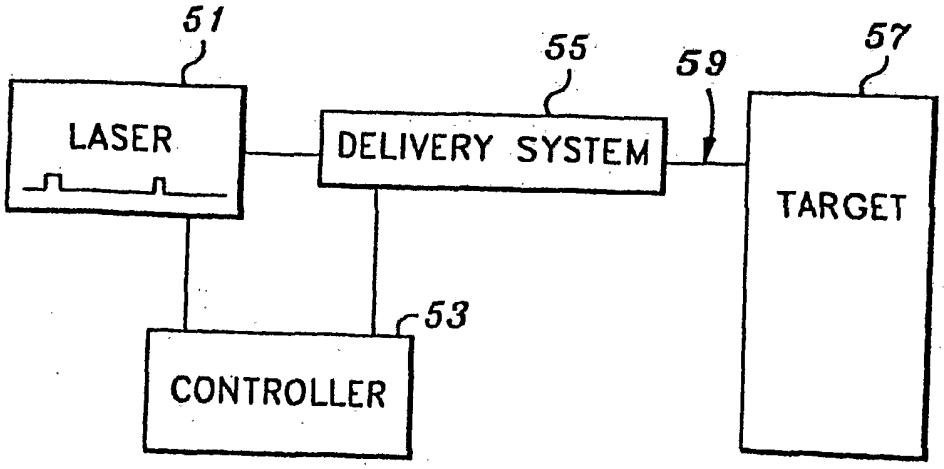

FIG. 2

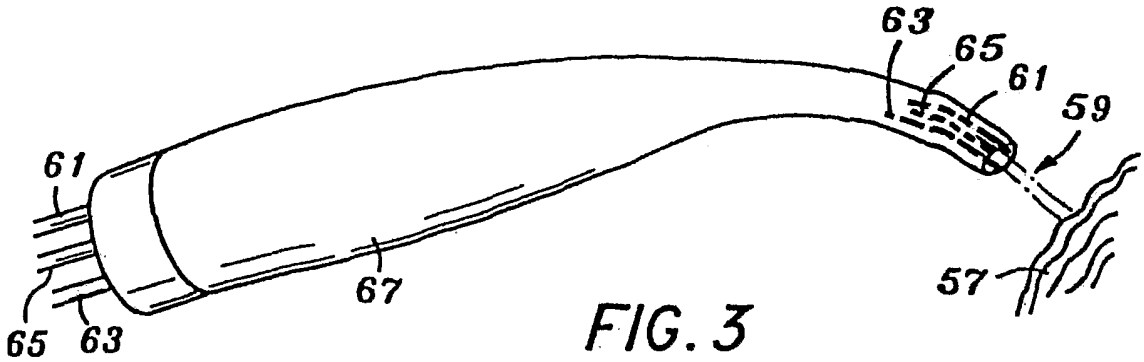

FIG. 3

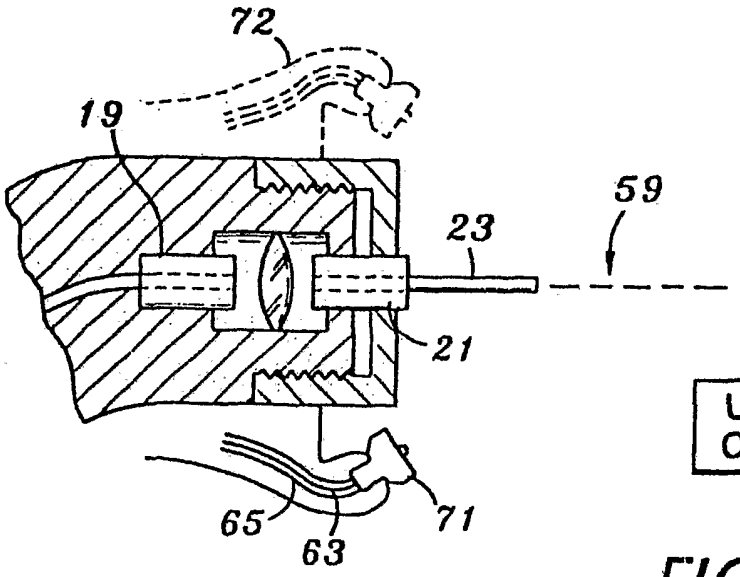

FIG. 4a

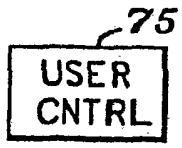

FIG. 4b

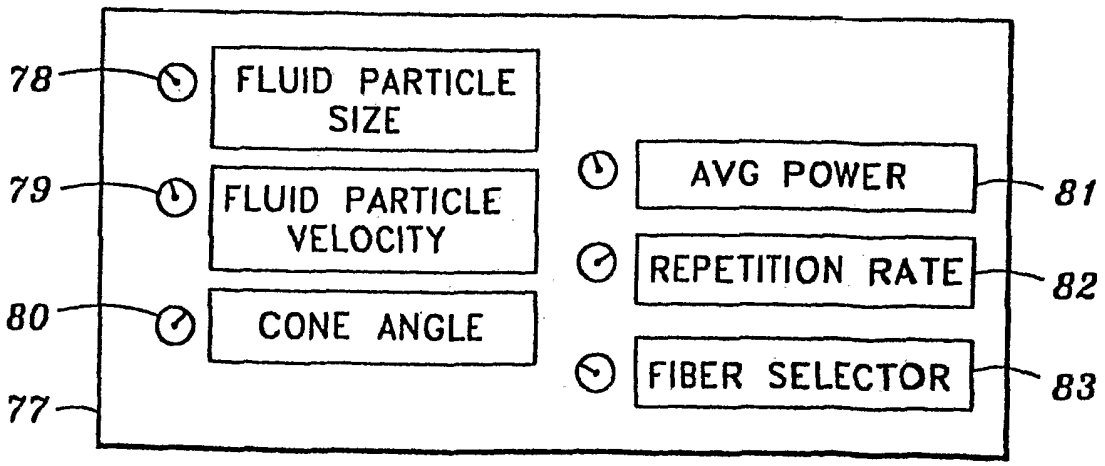

FIG. 5

FIG. 6

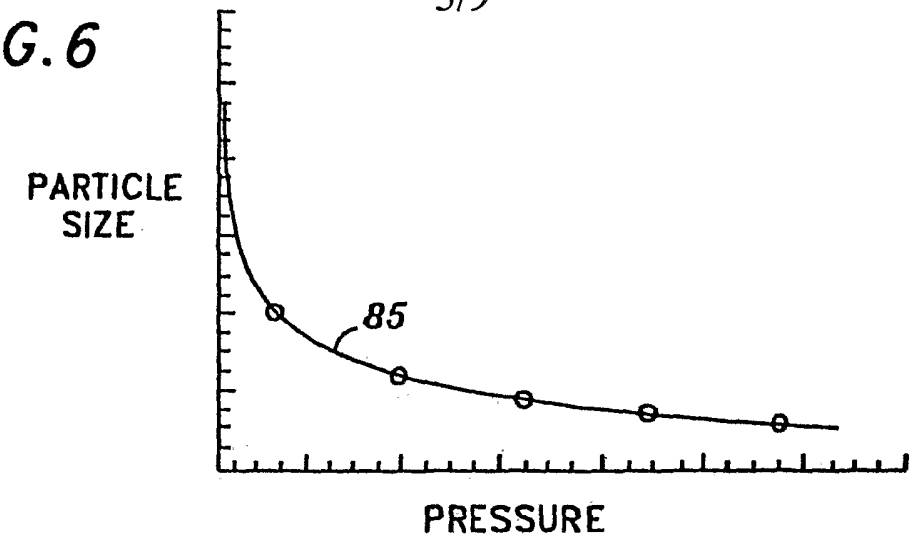

FIG. 7

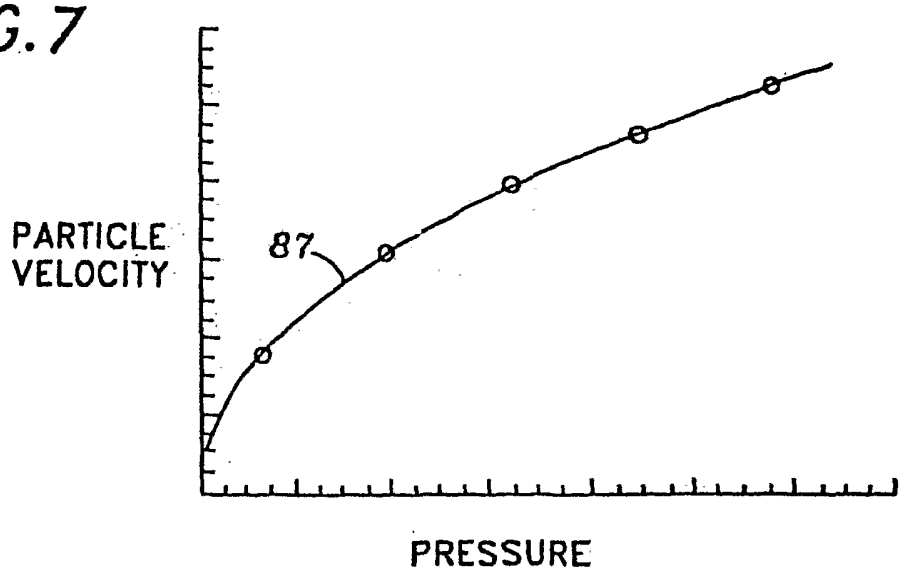

FIG. 8

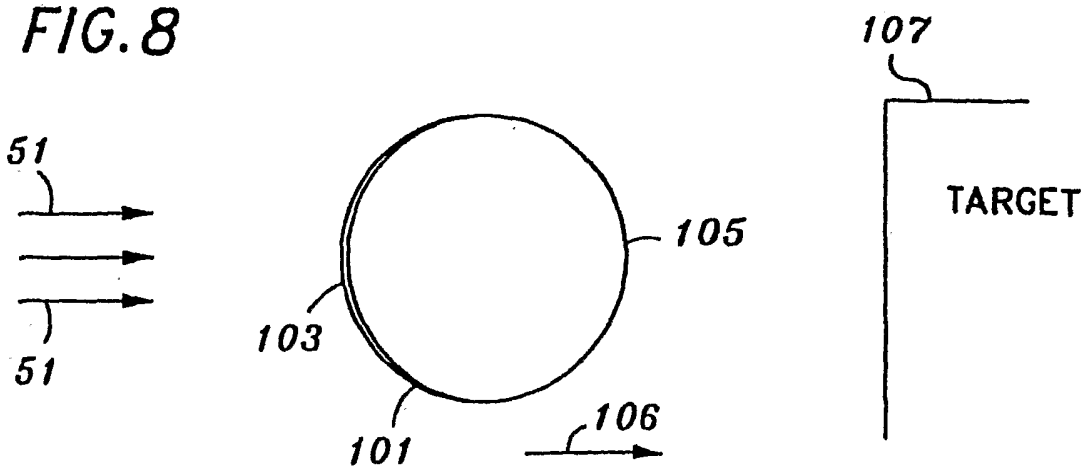

FIG. 9a

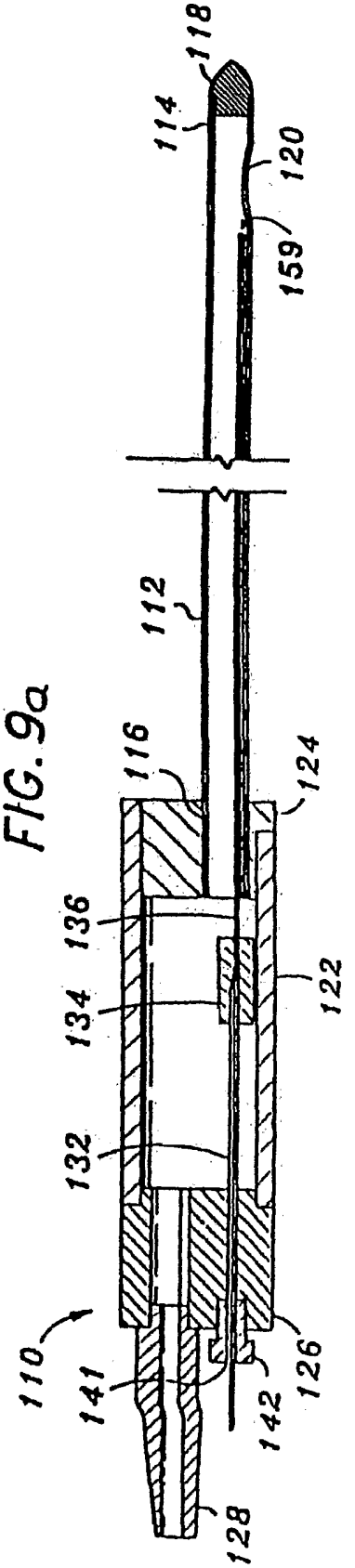
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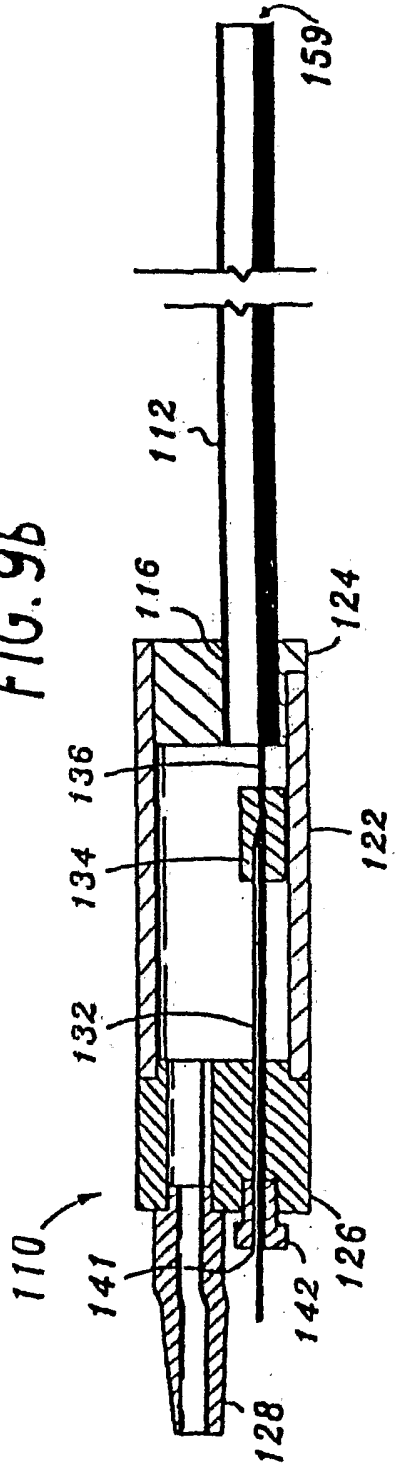
FIG. 9b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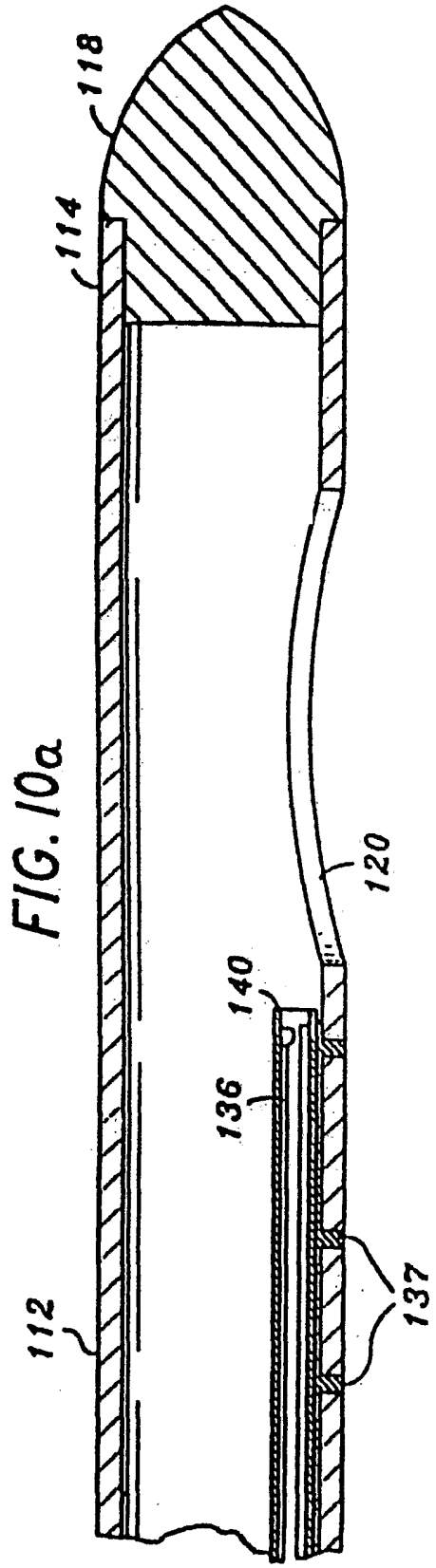

FIG. 10a

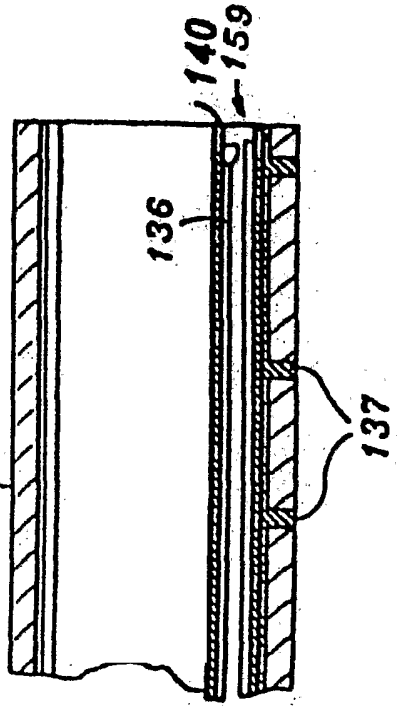

FIG. 10b

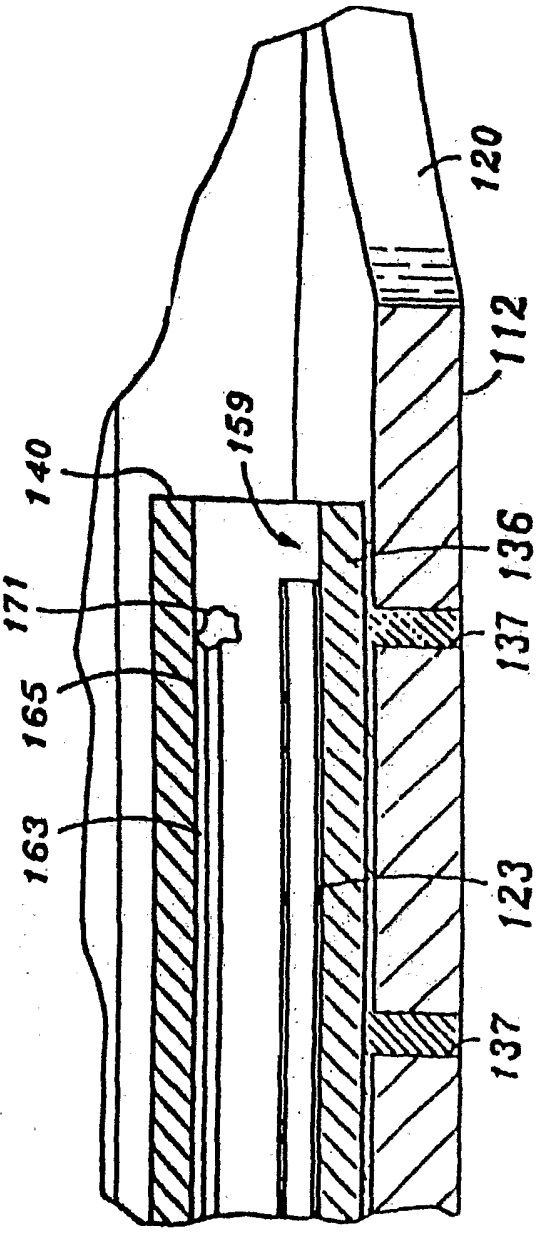

FIG. 11a

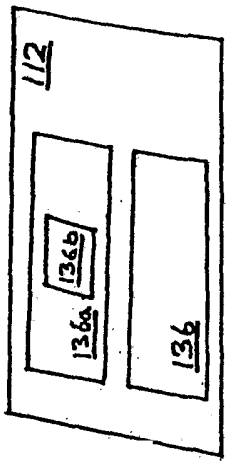

FIG. 11c

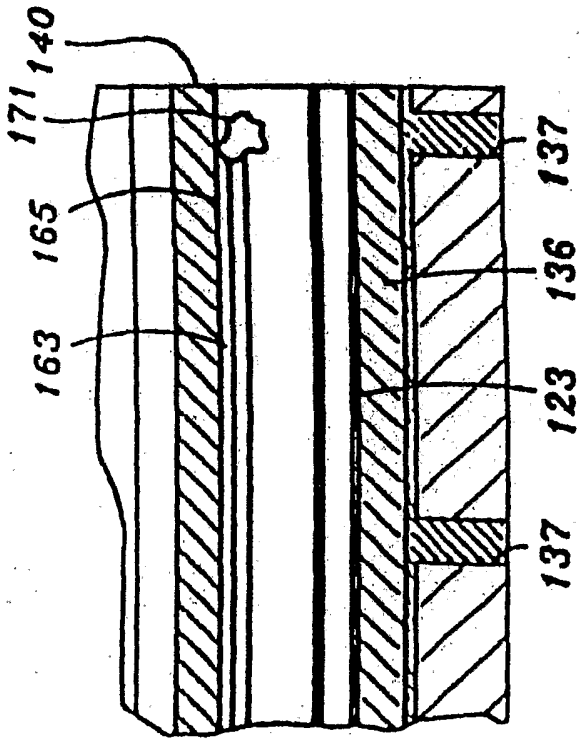

FIG. 11b

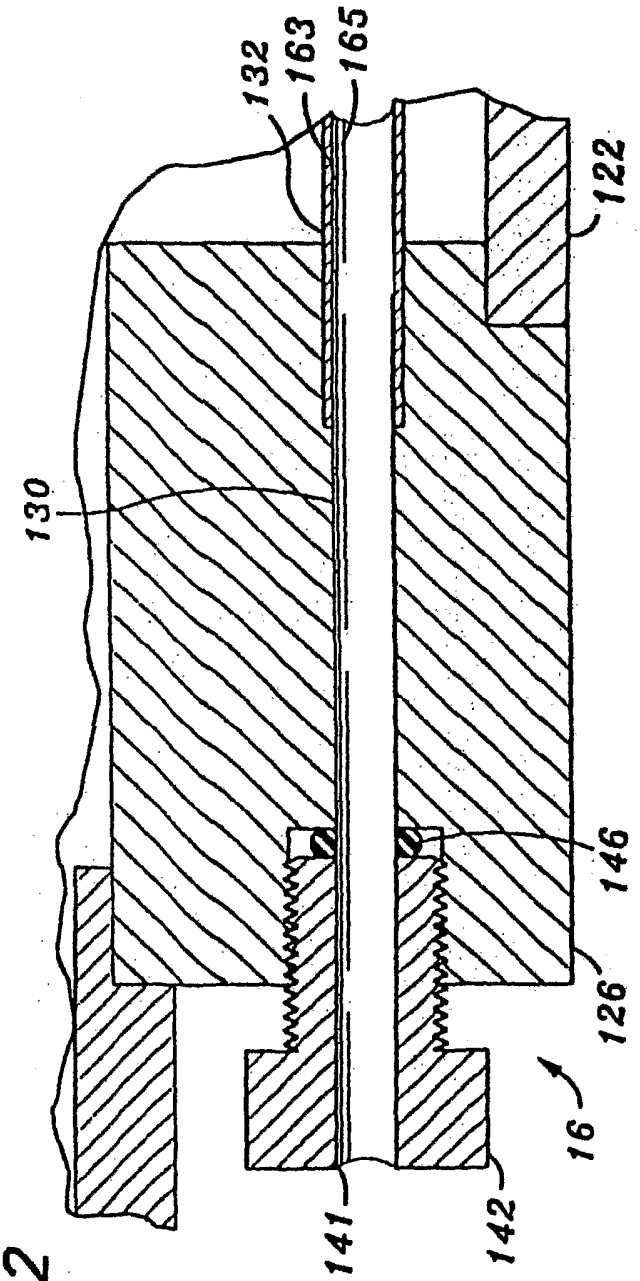

FIG. 12

FIG. 13

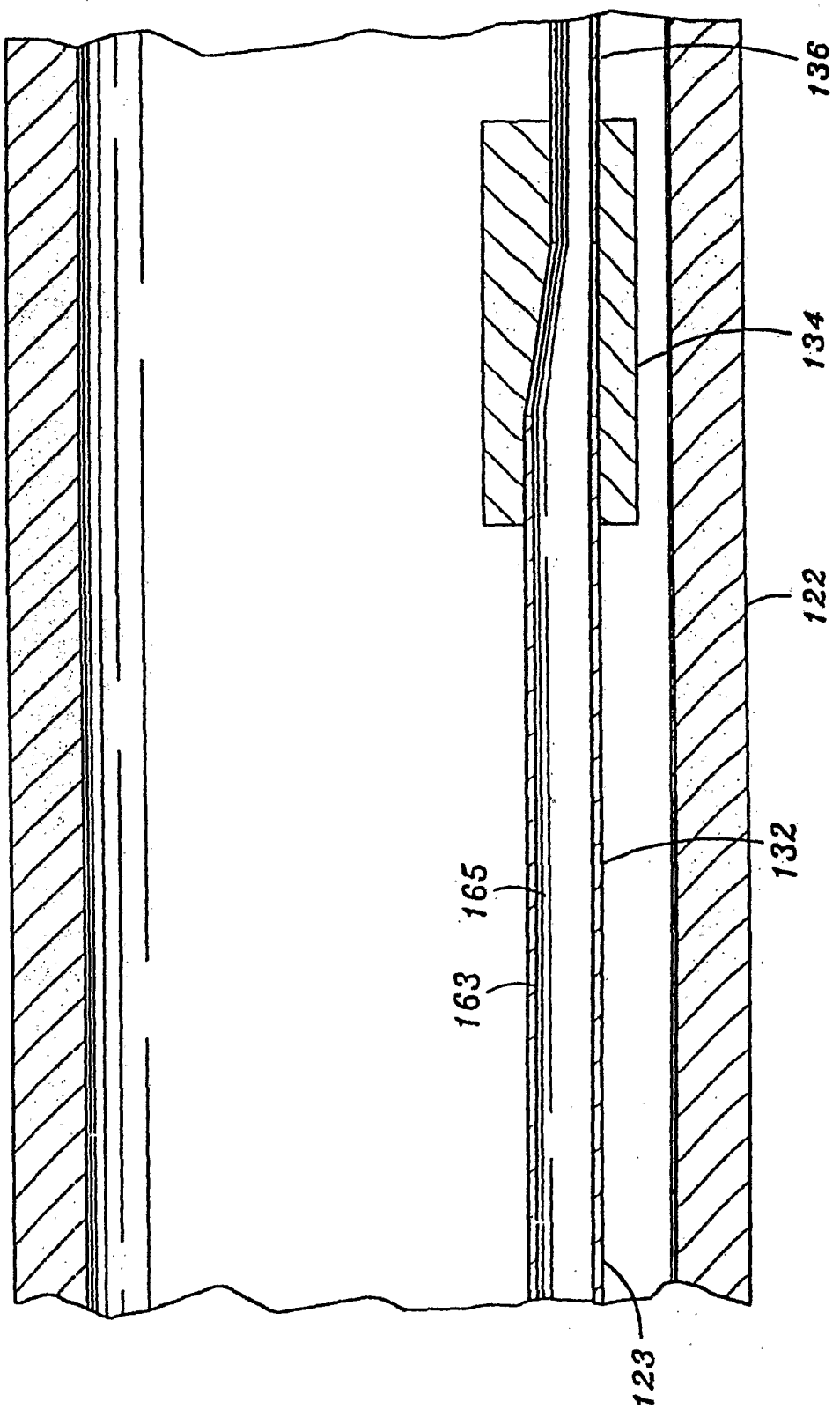

FIG. 14