



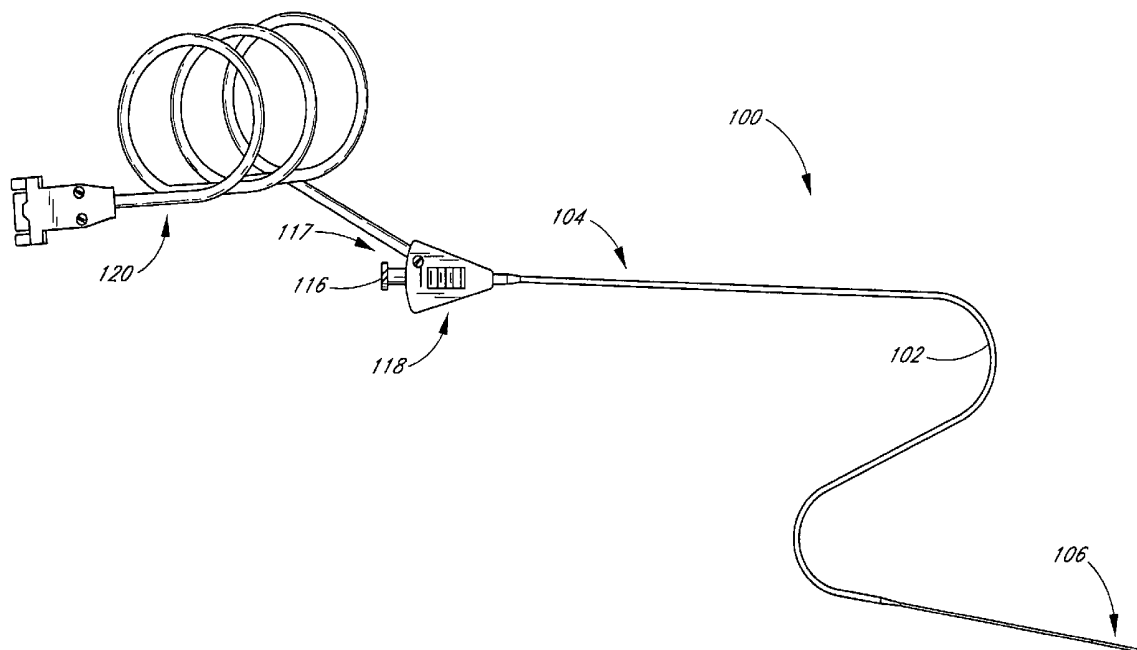
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(19) **United States**(12) **Patent Application Publication** (10) **Pub. No.: US 2004/0068189 A1**
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Wilson et al.(54) **ULTRASOUND CATHETER WITH
EMBEDDED CONDUCTORS**(52) **U.S. Cl.** **600/459; 600/466**(76) **Inventors:** **Richard R. Wilson**, Seattle, WA (US);
Tim Abrahamson, Seattle, WA (US);
Leonard R. Oliver, Seattle, WA (US)(57) **ABSTRACT**

Correspondence Address:

KNOBBE MARTENS OLSON & BEAR LLP
2040 MAIN STREET
FOURTEENTH FLOOR
IRVINE, CA 92614 (US)(21) **Appl. No.:** **10/378,032**(22) **Filed:** **Feb. 28, 2003****Related U.S. Application Data**(63) Continuation-in-part of application No. 10/309,417,
filed on Dec. 3, 2002.(60) Provisional application No. 60/361,341, filed on Feb.
28, 2002.**Publication Classification**(51) **Int. Cl.⁷** **A61B 8/14**

An ultrasound catheter comprises an elongate tubular body. The elongate tubular body has a proximal region and a distal region opposite the proximal region. The tubular body defines a central lumen having a central lumen diameter. The ultrasound catheter further comprises an elongate, hollow inner core extending through the central lumen. The elongate, hollow inner core has an inner core outer diameter that is less than or equal to the central lumen diameter. The ultrasound catheter further comprises an ultrasound radiating member positioned within the distal region of the tubular body and between the tubular body and the inner core. The ultrasound catheter further comprises at least two electrical conductors extending between the tubular body proximal region and the tubular body distal region. The at least two electrical conductors are positioned between the tubular body and the inner core. The at least two electrical conductors are electrically connected to the ultrasound radiating member. The at least two electrical conductors are wrapped around the inner core a plurality of times in a region between the ultrasound radiating member and the tubular body proximal region.



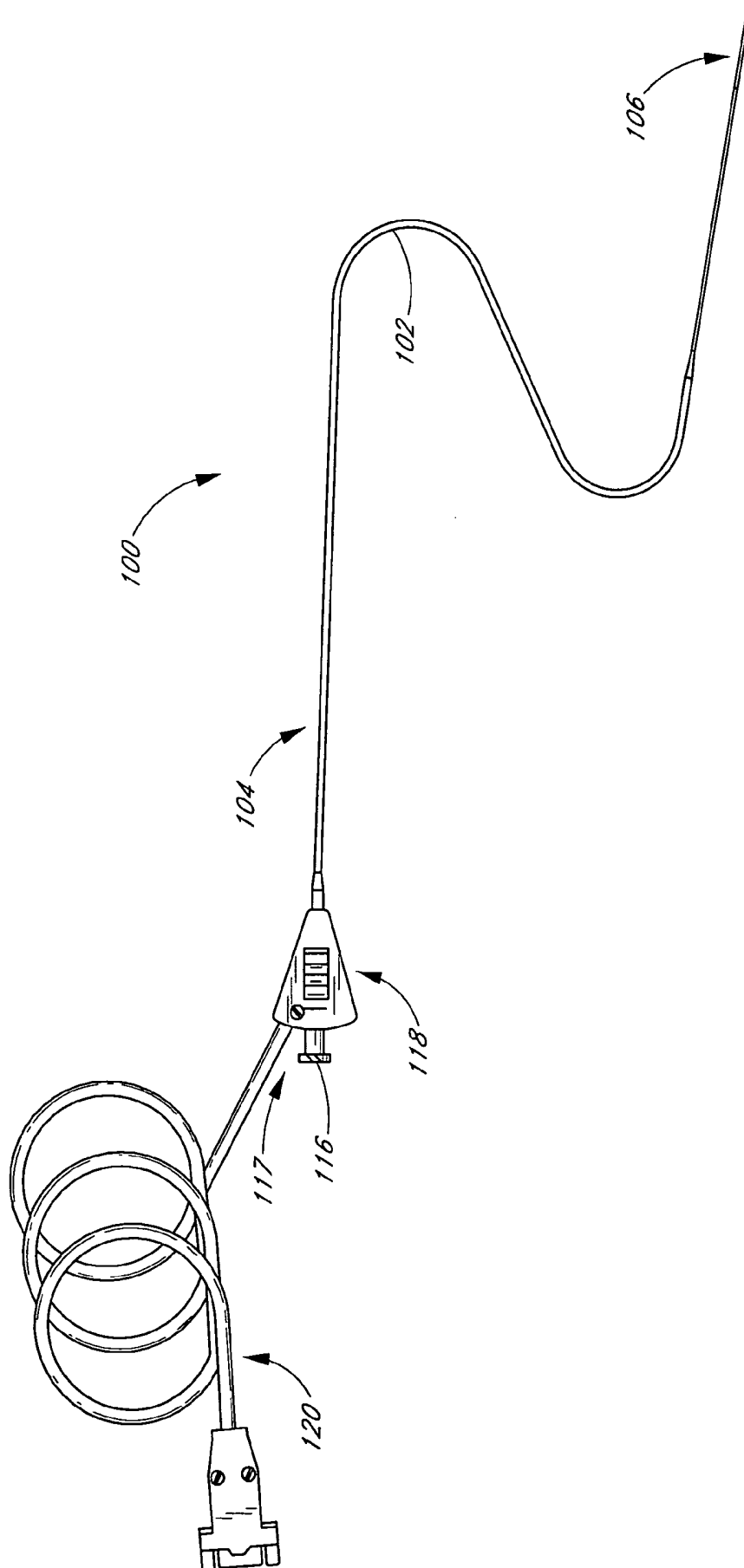


FIG. 1

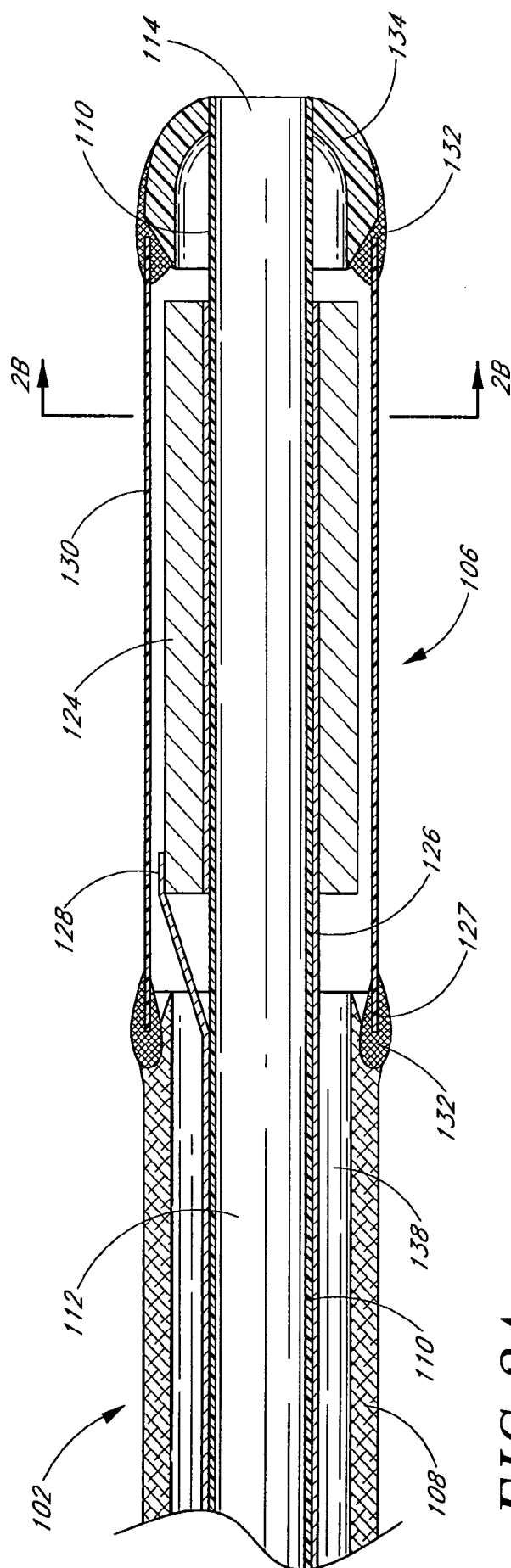


FIG. 2A

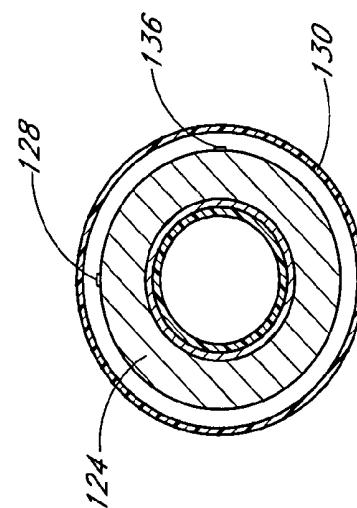


FIG. 2B

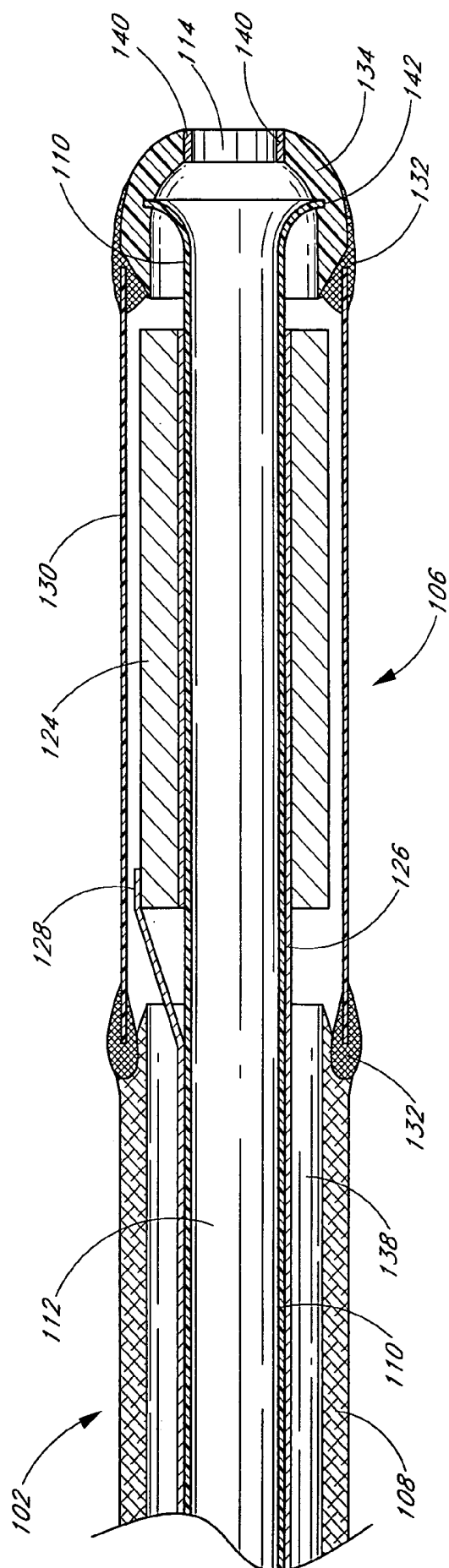


FIG. 3

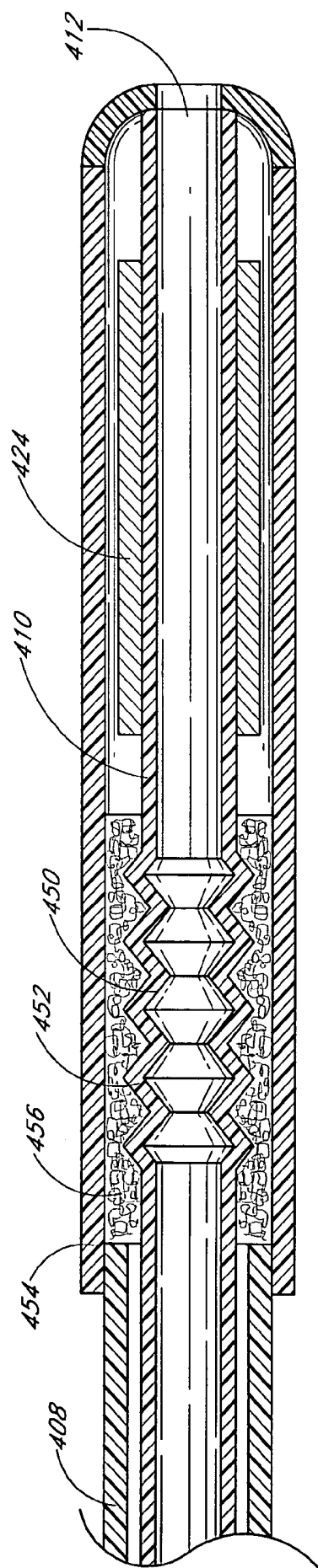


FIG. 4

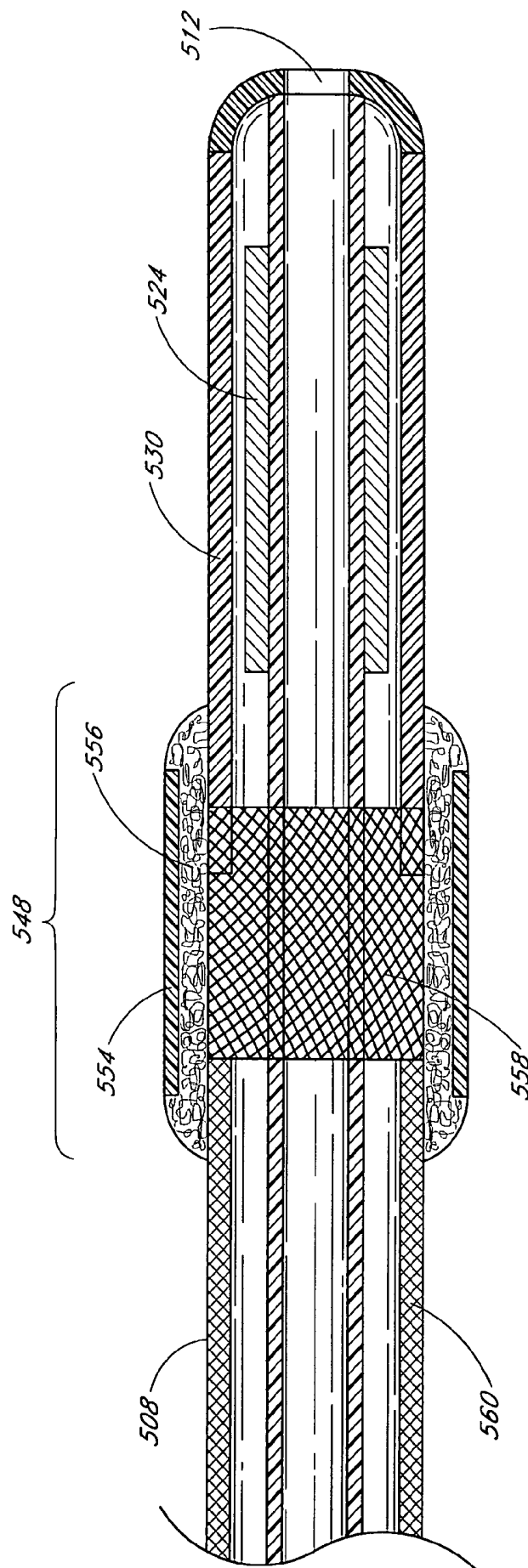


FIG. 5

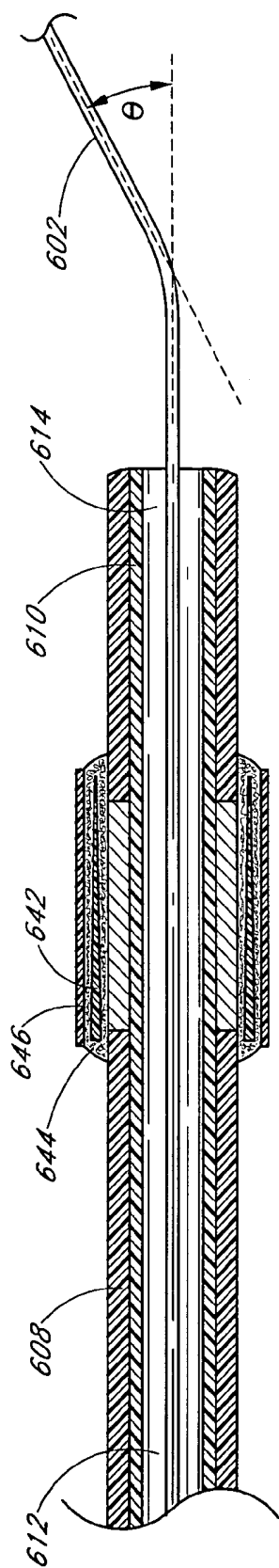


FIG. 6A

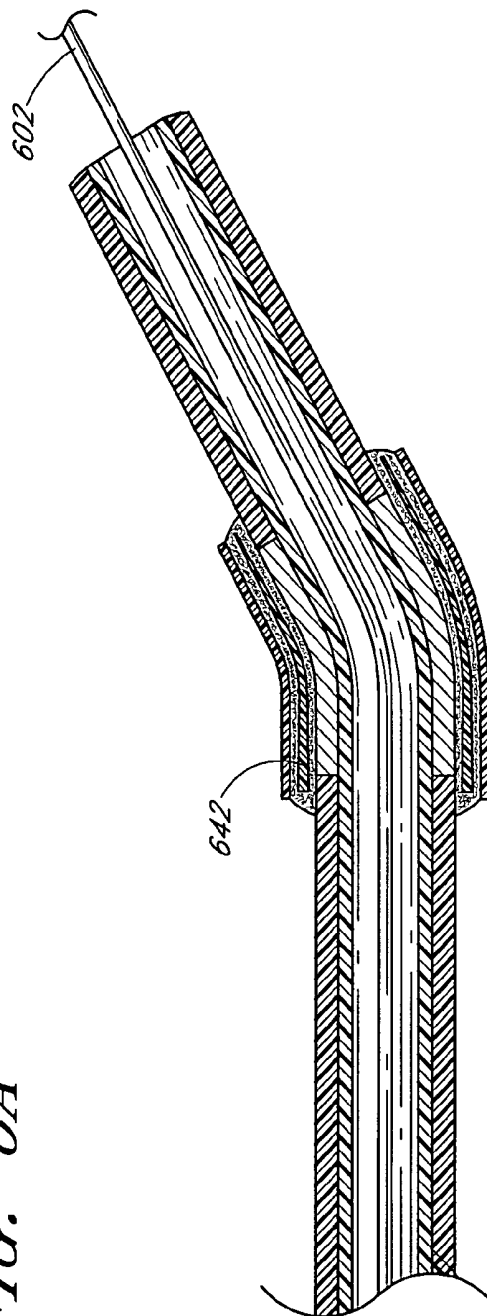


FIG. 6B

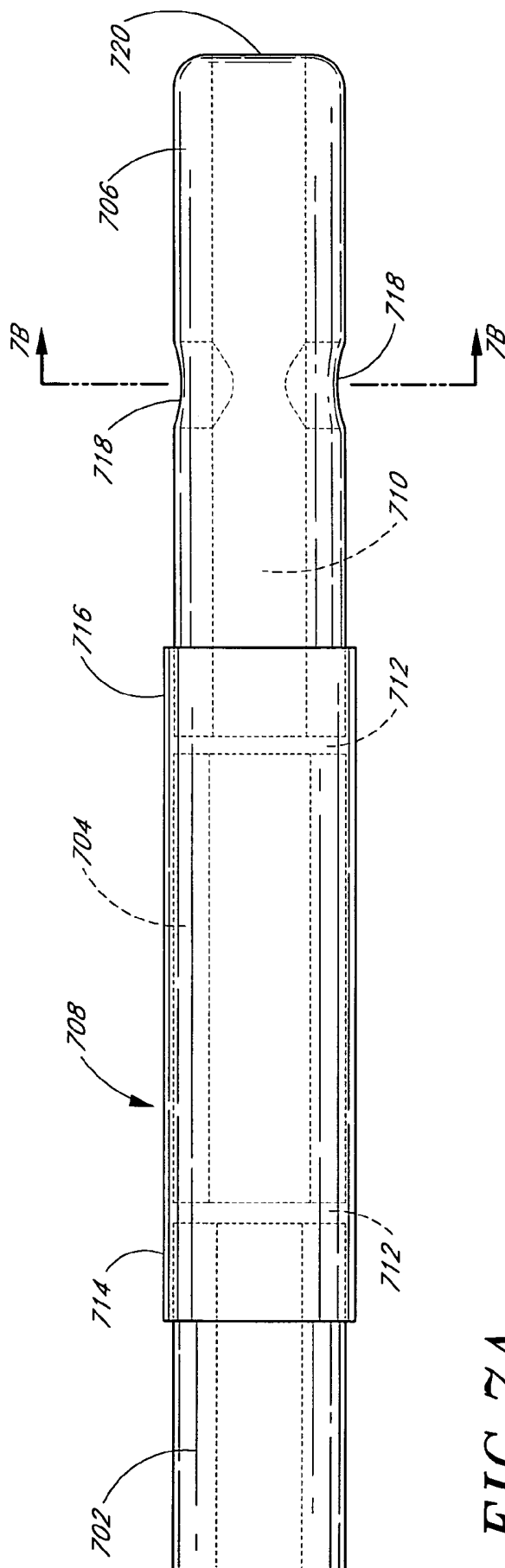


FIG. 7A

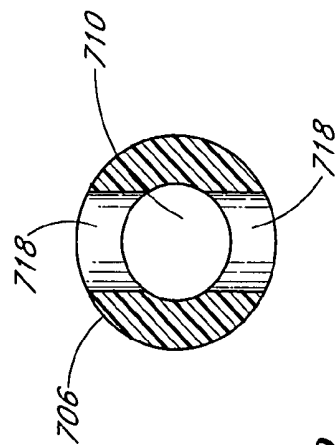


FIG. 7B

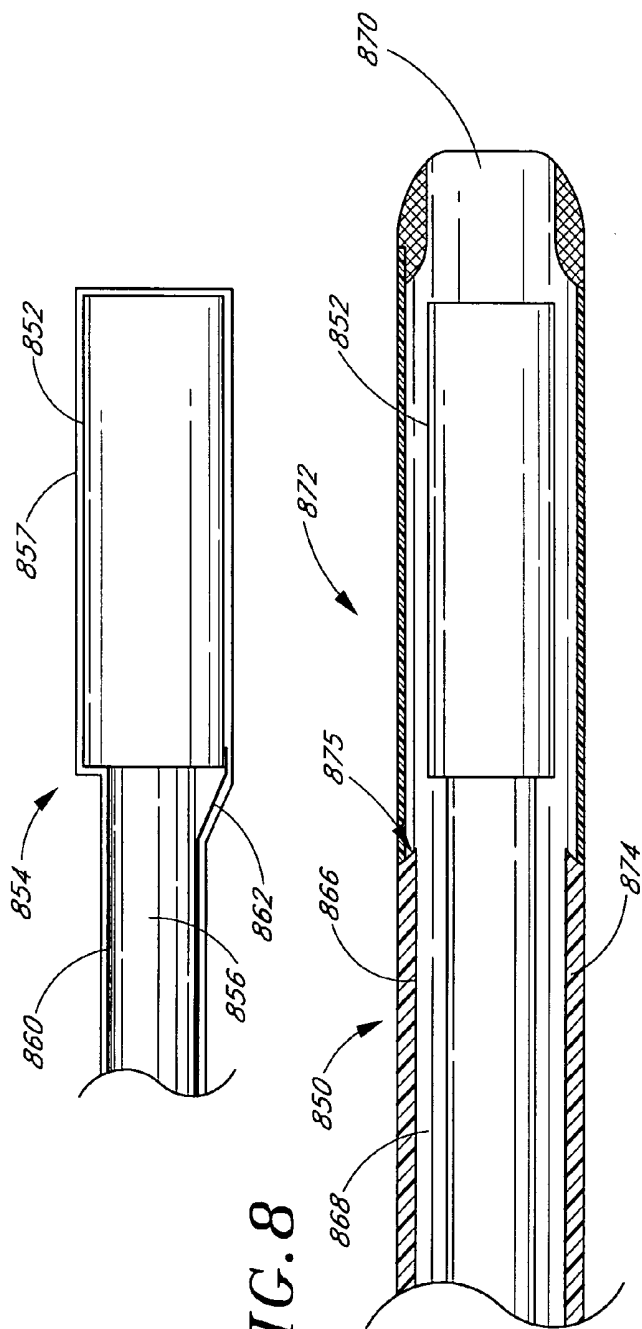


FIG. 8

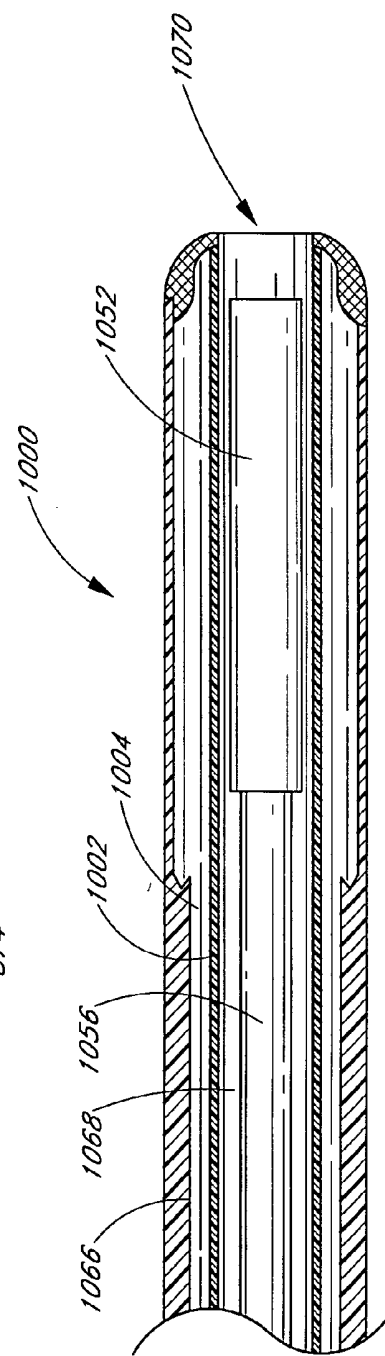
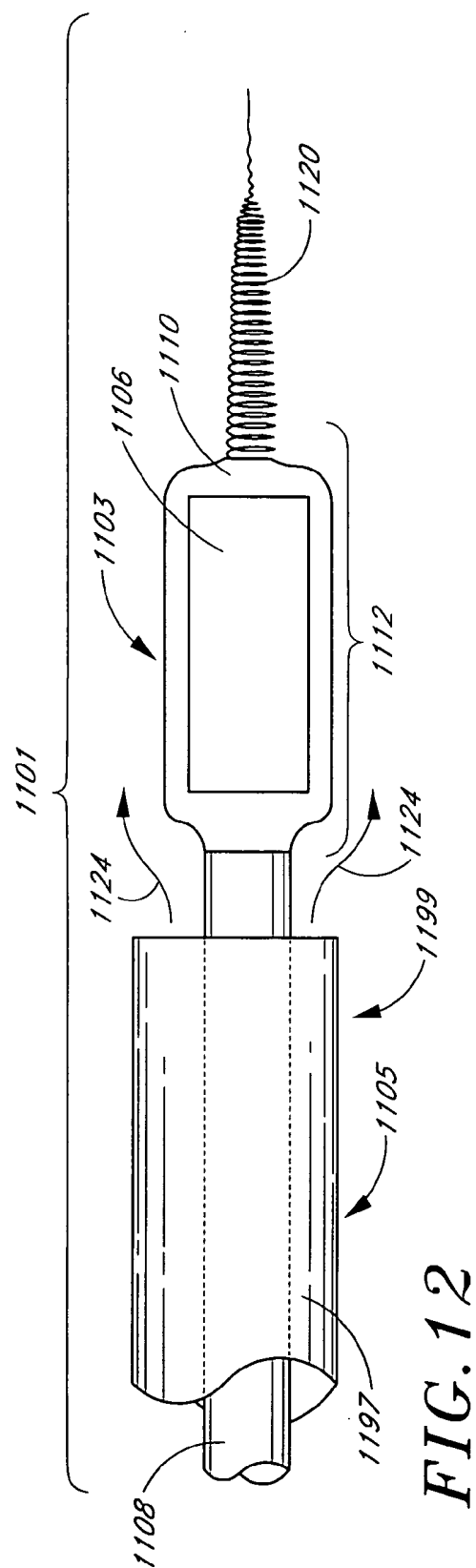
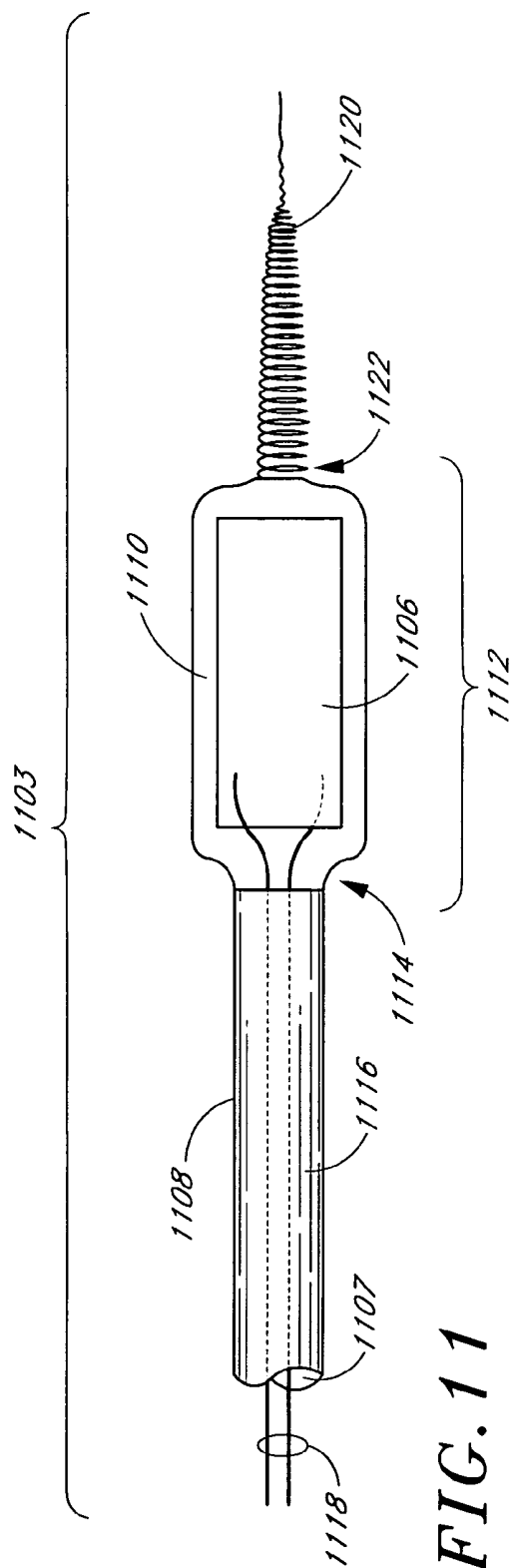


FIG. 9

FIG. 10



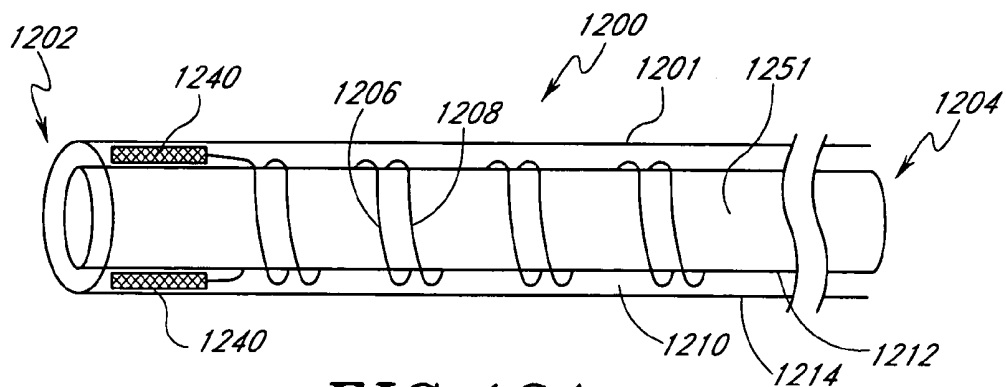


FIG. 13A

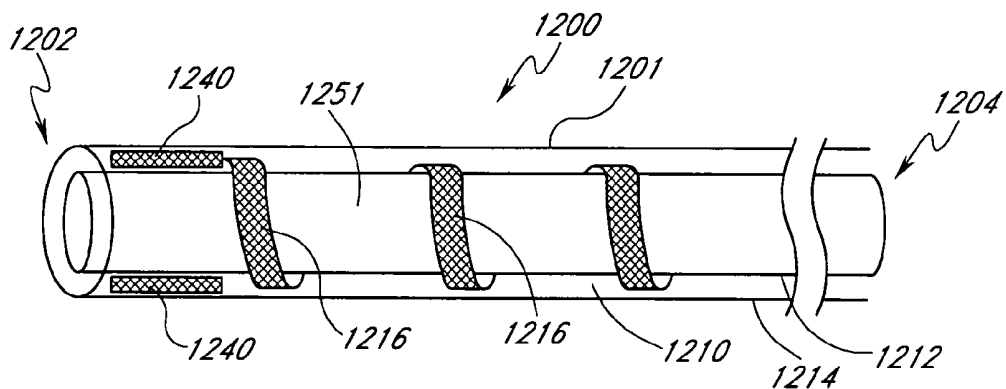


FIG. 13B

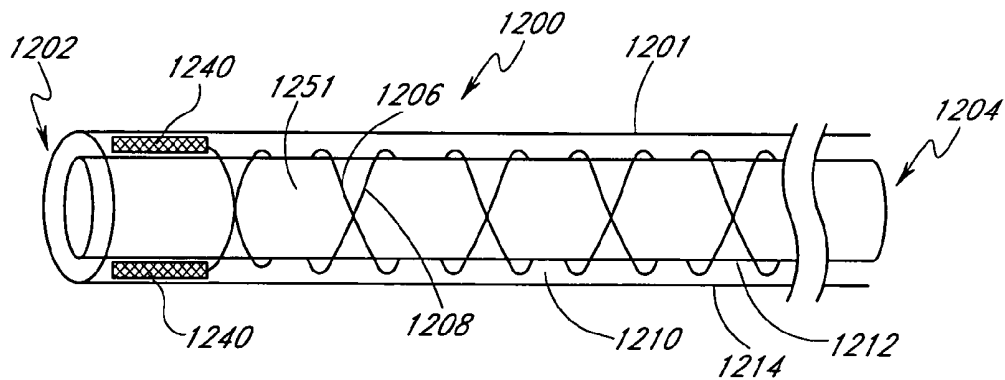


FIG. 14

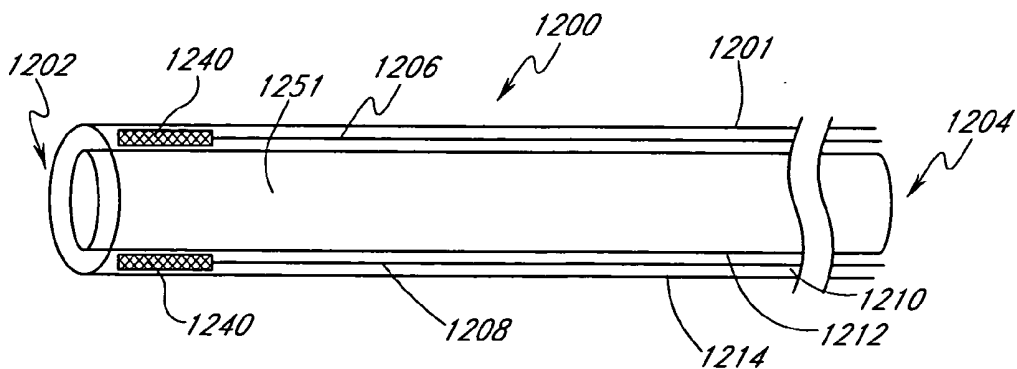


FIG. 15

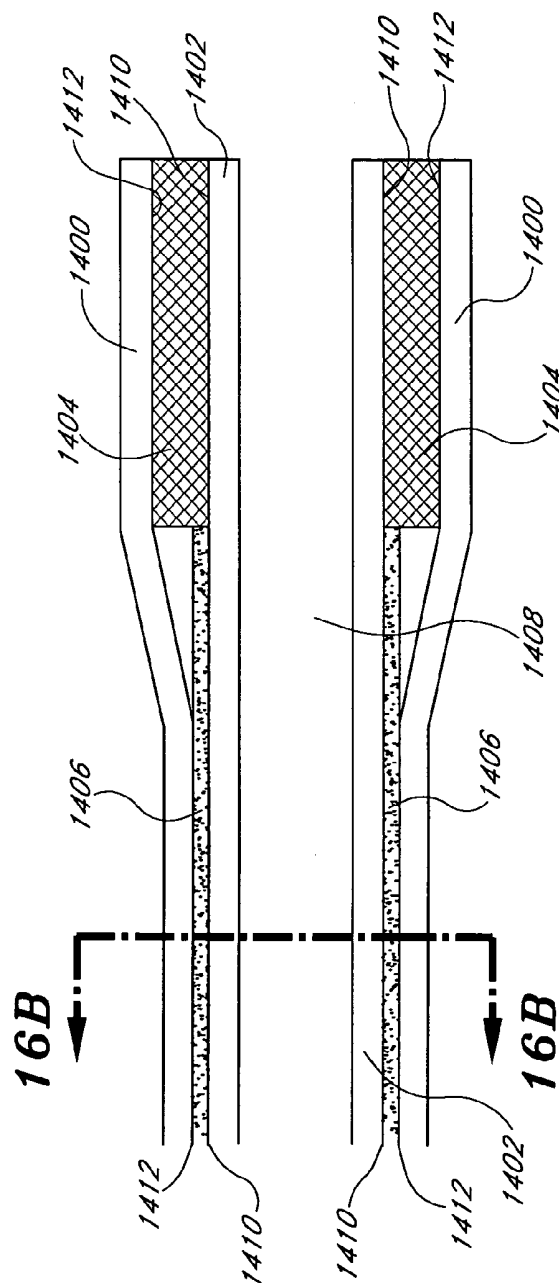


FIG. 16A

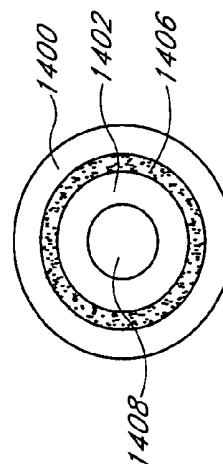


FIG. 16B

ULTRASOUND CATHETER WITH EMBEDDED CONDUCTORS

RELATED APPLICATIONS

[0001] J This application claims priority under 35 U.S.C. § 119(e) from U.S. Provisional Patent Application Serial No. 60/361,341, entitled "Small Vessel Catheter with Embedded Conductors" and filed Feb. 28, 2002. The entire disclosure of this priority document is hereby incorporated by reference in its entirety. In addition, the application is a continuation-in-part of U.S. patent application Ser. No. 10/309,417, entitled "Small Vessel Ultrasonic Catheter" and filed Dec. 3, 2002, which is hereby incorporated by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates to a catheter having an ultrasound assembly useful for delivering ultrasound energy at a treatment site in a body. The apparatus is particularly well suited for delivering ultrasound energy at a treatment site located within a small blood vessel in the distal anatomy.

BACKGROUND OF THE INVENTION

[0003] Several therapeutic and diagnostic applications use ultrasound energy. For example, ultrasound energy can be used to enhance the delivery and therapeutic effect of various therapeutic compounds. See e.g., U.S. Pat. Nos. 4,821,740, 4,953,565 and 5,007,438, the entire disclosure of which is hereby incorporated by reference herein. In some applications, it is desirable to use an ultrasound catheter to deliver the ultrasound energy and/or therapeutic compound to a specific treatment site in the body. Such an ultrasound catheter typically comprises an elongate member configured for advancement through a patient's vasculature. An ultrasound assembly is mounted along the distal end portion of the elongate member and is adapted for emitting ultrasound energy. The ultrasound catheter may include a delivery lumen for delivering the therapeutic compound to the treatment site. In this manner, the ultrasound energy can be emitted at the treatment site to enhance the desired therapeutic effects and/or delivery of the therapeutic compound.

[0004] In one particular application, ultrasound catheters have been successfully used to treat human blood vessels that have become occluded by plaque, thrombi, emboli or other substances that reduce the blood carrying capacity of the vessel. See e.g., U.S. Pat. No. 6,001,069, the entire disclosure of which is hereby incorporated by reference herein. To remove the blockage, the ultrasound catheter is advanced through the patient's vasculature to deliver solutions containing dissolution compounds directly to the blockage site. To enhance the therapeutic effects of the dissolution compound, ultrasound energy is emitted into the compound and/or the surrounding tissue.

[0005] In another application, ultrasound catheters may be used to perform gene therapy on an isolated region of a blood vessel or other body lumen. For example, as disclosed in U.S. Pat. No. 6,135,976, the entire disclosure of which is hereby incorporated by reference herein, an ultrasound catheter can be provided with one or more expandable members for occluding a section of the body lumen at a treatment site. A gene therapy composition is delivered to the treatment site

through the delivery lumen of the catheter. The ultrasound assembly is used to emit ultrasound energy at the treatment site to enhance the entry of the gene composition into the cells in the body lumen.

[0006] In addition to the applications discussed above, ultrasound catheters may be used for a wide variety of other purposes, such as, for example, delivering and activating light activated drugs with ultrasound energy (see e.g., U.S. Pat. No. 6,176,842, the entire disclosure of which is hereby incorporated by reference herein).

[0007] Over the years, numerous types of ultrasound catheters have been proposed for various therapeutic purposes. However, none of the existing ultrasound catheters is well adapted for effective use within small blood vessels in the distal anatomy. For example, in one primary shortcoming, the region of the catheter on which the ultrasound assembly is located (typically along the distal end portion) is relatively rigid and therefore lacks the flexibility necessary for navigation through difficult regions of the distal anatomy. Furthermore, it has been found that it is very difficult to manufacture an ultrasound catheter having a sufficiently small diameter for use in small vessels while providing adequate pushability and torqueability. Still further, it has been found that the distal tip of an ultrasound catheter can easily damage the fragile vessels of the distal anatomy during advancement through the patient's vasculature.

[0008] Accordingly, an urgent need exists for an improved ultrasound catheter that is capable of safely and effectively navigating small blood vessels. It is also desirable that such a device be capable of delivering adequate ultrasound energy to achieve the desired therapeutic purpose. It is also desirable that such a device be capable of accessing a treatment site in fragile distal vessels in a manner that is safe for the patient and that is not unduly cumbersome. The present invention addresses these needs.

SUMMARY OF THE INVENTION

[0009] In accordance with the foregoing, it is desired to provide an ultrasound catheter having increased flexibility and maneuverability. Such features are advantageous when a treatment is to be performed in the peripheral vasculature, and are especially advantageous when a treatment is to be performed in small vessels, such as in the neurovascular system.

[0010] As such, according to one embodiment of the present invention, an ultrasound catheter comprises an elongate tubular body. The elongate tubular body has a proximal region and a distal region opposite the proximal region. The tubular body defines a central lumen having a central lumen diameter. The ultrasound catheter further comprises an elongate, hollow inner core extending through the central lumen. The elongate, hollow inner core has an inner core outer diameter that is less than or equal to the central lumen diameter. The ultrasound catheter further comprises an ultrasound radiating member positioned within the distal region of the tubular body and between the tubular body and the inner core. The ultrasound catheter further comprises at least two electrical conductors extending between the tubular body proximal region and the tubular body distal region. The at least two electrical conductors are positioned between the tubular body and the inner core. The at least two electrical conductors are electrically connected to the ultrasound radi-

ating member. The at least two electrical conductors are wrapped around the inner core a plurality of times in a region between the ultrasound radiating member and the tubular body proximal region.

[0011] According to another embodiment of the present invention, an ultrasound catheter comprises an elongate tubular body. The elongate tubular body has a proximal region and a distal region opposite the proximal region. The tubular body defines a central lumen having a central lumen diameter. The ultrasound catheter further comprises an elongate, hollow inner core extending through the central lumen. The elongate, hollow inner core has an inner core outer diameter that is less than or equal to the central lumen diameter. The ultrasound catheter further comprises an ultrasound radiating member positioned within the distal region of the tubular body and between the tubular body and the inner core. The ultrasound catheter further comprises at least two electrical conductors extending between the tubular body proximal region and the tubular body distal region. The at least two electrical conductors are positioned between the tubular body and the inner core. The at least two electrical conductors are electrically connected to the ultrasound radiating member. The at least two electrical conductors are disposed substantially parallel to a catheter axis in a region between the ultrasound radiating member and the tubular body proximal region.

[0012] According to another embodiment of the present invention, an apparatus comprises an elongate, hollow body. The elongate, hollow body has a proximal region, a distal region opposite the proximal region, a body thickness, and an inner lumen. The apparatus further comprises an ultrasound radiating member positioned within the body thickness of the elongate, hollow body. The apparatus further comprises a plurality of elongate electrical conductors extending between the elongate, hollow body proximal region and the ultrasound radiating member. The plurality of elongate electrical conductors are positioned within the body thickness of the elongate, hollow body.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1 is a side view of an ultrasound catheter that is particularly well suited for insertion into small blood vessels of the human body.

[0014] FIG. 2A is a cross-sectional view of a distal end of the ultrasound catheter of FIG. 1.

[0015] FIG. 2B is a cross-sectional view of the ultrasound catheter taken through line 2B-2B of FIG. 2A.

[0016] FIG. 3 is an alternative embodiment of the ultrasound catheter including a stiffener at the distal tip.

[0017] FIG. 4 is a cross-sectional view of the distal end of an ultrasound catheter wherein a portion of the inner core has a corrugated configuration for enhanced flexibility.

[0018] FIG. 5 is a cross-sectional view of the distal end of an ultrasound catheter wherein the proximal joint comprises braided sections for enhanced flexibility.

[0019] FIG. 6A is a cross-sectional view of the distal end of an ultrasound catheter including a bendable wire adapted for providing a shapeable tip.

[0020] FIG. 6B is a cross-sectional view of the embodiment of FIG. 6A with the shapeable tip pre-formed to facilitate advancement over a guidewire.

[0021] FIG. 7A is a top view of the distal end of an ultrasound catheter having a soft tip assembly.

[0022] FIG. 7B is a cross-sectional view of the soft tip assembly taken through line 7B-7B of FIG. 7A.

[0023] FIG. 8 is a side view an ultrasound element attached to the distal end of a guidewire.

[0024] FIG. 9 is a cross-sectional view of an ultrasound catheter used with the ultrasound element and guidewire of FIG. 8.

[0025] FIG. 10 is a cross-sectional view of a distal end of another modified embodiment of an ultrasound catheter that can be used with the ultrasound element and guidewire of FIG. 8.

[0026] FIG. 11 is a side view of a distal end of a treatment wire wherein an ultrasound element is provided along the distal end of a hypotube.

[0027] FIG. 12 is a side view of a distal end of an ultrasound catheter that incorporates the treatment wire of FIG. 11.

[0028] FIG. 13A is a partial cutaway view of one embodiment of an ultrasound catheter with embedded conductive wires that are spirally wrapped parallel to each other.

[0029] FIG. 13B is a partial cutaway view of one embodiment of an ultrasound catheter with embedded conductive wires that are spirally wrapped into a unitary cable.

[0030] FIG. 14 is a partial cutaway view of one embodiment of an ultrasound catheter with embedded conductive wires that are spirally wrapped in a nonparallel

[0031] FIG. 15 is a partial cutaway view of one embodiment of an ultrasound catheter with embedded conductive wires that are disposed substantially parallel to the

[0032] FIG. 16A illustrates a longitudinal cross-sectional view of an ultrasound catheter having internal surfaces that are electrically conductive.

[0033] FIG. 16B illustrates a cross-sectional view of the ultrasound catheter of FIG. 16A taken along line 16B-16B.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0034] The advancement of an ultrasound catheter through a blood vessel to a treatment can be difficult and dangerous, particularly when the treatment site is located with a small vessel in the distal region of a patient's vasculature. To reach the treatment site, it is often necessary to navigate a tortuous path around difficult bends and turns. During advancement through the vasculature, bending resistance along the distal end portion of the catheter can severely limit the ability of the catheter to make the necessary turns. Moreover, as a catheter is advanced, the distal tip of the catheter is often in contact with the inner wall of the blood vessel. The stiffness and rigidity of the distal tip of the catheter may lead to significant trauma or damage to the tissue along the inner wall of the blood vessel. As a result, advancement of an ultrasound catheter through small blood vessels can be extremely hazardous. Therefore, a need exists for an improved ultrasound catheter design that allows a physician

to more easily navigate difficult turns in small blood vessels while minimizing trauma and/or damage along the inner walls of the blood vessels.

[0035] To address this need, preferred embodiments of the present invention described herein provide an ultrasound catheter that is well suited for use in the treatment of small blood vessels or other body lumens having a small inner diameter. The ultrasound catheter can be used to enhance the therapeutic effects of drugs, medication and other pharmacological agents at a treatment site within the body. See e.g., U.S. Pat. Nos. 5,318,014, 5,362,309, 5,474,531, 5,628,728, 6,001,069, and 6,210,356. Certain preferred embodiments of the ultrasound catheter are particularly well suited for use in the treatment of thrombotic occlusions in small blood vessels, such as, for example, the cerebral arteries. In addition, preferred embodiments may also find utility in other therapeutic applications, such as, for example, performing gene therapy (see e.g., U.S. Pat. No. 6,135,976), activating light activated drugs for producing targeted tissue death (see e.g., U.S. Pat. No. 6,176,842) and causing cavitation to produce various desirable biological effects (see e.g., U.S. Patent No. RE36,939). Moreover, such therapeutic applications may be used in wide variety of locations within the body, such as, for example, in other parts of the circulatory system, solid tissues, duct systems and body cavities. It is also anticipated that the ultrasound catheters disclosed herein, and variations thereof, may find utility in other medical applications, such as, for example, diagnostic and imaging applications.

[0036] Ultrasound catheters and methods disclosed herein, and similar variations thereof, may also be useful for applications wherein the ultrasound energy provides a therapeutic effect by itself. For example, ultrasound energy may be effective for uses such as preventing and/or reducing stenosis and/or restenosis, tissue ablation, abrasion or disruption, promoting temporary or permanent physiological changes in intracellular or intercellular structures, or rupturing microballoons or micro-bubbles for drug delivery. See e.g., U.S. Pat. Nos. 5,269,291 and 5,431,663. In addition, the methods and devices disclosed herein may also find utility in applications that do not require the use of a catheter. For example the methods and devices may be used for enhancing hyperthermic drug treatment or using an external ultrasound source to enhance the therapeutic effects of drugs, medication and other pharmacological agents at a specific site within the body or to provide a therapeutic or diagnostic effect by itself. See e.g., U.S. Pat. Nos. 4,821,740, 4,953,565, 5,007,438 and 6,096,000. The entire disclosure of each of the patents mentioned in this paragraph and the previous paragraph is hereby incorporated by reference herein and made a part of this specification.

[0037] As used herein, the term "ultrasound energy" is a broad term and is used in its ordinary sense and means, without limitation, mechanical energy transferred through pressure of compression waves with a frequency greater than about 20 KHz. In one embodiment, the waves of the ultrasound energy have a frequency between about 500 KHz and 20 MHz and in another embodiment between about 1 MHz and 3 MHz. In yet another embodiment, the waves of the ultrasound energy have a frequency of about 3 MHz.

[0038] As used herein, the term "catheter" is a broad term and is used in its ordinary sense and means, without limi-

tation, an elongate flexible tube configured to be inserted into the body of a patient, such as, for example, a body cavity, duct or vessel.

Preferred Features of an Ultrasound Catheter

[0039] Referring now to **FIGS. 1 through 2B**, for purposes of illustration, preferred embodiments of the present invention provide an ultrasound catheter **100** that is particularly well suited for use within small vessels of the distal anatomy, such as, for example, in the remote, small diameter, neurovasculature in the brain.

[0040] As shown in **FIGS. 1 and 2A**, the ultrasound catheter **100** generally comprises a multi-component tubular body **102** having a proximal end **104** and a distal end **106**. The tubular body **102** and other components of the catheter **100** can be manufactured in accordance with any of a variety of techniques well known in the catheter manufacturing field. As discussed in more detail below, suitable material dimensions can be readily selected taking into account the natural and anatomical dimensions of the treatment site and of the desired percutaneous access site.

[0041] Preferably, the tubular body **102** can be divided into at least three sections of varying stiffness. The first section, which preferably includes the proximal end **104**, is generally more stiff than a second section, which lies between the proximal end **104** and the distal end **106** of the catheter. This arrangement facilitates the movement and placement of the catheter **102** within small vessels. The third section, which includes ultrasound radiating element **124**, is generally stiffer than the second section due to the presence of the ultrasound radiating element **124**.

[0042] In each of the embodiments described herein, the assembled ultrasound catheter preferably has sufficient structural integrity, or "pushability," to permit the catheter to be advanced through a patient's vasculature to a treatment site without buckling or kinking. In addition, the catheter has the ability to transmit torque, such that the distal portion can be rotated into a desired orientation after insertion into a patient by applying torque to the proximal end.

[0043] The elongate flexible tubular body **102** comprises an outer sheath **108** (see **FIG. 2A**) that is positioned upon an inner core **110**. In an embodiment particularly well suited for small vessels, the outer sheath **108** comprises extruded PEBAX, PTFE, PEEK, PE, polyimides, braided polyimides and/or other similar materials. The distal end portion of the outer sheath **108** is adapted for advancement through vessels having a very small diameter, such as those in the neurovasculature of the brain. Preferably, the distal end portion of the outer sheath **108** has an outer diameter between about 2 and 5 French. More preferably, the distal end portion of the outer sheath **108** has an outer diameter of about 2.8 French. In one preferred embodiment, the outer sheath **108** has an axial length of approximately 150 centimeters.

[0044] In other embodiments, the outer sheath **108** can be formed from a braided tubing formed of, by way of example, high or low density polyethylenes, urethanes, nylons, etc. Such an embodiment enhances the flexibility of the tubular body **102**. For enhanced pushability and torqueability, the outer sheath **108** may be formed with a variable stiffness from the proximal to the distal end. To achieve this, a stiffening member may be included along the proximal end of the tubular body **102**.

[0045] The inner core **110** defines, at least in part, a delivery lumen **112**, which preferably extends longitudinally along the entire length of the catheter **100**. The delivery lumen **112** has a distal exit port **114** and a proximal axis port **116**. Referring again to **FIG. 1**, the proximal access port **116** is defined by drug inlet port **117** of a back end hub **118**, which is attached to the proximal end **104** of the other sheath **108**. The illustrated back end hub **118** is preferably attached to a control box connector **120**, the utility of which will be described in more detail below.

[0046] The delivery lumen **112** is preferably configured to receive a guide wire (not shown). Preferably, the guidewire has a diameter of approximately 0.008 to 0.012 inches. More preferably, the guidewire has a diameter of about 0.010 inches. The inner core **110** is preferably formed from polyimide or a similar material which, in some embodiments, can be braided to increase the flexibility of the tubular body **102**.

[0047] With particular reference to **FIGS. 2A and 2B**, the distal end **106** of the catheter **102** preferably includes the ultrasound radiating element **124**. In the illustrated embodiment, the ultrasound radiating element **124** comprises an ultrasound transducer, which converts, for example, electrical energy into ultrasound energy. In a modified embodiment, the ultrasound energy can be generated by an ultrasound transducer that is remote from the ultrasound radiating element **124** and the ultrasound energy can be transmitted via, for example, a wire to the ultrasound radiating element **124**.

[0048] In the embodiment illustrated in **FIGS. 2A and 2B**, the ultrasound radiating element **124** is configured as a hollow cylinder. As such, the inner core **110** can extend through the lumen of the ultrasound radiating element **124**. The ultrasound radiating element **124** can be secured to the inner core **110** in any suitable manner, such as with an adhesive. A potting material may also be used to further secure the mounting of the ultrasound radiating element along the central core.

[0049] In other embodiments, the ultrasound radiating element **124** can be configured with a different shape without departing from the scope of the invention. For example, the ultrasound radiating element may take the form of a solid rod, a disk, a solid rectangle or a thin block. Still further, the ultrasound radiating element **124** may comprise a plurality of smaller ultrasound radiating elements. The illustrated arrangement is the generally preferred configuration because it provides for enhanced cooling of the ultrasound radiating element **124**. For example, in one preferred embodiment, a drug solution can be delivered through the delivery lumen **112**. As the drug solution passes through the lumen of the ultrasound radiating element, the drug solution may advantageously provide a heat sink for removing excess heat generated by the ultrasound radiating element **124**. In another embodiment, a return path can be formed in the space **138** between the outer sheath and the inner core such that coolant from a coolant system can be directed through the space **138**.

[0050] The ultrasound radiating element **40** is preferably selected to produce ultrasound energy in a frequency range that is well suited for the particular application. Suitable frequencies of ultrasound energy for the applications described herein include, but are not limited to, from about

20 KHz to about 20 MHz. In one embodiment, the frequency is between about 500 KHz and 20 MHz and in another embodiment from about 1 MHz and about 3 MHz. In yet another embodiment, the ultrasound energy has a frequency of about 3 MHz.

[0051] As mentioned above, in the illustrated embodiment, ultrasound energy is generated from electrical power supplied to the ultrasound radiating element **124**. The electrical power can be supplied through the controller box connector **120**, which is connected to a pair of wires **126, 128** that extend through the catheter body **102**. The electrical wires **126, 128** can be secured to the inner core **110**, lay along the inner core **110** and/or extend freely in the space between the inner core **110** and the outer sheath **108**. In the illustrated arrangement, the first wire **126** is connected to the hollow center of the ultrasound radiating element **124** while the second wire **128** is connected to the outer periphery of the ultrasound radiating element **124**. The ultrasound radiating element **124** is preferably, but is not limited to, a transducer formed of a piezoelectric ceramic oscillator or a similar material.

[0052] With continued reference to **FIGS. 2A and 2B**, the distal end **104** of the catheter **100** preferably includes a sleeve **130**, which is generally positioned about the ultrasound radiating element **124**. The sleeve **130** is preferably constructed from a material that readily transmits ultrasound energy. Suitable materials for the sleeve **130** include, but are not limited to, polyolefins, polyimides, polyester and other materials having a relatively low impedance to ultrasound energy. Low ultrasound impedance materials are materials that readily transmit ultrasound energy with minimal absorption of the ultrasound energy. The proximal end of the sleeve **130** can be attached to the outer sheath **108** with an adhesive **132**. To improve the bonding of the adhesive **132** to the outer sheath **108**, a shoulder **127** or notch may be formed in the outer sheath for attachment of the adhesive thereto. Preferably, the outer sheath **108** and the sleeve **130** have substantially the same outer diameter.

[0053] In a similar manner, the distal end of the sleeve **130** can be attached to a tip **134**. In the illustrated arrangement, the tip **134** is also attached to the distal end of the inner core **110**. Preferably, the tip is between about 0.5 and 4.0 millimeters in length. More preferably, the tip is about 2.0 millimeters in length. As illustrated, the tip is preferably rounded in shape to reduce trauma or damage to tissue along the inner wall of a blood vessel or other body structure during advancement toward a treatment site.

[0054] With continued reference to **FIG. 2B**, the catheter **100** preferably includes at least one temperature sensor **136** along the distal end **106**. The temperature sensor **136** is preferably located on or near the ultrasound radiating element **124**. Suitable temperature sensors include but are not limited to, diodes, thermistors, thermocouples, resistance temperature detectors (RTDs), and fiber optic temperature sensors that used thermochromic liquid crystals. The temperature sensor is preferably operatively connected to a control box (not shown) through a control wire, which extends through the catheter body **102** and back end hub **118** and is operatively connected to a control box through the control box connector **120**. The control box preferably includes a feedback control system having the ability to monitor and control the power, voltage, current and phase

supplied to the ultrasound radiating element. In this manner, the temperature along the relevant region of the catheter can be monitored and controlled for optimal performance. Details of the control box can be found in Assignee's copending provisional application entitled CONTROL POD FOR ULTRASONIC CATHETER, Application Serial No. 60/336,630, filed Dec. 3, 2001, which is incorporated by reference in its entirety.

[0055] In one exemplary application of the ultrasound catheter **100** described above, the apparatus may be used to remove a thrombotic occlusion from a small blood vessel. In one preferred method of use, a free end of a guidewire is percutaneously inserted into the patient's vasculature at a suitable first puncture site. The guidewire is advanced through the vasculature toward a treatment site wherein the blood vessel is occluded by the thrombus. The guidewire wire is preferably then directed through the thrombus.

[0056] After advancing the guidewire to the treatment site, the catheter **100** is thereafter percutaneously inserted into the vasculature through the first puncture site and is advanced along the guidewire towards the treatment site using traditional over-the-guidewire techniques. The catheter **100** is advanced until the distal end **106** of the catheter **100** is positioned at or within the occlusion. The distal end **106** of the catheter **100** may include one or more radiopaque markers (not shown) to aid in positioning the distal end **106** within the treatment site.

[0057] After placing the catheter, the guidewire can then be withdrawn from the delivery lumen **112**. A drug solution source (not shown), such as a syringe with a Luer fitting, is attached to the drug inlet port **117** and the controller box connector **120** is connected to the control box. As such, the drug solution can be delivered through the delivery lumen **112** and out the distal access port **114** to the thrombus. Suitable drug solutions for treating a thrombus include, but are not limited to, an aqueous solution containing Heparin, Urokinase, Streptokinase, and/or tissue Plasminogen Activator (TPA).

[0058] The ultrasound radiating element **124** is activated to emit ultrasound energy from the distal end **106** of the catheter **100**. As mentioned above, suitable frequencies for the ultrasound radiating element **124** include, but are not limited to, from about 20 KHz to about 20 MHz. In one embodiment, the frequency is between about 500 KHz and 20 MHz and in another embodiment between about 1 MHz and 3 MHz. In yet another embodiment, the ultrasound energy is emitted at a frequency of about 3 MHz. The drug solution and ultrasound energy are applied until the thrombus is partially or entirely dissolved. Once the thrombus has been dissolved to the desired degree, the catheter **100** is withdrawn from the treatment site.

Stiffening Component

[0059] Referring again to **FIG. 2A**, because the diameter of the distal exit port **114** is often relatively large compared with the diameter of the guidewire (not shown), a gap may exist between the inner rim of the tip **134** and the guidewire. If sufficiently large, this gap may cause the tip **134** of the catheter to catch or snag on an object along the exit port **114**. If the tip **134** catches on an object, the exit port **114** may stretch (i.e., increase in diameter) as the catheter is pushed

forward. This effect is particularly likely to occur at vessel bifurcations and will hereinafter be referred to as "fish-mouthing."

[0060] **FIG. 3** illustrates an embodiment adapted to reduce the likelihood of fish-mouthing wherein a circular stiffening component **140** is provided along the distal tip **134**. The circular stiffening component **140** reduces the gap between the tip **134** and the guidewire, and is preferably made of a stiff material, such as, for example, aluminum, that will prevent the tip **134** from fish-mouthing. Additionally, if the guidewire is formed with a variable diameter, cooperation of the guidewire and the circular stiffening component **140** may be advantageously used as a valve. By adjusting the relative positions of the guidewire and catheter, it is possible to control the delivery of drugs, medications, or other therapeutic compounds through the exit port **114** along the tip **134**. As seen in **FIG. 3**, this embodiment also includes a variation of the inner core **110A** having a flared end that may be inserted into a circumferential notch **142** formed in the distal tip **134**. Insertion of the flared end into the circumferential notch provides for enhanced structural integrity.

[0061] In alternative embodiments, fish-mouthing may be prevented by increasing the thickness of the tip **134**, or by manufacturing the tip **134** using a material with increased stiffness. In such embodiments, the tip **134** will have decreased flexibility, and therefore will be less susceptible to fish-mouthing.

Flexible Joint

[0062] Referring again to **FIG. 2A**, in modified embodiments of the present invention, the rigidity of the catheter along the joint (hereinafter referred to as the "proximal element joint") between the outer sheath **108** and sleeve **130** may be reduced significantly. The rigidity of the proximal element joint is reduced to further enhance flexibility, prevent kinking of the flexible support section of the catheter, and to facilitate tracking of the catheter over the guidewire.

[0063] In such embodiments, the use of an adhesive may be eliminated, and the proximal end of the sleeve **130** may be attached to the outer sheath **108** at the proximal element joint using a direct bonding method adapted to create a more flexible proximal element joint. Examples of such direct bonding methods include, but are not limited to, the use of heat, a solvent, a mold, or a cast. Alternatively, a reflow, or "die wiping" technique may be employed wherein an extruded catheter shaft is covered with a heat shrink tube and heated to reflow and bond the polymers within the catheter shaft. An external heat source may be employed in a reflow technique, or if the catheter includes metal components at the proximal element joint, radio frequency ("RF") energy may be used to heat and bond the polymers within the catheter shaft.

[0064] **FIG. 4** illustrates yet another alternative embodiment for reducing the rigidity of the proximal element joint to thereby enhance the flexibility of the ultrasound catheter. As illustrated in **FIG. 4**, the inner core **410** includes a corrugated portion **452** along the proximal element joint just proximal of the ultrasound radiating element **424**. In such embodiments, a Teflon® liner **450** may be adapted to surround the inner surface of the corrugated portion **452** of the inner core **410** to prevent the guidewire from catching on the corrugations. Additionally, a flexible filler material **456**

and a flexible cover sleeve **454** may be adapted to cover the exterior surface of the corrugated portion **452** of the catheter to prevent the catheter from catching on the interior walls of the vessel anatomy. A corrugated portion **452** of the inner core **410** may be created by placing a close-fitting pin within a portion of the polyimide material used to form the inner core, and applying a compressive force to the polyimide material on either side of the pin. When the pin is removed from the inner core **410**, the corrugated portion **452** of the inner core **410** will have enhanced flexibility and will thereby increase the flexibility of the ultrasound catheter.

[0065] In still other embodiments, the rigidity of the proximal element joint may be further reduced by forming the inner core **410** of the delivery lumen **412** of a material with increased flexibility and resistance to kinking. For example, the inner core **410** of the delivery lumen **412** may comprise a Teflon®-lined polyimide shaft. Additionally, a coil or braid may be incorporated into the delivery lumen **412**, thereby further reducing susceptibility to kinking without increasing the rigidity of the catheter.

[0066] FIG. 5 illustrates yet another alternative embodiment wherein the rigidity of the proximal element joint **548** is reduced by providing an outer sheath **508** that includes an embedded braid **560**. Furthermore, the outer sheath **508** is attached to the sleeve **530** using a flexible exposed braided portion **558**. A flexible filler material **556** and a flexible cover sleeve **554** are used to bond the outer sheath **508**, the sleeve **530** and the exposed braided portion **558** together. This embodiment provides the catheter with a flexible region just proximal to the ultrasound radiating member **524**. In various preferred embodiments, the braided sections may be formed of high or low density polyethylenes, urethanes or nylons.

Shapeable Tip

[0067] FIG. 6A illustrates yet another modified embodiment wherein the ultrasound catheter provides improved tracking over the guidewire **602**. Prolapsing of a guidewire is most likely to occur at small vessel radii, where the guidewire **602** follows a sharp turn, and where the angle θ formed by the intersection between the guidewire **602** and the catheter body is large. In order to reduce the incident angle θ between the guidewire and catheter body, a tapered wire **642** is provided along the exterior of the outer sheath **608** for shaping the distal end of the catheter. The tapered wire **642** may be set in a flexible potting or filler material **644**, which is contained within a flexible sleeve **646**. The tapered wire **642** is preferably comprised of a pliable material, such that it may be pre-formed into a selectable desired orientation before use. Pre-forming of the tapered wire **642** assists the physician in steering the catheter to follow the guidewire **602** reliably around small vessel radii by reducing the angle θ formed by the intersection between the guidewire **602** and the catheter body. The tapered wire is preferably provided in the region surrounding the ultrasound radiating element **624**. FIG. 6B illustrates the embodiment of FIG. 6A in use with the tip pre-formed for improved tracking over the guidewire.

Soft Tip Assembly

[0068] In addition to having excellent flexibility, it is also desirable for an ultrasound catheter to have a rounded and/or

soft tip assembly for minimizing trauma or damage to the tissue along the inner wall of the blood vessel. This feature is particularly important during advancement through small blood vessels in the neurovasculature.

[0069] FIG. 7A illustrates an alternative embodiment wherein the distal end portion of an ultrasound catheter is provided with a soft tip assembly **700**. In the illustrated embodiment, the ultrasound catheter generally comprises an elongate shaft body **702**, an ultrasound radiating element **704**, an elongate soft tip **706** and a connecting sleeve **708**. The soft tip **706** of the catheter is constructed to be softer and more flexible than the shaft body **702** for the purpose of minimizing or eliminating damage to the tissue along the inner wall of a blood vessel. In the illustrated embodiment, the soft tip **706** is configured as a substantially hollow member including a delivery lumen **710**. The lumen **710** may be used for receiving a guidewire and/or for delivering drugs to a treatment site. Preferably, the shaft body **702** and the soft tip **706** have substantially the same outer diameter. The delivery lumen **710** terminates at an exit port **720** at the extreme distal tip of the soft tip assembly.

[0070] Still referring to FIG. 7A, the ultrasound radiating element **704** is provided at a location just distal to the shaft body **702** and just proximal of the soft tip **710**. Preferably, a small gap **712** is provided between the ultrasound radiating element **704** and the elongate body **702** and also between the ultrasound radiating element **704** and the soft tip **706**. In the illustrated embodiment, a single cylindrical ultrasound radiating element **704** is provided, however, in alternative embodiments, others variations may be used, such as, for example a plurality of smaller ultrasound radiating elements.

[0071] In the illustrated embodiment, the shaft body **702**, ultrasound radiating element **704** and soft tip **706** are secured together by the sleeve **708**. The ultrasound radiating element **704** is contained within the lumen of the sleeve **708**. The proximal end **714** of the sleeve **708** extends over the distal portion of the shaft body **702**. The distal end **716** of the sleeve **708** extends over the proximal end of the soft tip **706**. In one embodiment, the sleeve **708** is formed of heat shrink tubing. To maximize effectiveness of the ultrasound catheter, the sleeve **708** is preferably constructed of a material having a low impedance to ultrasound energy. FIG. 7B illustrates a cross-sectional view of the soft tip assembly of FIG. 7A as seen through line 7B-7B.

[0072] Referring again to FIG. 7A, the illustrated embodiment of the soft tip assembly **706** is formed with a plurality of side holes **718**. The side holes **718** are in communication with the delivery lumen **710** and are provided for enhancing the delivery of drugs to the treatment site. Using the side holes **718**, the therapeutic agent can be delivered radially at a location closer to the ultrasound radiating element **704**. The illustrated embodiment includes two side holes, however, in alternative embodiments, any number of side holes may be used without departing from the spirit and scope of the invention. Alternatively, the soft tip assembly may be configured without any side holes.

[0073] In alternative embodiments, the soft tip assembly may have a solid tip wherein drugs exit the tip assembly only through side ports. In the embodiments with a solid tip, the guidewire exits the catheter through a side port, such as in a rapid exchange or monorail catheter design. In another embodiment, the soft tip assembly includes a radiopaque

material to provide for high visibility under fluoroscopy. In various alternative embodiments, the soft tip assembly may have a variety of different lengths, such as, for example, 1 mm, 3 mm and 6 mm.

[0074] In operation, the ultrasound catheter is advanced over a guidewire that extends through the delivery lumen 710. As the ultrasound catheter is advanced through a small blood vessel, the soft tip assembly bends and conforms to the shape of the blood vessel to reduce the pressure applied along the inner wall. The rounded tip of the soft tip assembly also minimizes trauma to the tissue as it is advanced along the inner walls of the blood vessels. The soft tip assembly can bend to facilitate the advancement of the catheter, yet will return to substantially its original shape. After the ultrasound element is positioned in the desired location, the guidewire may be removed and the delivery lumen 710 used for the delivery of a therapeutic agent to the treatment site.

[0075] The soft tip assembly is preferably made of a soft polymer extrusion, such as, for example, polyimide. In one preferred method of construction, the soft tip assembly is constructed by first cutting the extruded soft tubular body into a length of approximately 3 to 6 mm. The distal tip is then rounded and smoothed using a heated die with the desired contour. In the embodiments wherein side holes are provided, the side holes are created using a 0.010 inch hole plunger. The soft tip assembly is then attached to the elongate shaft body using an adhesive or by thermal bonding. Alternatively, a length of heat shrink tubing may be used to secure the shaft body to the soft tip assembly.

Ultrasound Element on a Guidewire

[0076] FIGS. 8 and 9 illustrate another modified embodiment of an ultrasound catheter 850. As shown in FIG. 8, in this embodiment, an ultrasound radiating element 852 is connected to or mounted on a distal end 854 of a guidewire 856. In the illustrated arrangement, the ultrasound radiating element 852 is in the shape of a hollow cylinder. As such, the guidewire 856 can extend through the ultrasound radiating element 852, which is positioned over the guidewire 856. The ultrasound radiating element 852 can be secured to the guidewire 856 in any suitable manner, such as with an adhesive. In other embodiments, the ultrasound radiating element 856 can be of a different shape, such as, for example, a solid cylinder, a disk, a solid rectangle or a plate attached to the guidewire 856. The ultrasound radiating element 852 can also be formed from a plurality of smaller ultrasound elements.

[0077] In the illustrated embodiment, ultrasound energy is generated from electrical power supplied to the ultrasound radiating element 852. As such, the ultrasound radiating element 852 is connected to a pair of wires 860, 862 that can extend through the catheter body. In the illustrated embodiment, the wires 860, 862 are preferably secured to the guidewire 856 with the first wire 860 is connected to the hollow center of the ultrasound radiating element 852 and the second wire 862 connected to the outer periphery of the ultrasound radiating element 852. As with the previous embodiments, the ultrasound radiating element 852 is preferably formed from, but is not limited to, a piezoelectric ceramic oscillator or a similar material. Other wiring schemes include wires connected to both ends of a solid transducer or both sides of a block. The ultrasound radiating

element 852 and the wires 860, 862 are preferably covered with a thin insulating material 857.

[0078] FIG. 9 illustrates one embodiment of a catheter 850 that can be used with the guidewire 856 described above. In this embodiment, the catheter 850 includes an outer sheath 866, which defines the delivery lumen 868. As such, the illustrated embodiment does not include an inner core. The delivery lumen 868 includes a distal opening 870. As will be explained below, in one arrangement, the distal opening 870 can be configured such that the guidewire 856 and the ultrasound radiating element 852 can be withdrawn into the catheter 850 through the distal opening 870. In such an arrangement, a distal end 872 of the catheter 850 preferably includes a sleeve 874, that is constructed from a material that readily transmits ultrasound energy as described above. In another arrangement, the distal opening 870 can be configured such that ultrasound radiating element 852 can not be withdrawn into the catheter 850 through the distal opening 870. In such an arrangement, the ultrasound radiating element 852 is configured to operate outside the catheter 850 near the distal opening 870.

[0079] In one embodiment, the distal end 854 of the guidewire 856 is percutaneously inserted into the arterial system at a suitable first puncture site. The guidewire 856 and the ultrasound radiating element 852 are advanced through the vessels towards a treatment site, which includes a thrombotic occlusion. The guidewire 856 is preferably then directed through the thrombotic occlusion.

[0080] The catheter 850 is thereafter percutaneously inserted into the first puncture site and advanced along the guidewire 856 towards the treatment site using traditional over-the-wires, guidewire techniques. The catheter 850 is advanced until the distal end of the catheter 856 is positioned at or within the occlusion. Preferably, the distal end includes radio opaque markers to aid positioning the distal end within the treatment site.

[0081] In one embodiment, the guidewire 856 can then be withdrawn until the ultrasound radiating element 852 is positioned within the distal end 874 of the catheter 850. In such an arrangement, the catheter 850 can include a proximal stop 875 to aid the positioning of the ultrasound radiating element 852. In another embodiment, the guidewire can be withdrawn until the ultrasound radiating element 852 is located near or adjacent the distal opening 870. The catheter 850 can then be operated as described above.

[0082] In another modified embodiment, a standard guidewire (not shown) is percutaneously inserted into the first puncture site and advanced through the vessels towards and preferably through the occlusion. The catheter 850 is thereafter percutaneously inserted into the first puncture site and advanced along the standard guidewire towards the treatment site using traditional over-the-guidewire techniques. The catheter 850 preferably is advanced until the distal end of the catheter 850 is positioned at or within the occlusion. The standard guidewire can then be withdrawn from the delivery lumen. The guidewire 856 and ultrasound radiating element 852 of FIG. 8 can then be inserted into the delivery lumen. In one embodiment, the ultrasound radiating element 852 is advanced until it is positioned in the distal end of the catheter 850. In another embodiment, the ultrasound radiating element 852 is advanced until it exits the

distal end **870** of the delivery lumen **868**. The catheter can then be operated as describe above.

[0083] **FIG. 10** illustrates yet another modified embodiment of an ultrasound catheter **1000** that can be used with the guidewire **1056** and ultrasound radiating element **1052**, as described above. In this embodiment, the guidewire lumen **1068** is defined by an inner sleeve or tube **1002**. The distal end **1070** of the delivery lumen **1068** can be configured as described above for preventing or withdrawing the ultrasound radiating element **1052** into catheter **1050**. In the illustrated arrangement, the delivery lumen **1068** can be used to transport the drug solution. In another arrangement, the space **1004** between the inner core **1002** and the outer sheath **1066** can be used to transport the drug solution. In such an arrangement, the outer sheath **1066** preferably includes one or more holes positioned at the distal end **1072** of the outer sheath **1066**. The catheter can be advanced on the guidewire **856** of **FIG. 8** or a standard guidewire as described above.

Ultrasound Element on a Hypotube

[0084] **FIGS. 11 and 12** illustrate yet another embodiment of an ultrasound catheter **1101** that is particularly well suited for use with small vessels of the distal anatomy. As shown in **FIG. 12**, this embodiment of the ultrasound catheter **1101** generally comprises a treatment wire **1103** and a microcatheter **1105**.

[0085] **FIG. 11** illustrates a preferred embodiment of a treatment wire **1103**. As shown in **FIG. 11**, in this embodiment, an ultrasound radiating element **1106** is connected to the distal tip of a hypotube **1108**. As discussed with reference to the small vessel catheters described above, the ultrasound radiating element can take many shapes and forms. The ultrasound radiating element **1106** is potted in an insulating material either as a conformal coating or potted inside an outer sleeve. The potting **1110** over the ultrasound radiating element **1106** sections is optimized for transmission of ultrasound energy. In the embodiment illustrated in **FIG. 11**, the width of the potted ultrasound radiating element **1112** is approximately 0.018 inches. An epoxy or similar adhesive known in the catheter manufacturing field connects the potted ultrasound radiating element **1112** with the hypotube **1108** at junction **1114**.

[0086] The hypotube **1108** is made from Nitinol or stainless steel or other suitable material in accordance with the techniques and materials known in the catheter manufacturing field. In one embodiment, the hypotube has a diameter of approximately 0.014 to 0.015 inches. The hypotube **1108** provides an insulated lumen **1116** through which one can run power wires **1118** for the ultrasound radiating element **1106** or wires for temperature sensors (not shown) in the microcatheter **1105**. The microcatheter **1105**, into which the treatment wire **1103** is inserted, has a diameter greater than the width of the potted ultrasound radiating element **1112**.

[0087] As shown in **FIG. 11**, in this embodiment, a flexible nose **1120** is connected to the distal end of the potted ultrasound radiating element **1112**. An epoxy or similar adhesive known in the catheter manufacturing field connects the flexible nose **1120** to the potted ultrasound radiating element **1112** at junction **1122**. The flexible nose **1120** is at least approximately 3 millimeters in length and functions as a guidewire when the treatment wire **1103** is inserted into a

microcatheter **1105**. In the embodiment illustrated in **FIG. 11**, the flexible nose **1120** is a soft coil made of metal or another suitable material known in the art. The flexible nose **1120** facilitates the delivery of the potted ultrasound radiating element **1112** through the microcatheter **1105** and into the vessel lumen of the treatment site. Preferably, the flexible nose **1120** is tapered in a manner so that the distal end of the nose has a smaller diameter than the proximal end.

[0088] In use, a free end of a guidewire is percutaneously inserted into the arterial system at a suitable first puncture site. The guidewire is advanced through the vessels toward a treatment site, such as, for example, a thrombotic occlusion in the middle cerebral artery.

[0089] The microcatheter **1105** is thereafter percutaneously inserted into the first puncture site and advanced along the guidewire towards the treatment site using traditional over-the-guidewire techniques. The catheter **1105** is advanced until the distal end **1199** of the catheter **1105** is positioned at or within the occlusion. Preferably, the distal end **1199** includes radio opaque markers to aid positioning the distal end **1199** within the treatment site.

[0090] The guidewire can then be withdrawn from the delivery lumen **1197** of the microcatheter **1105**. As illustrated in **FIG. 12**, the treatment wire **1103** is then inserted and advanced through the microcatheter **1105** to the treatment site. The potted ultrasound radiating element **1112** of the treatment wire **1103** is advanced beyond the distal end **1199** of the microcatheter and into lumen of the vessel. Once at the target site, the ultrasound radiating element **1106** provides ultrasound energy.

[0091] Preferably, drugs **1124**, including but not limited to drugs having thrombolytic effects, are infused through the microcatheter **1105** and delivered into the vessel around the ultrasound radiating element **1106** at the same time the ultrasound radiating element **1106** emits energy. It is believed that the transmission of ultrasound energy at the treatment site enhances drug uptake and activity and has other therapeutic effects. Preferably, the potted ultrasound radiating element **1112** extends far enough away from the distal tip **1199** of the microcatheter **1105** to facilitate the infusion of drugs (shown by arrow **1124**) through the microcatheter **1105** and into the vessel.

Overview of Ultrasound Catheter with Embedded Conductors

[0092] In certain embodiments, wherein an ultrasound radiating member is positioned between an inner elongate tubular body and an outer elongate tubular body, it is desired to pass elongate electrical conductors to the ultrasound radiating member from the proximal end of the catheter, thereby allowing an externally-generated driving signal to be provided to the ultrasound radiating member. In addition, in embodiments wherein a temperature sensor is positioned in the distal region of the catheter, it is desired to pass one or more elongate electrical conductors to the temperature sensor from the proximal end of the catheter, thereby allowing a distal temperature signal to be monitored at the proximal end of the catheter. The configuration of such elongate electrical conductors can be manipulated to affect the stiffness, torqueability, pushability, flexibility and other mechanical parameters of the catheter, thereby affecting accessibility of remote targets in the patient's vasculature.

[0093] Such embedded conductor configurations are discussed in greater detail in this section. These embodiments are particularly well-suited for use with small vessels of the distal anatomy, such as, for example, the vessels of the neurovascular system. However, such embodiments are also well-suited for the treatment of long segment peripheral arterial occlusions.

[0094] Referring now to FIG. 13A, an ultrasonic catheter 1200 generally comprises a multi-component tubular body 1201 having a proximal end 1204 and a distal end 1202. The tubular body 1201 and other components of the catheter 1200 can be manufactured in accordance with any of a variety of techniques well known in the catheter manufacturing field, and as explained above.

[0095] The ultrasonic catheter 1200 also comprises one or more ultrasound radiating members 1240 at its distal end 1202. Suitable material dimensions for the ultrasound radiating member 1240 can be readily selected taking into account the natural and anatomical dimensions of the treatment site and of the desired percutaneous access site, as explained above. In other embodiments, the ultrasonic catheter 1200 further comprises a temperature sensor (not shown) positioned within the catheter distal region, as described above. In one preferred embodiment of an ultrasonic catheter 1200, a central lumen 1251 can be concentrically placed over a guidewire (not shown) which has been previously navigated to the target area under, for example, fluoroscopic localization by a skilled surgeon or medical practitioner.

[0096] The ultrasonic catheter 1200 generally comprises one or more electrically conductive wires or fibers 1206, 1208 that extend along the length of the catheter 1200. In certain embodiments, the conductive wires 1206, 1208 generally reside within the wall 1210 of the tubular body 1201. In such embodiments, the wall 1210 of the tubular body 1201 comprises an inner portion 1212 and an outer portion 1214. In such embodiments, the conductive wires 1206, 1208 can be located in between the inner portion 1212 and outer portion 1214 of the wall 1210.

[0097] The inner portion 1212 provides a barrier against the contents of the central lumen 1251, such as, for example, therapeutic drugs infused through the central lumen 1251 and out the distal end 1202 of the catheter to a treatment site within the patient's vasculature. The outer portion 1214 provides a barrier against the environment in which the catheter 1200 resides, which may include, for example, blood or other bodily fluids.

[0098] The inner portion 1212 and outer portion 1214 of the wall 1210, and the wall 1210 in general, with the exception of the conductive wires 1206, 1208 embedded in the wall 1210, is made of insulating material, such as, for example, polyimide, high or low density polyethylenes, urethanes, nylons, and the like. Consequently, the conductive wires 1206, 1208 are electrically isolated from the central lumen 1251 and the environment in which the catheter 1200 resides.

[0099] The conductive wires 1206, 1208 are also preferably electrically isolated from each other. In one embodiment, the wires 1206, 1208 are arranged and configured in a manner to prevent contact between them. For example, the wires 1206, 1208 may be arranged along and/or around the

central lumen in a manner which prevents any contact between the wires 1206, 1208. Also, electrically insulating material may be placed between the wires 1206, 1208 to prevent contact between them. In another embodiment, the wires 1206, 1208 are covered with insulating coating material either in addition to or in lieu of placing insulating material between the wires 1206, 1208 or making the wall 1210 from insulating material.

[0100] The physical configuration or layout of the conductive wires 1206 and 1208 embedded within the wall 1210 of the tubular body 1201 can be adjusted to determine the mechanical attributes of the catheter 1200. The conductive wires 1206, 1208 may be arranged in various architectures such as, for example, linear arrays, weaving, spiraling, and other patterns which modulate stiffness, torquability, pushability, flexibility and other mechanical parameters of the catheter which relate to accessibility of remote targets.

[0101] In one embodiment, shown in FIG. 13A, both conductive wires 1206, 1208 spiral around the central lumen 1251 and remain substantially parallel to each other at all times along the length of the catheter 1200. In a modified embodiment, the wires 1206, 1208 are covered with insulating coating material. In another modified embodiment, illustrated in FIG. 13B, the conductive wires 1206, 1208 are covered with insulating coating material or separated with insulating material and are contained in a unitary cable 1216. In such embodiments, the cable 1216 spirals around the central lumen 1251 along the length of the catheter 1200.

[0102] In another embodiment, illustrated in FIG. 14, the conductive wires 1206, 1208 are covered with insulating coating material and are spiraled in opposite directions, thereby forming a helix or helical pattern around the central lumen 1251. In forming a helical pattern, the wires 1206, 1208 cross each other, but remain electrically isolated from each other due to the insulating coating material around each wire.

[0103] In another embodiment, illustrated in FIG. 15, the conductive wires 1206, 1208 run in a generally straight line along the length of the catheter 1200, and do not spiral around the central lumen 1251 or cross each other. In such embodiments, the wires 1206, 1208 can optionally be covered with an insulating coating material.

[0104] In a modified embodiment, illustrated in FIGS. 16A and 16B, the ultrasonic catheter comprises an outer tubular body 1400 surrounding an inner core 1402. The inner core 1402 defines a central lumen 1408 that can be used to pass a guidewire, a cooling fluid or a therapeutic compound through the ultrasonic catheter. In a distal region of the ultrasonic catheter, a tubular ultrasound radiating member 1404 is positioned between the outer tubular body 1400 and the inner core 1402. In regions proximal to the ultrasound radiating member 1404, the outer tubular body 1400 and the inner core 1402 are separated by an insulating layer 1406. Preferably, the inner core outer surface 1410 and the outer tubular body inner surface 1412 are electrically conductive, and are electrically connected to opposite poles of a power supply (not shown). Such electrically conductive surfaces can be created by depositing an electrically conductive material onto the desired surface.

[0105] In such embodiments, the conductive surfaces are separated by the insulating layer 1406 along the length of the

catheter, and the presence of the ultrasound radiating member **1404** in the catheter distal region completes the electric circuit. In particular, because opposite surfaces of the ultrasound radiating member contact conductive surfaces of opposite polarity **1410**, **1412**, a voltage difference is created across the ultrasound radiating member, thereby causing ultrasonic vibrations to be created.

[**0106**] Such embodiments allow the ultrasound radiating member **1404** to be driven while eliminating any wires passing along the catheter body, such as illustrated in **FIGS. 13A through 15**. Elimination of wiring in the catheter body reduces manufacturing costs and reduces overall catheter dimensions, thereby increasing catheter maneuverability. Elimination of wiring can also increase catheter flexibility. Thus, in applications where the ultrasound catheter is to be passed through a small or tortuous portion of the vasculature, it may be desired to use such embodiments.

[**0107**] Small vessel ultrasonic catheters with conducting wires or fibers embedded in the walls of the catheter, as described above, can be assembled in a number of ways. See, for example, U.S. Pat. Nos. 4,277,432 and 6,030,371, both of which are incorporated by reference herein. In one method, the catheter is made from tubing which is fabricated from a polymer material that is extruded through a dye in a molten state and that is solidified while being drawn. In one preferred embodiment of the present invention, an electrically insulating material is extruded through the dye.

[**0108**] Conventionally, manufacturing equipment is used to co-extrude polymer support fibers, such as, for example, Kevlar, into the tubing wall in a linear, spiral, or woven pattern. In certain embodiments of the present invention, electrically conductive wires or fibers are used in lieu of polymer support fibers. Examples of conductive fibers include, but are not limited to, copper, carbon, steel, and stainless steel. In a modified embodiment, the conductive fibers are pre-coated with an insulating coating before they are co-extruded.

[**0109**] In another method of assembling small vessel catheters with conducting wires or fibers embedded in the walls of the catheter, the wires are sandwiched between two concentric tubes, an inner tube and an outer tube, both of which initially have approximately half the wall thickness of the final assembled catheter. The inner diameter of the inner tube determines the diameter of the final assembled catheter. The inner diameter of the outer tube is significantly greater than the outer diameter of the inner tube. For example, the inner and outer tubes can be made from an electrically isolating material.

[**0110**] In such embodiments, the catheter is assembled by winding or placing conductive fiber or wire over the inner tube; concentrically translating the outer tube over the inner tube and the fiber wrapping or abutting the inner tube; and radially shrinking the outer tube onto the inner tube such that the conductive fiber is trapped between the inner and outer tubes. In a modified embodiment, the conductive fibers are pre-coated with an insulating coating before they are incorporated into the above described sandwich construction.

[**0111**] As described above, the various configurations and arrangements of the elongate electrical conductors described herein can be used regardless of whether such elongate electrical conductors are connected to an ultrasound radiating member or a temperature sensor at the catheter distal end.

CONCLUSION

[**0112**] While the foregoing detailed description has described several embodiments of the apparatus and methods of the present invention, it is to be understood that the above description is illustrative only and not limiting of the disclosed invention. It will be appreciated that the specific dimensions of the various catheters and guidewires can differ from those described above, and that the methods described can be used within any biological conduit within the body and remain within the scope of the present invention. Thus, the invention is to be limited only by the claims which follow.

We claim:

1. An ultrasound catheter comprising:

an elongate tubular body having a proximal region and a distal region opposite the proximal region, the tubular body defining a central lumen having a central lumen diameter;

an elongate, hollow inner core extending through the central lumen and having an inner core outer diameter that is less than or equal to the central lumen diameter;

an ultrasound radiating member positioned within the distal region of the tubular body and between the tubular body and the inner core;

at least two electrical conductors extending between the tubular body proximal region and the tubular body distal region, the at least two electrical conductors positioned between the tubular body and the inner core, and electrically connected to the ultrasound radiating member, wherein the at least two electrical conductors are wrapped around the inner core a plurality of times in a region between the ultrasound radiating member and the tubular body proximal region.

2. The ultrasound catheter of claim 1, further comprising:

a temperature sensor positioned adjacent the distal region of the elongate tubular body; and

at least one temperature sensor wire extending between the tubular body proximal region and the tubular body distal region, wherein at least a portion of the at least one temperature sensor wire is positioned between the tubular body and the inner core, and wherein the at least one temperature sensor wire is electrically connected to the temperature sensor.

3. The ultrasound catheter of claim 1, wherein the at least two electrical conductors are substantially parallel in a region between the ultrasound radiating member and the tubular body proximal region.

4. The ultrasound catheter of claim 3, wherein the at least two electrical conductors are integrated into a unitary cable.

5. The ultrasound catheter of claim 1, wherein the at least two electrical conductors do not cross paths in a region between the ultrasound radiating member and the tubular body proximal region.

6. The ultrasound catheter of claim 5, wherein the at least two electrical conductors are integrated into a unitary cable.

7. The ultrasound catheter of claim 1, wherein the at least two electrical conductors are wrapped around the inner core in opposite directions.

8. The ultrasound catheter of claim 1, wherein the at least two electrical conductors comprise electrically conductive fibers.

9. An ultrasound catheter comprising:

an elongate tubular body having a proximal region and a distal region opposite the proximal region, the tubular body defining a central lumen having a central lumen diameter;

an elongate, hollow inner core extending through the central lumen and having an inner core outer diameter that is less than or equal to the central lumen diameter;

an ultrasound radiating member positioned within the distal region of the tubular body and between the tubular body and the inner core;

at least two electrical conductors extending between the tubular body proximal region and the tubular body distal region, the at least two electrical conductors positioned between the tubular body and the inner core, and electrically connected to the ultrasound radiating member, wherein the at least two electrical conductors are disposed substantially parallel to a catheter axis in a region between the ultrasound radiating member and the tubular body proximal region.

10. The ultrasound catheter of claim 9, further comprising:

a temperature sensor positioned adjacent the distal region of the elongate tubular body; and

at least one temperature sensor wire extending between the tubular body proximal region and the tubular body distal region, wherein at least a portion of the at least one temperature sensor wire is positioned between the tubular body and the inner core, and wherein the at least one temperature sensor wire is electrically connected to the temperature sensor.

11. The ultrasound catheter of claim 9, wherein the ultrasound catheter comprises two electrical conductors which are disposed at substantially radially opposite points around the inner core.

12. The ultrasound catheter of claim 9, wherein the at least two electrical conductors comprise electrically conductive fibers.

13. An apparatus comprising:

an elongate, hollow body having a proximal region, a distal region opposite the proximal region, a body thickness, and an inner lumen;

an ultrasound radiating member positioned within the body thickness of the elongate, hollow body; and

a plurality of elongate electrical conductors extending between the elongate, hollow body proximal region and the ultrasound radiating member, and positioned within the body thickness of the elongate, hollow body.

14. The apparatus of claim 13, further comprising:

a temperature sensor positioned adjacent the elongate, hollow body distal region; and

at least one temperature sensor wire extending between the elongate, hollow body proximal region and the temperature sensor, and positioned within the body thickness of the elongate, hollow body.

15. The apparatus of claim 13, wherein the plurality of electrical conductors are substantially parallel in a region between the ultrasound radiating member and the elongate, hollow body proximal region.

16. The apparatus of claim 15, wherein the plurality of electrical conductors are integrated into a unitary cable.

17. The apparatus of claim 13, wherein the plurality of electrical conductors do not cross paths in a region between the ultrasound radiating member and the elongate, hollow body proximal region.

18. The apparatus of claim 17, wherein the plurality of electrical conductors are integrated into a unitary cable.

19. The apparatus of claim 13, wherein the plurality of electrical conductors are wrapped around the inner core in opposite directions.

20. The ultrasound catheter of claim 13, wherein the plurality of electrical conductors comprise electrically conductive fibers.

21. A method comprising:

maneuvering a guidewire through a patient's vasculature, such that a guidewire distal region is adjacent to a treatment site;

passing an elongate tubular body over the guidewire, the elongate tubular body having a distal region, a proximal region opposite the distal region and a tubular ultrasound radiating member mounted to the elongate tubular body distal region, such that the ultrasound radiating member is adjacent the treatment site;

withdrawing the guidewire from the elongate tubular body;

passing an electronic driving signal to the ultrasound radiating member to cause the ultrasound radiating member to deliver ultrasonic energy to the treatment site;

passing a therapeutic compound through the elongate tubular body to the treatment site, such that a quantity of therapeutic compound delivered to the treatment site is exposed to ultrasonic energy.

22. The method of claim 21, wherein the ultrasound radiating member is positioned within the elongate tubular body.

23. The method of claim 21, further comprising sensing a temperature at the treatment site.

24. A method of manufacturing an ultrasonic catheter comprising:

providing an inner tube having an inner diameter sufficient to accommodate a guidewire;

mounting a tubular ultrasound radiating member around a distal region of the inner tube;

positioning a first and a second electrical conductor along the inner tube, such that the first electrical conductor contacts an inner side of the ultrasound radiating member, and the second electrical conductor contacts an outer side of the ultrasound radiating member;

concentrically translating an outer tube over the inner tube and the ultrasound radiating member; and

radially shrinking the outer tube onto the inner tube.

25. The method of claim 24, further comprising:

mounting a temperature sensor adjacent to the distal region of the inner tube; and

positioning at least one temperature sensor wire along the inner tube, such that the temperature sensor wire is electrically connect to the temperature sensor.

26. The method of claim 24, wherein the first and second electrical conductors are positioned along the inner tube in a substantially parallel configuration.

27. The method of claim 26, wherein the first and second electrical conductors are positioned along the inner tube at substantially radially opposite points.

28. The method of claim 24, further comprising integrating the first and second electrical conductors into a unitary cable.

29. The method of claim 24, wherein the first and second electrical conductors are wrapped around the inner core in opposite directions.

30. The method of claim 24, further comprising connecting the first and second electrical conductors to opposite poles of a power supply at a proximal end of the ultrasonic catheter.

31. An apparatus comprising:

an elongate tubular body having a proximal region and a distal region opposite the proximal region, the tubular body defining a central lumen having a central lumen surface that is electrically conductive;

an elongate, hollow inner core extending through the central lumen and having an inner core outer surface that is electrically conductive;

an ultrasound radiating member positioned within the distal region of the tubular body and between the tubular body and the inner core, such that the tubular body conductive surface and the inner core conductive surface are both in electrical contact with the ultrasound radiating member; and

an insulating sleeve positioned between the tubular body and the inner core in a region proximal to the ultrasound radiating member.

32. The apparatus of claim 31, further comprising a temperature sensor positioned adjacent the elongate tubular body distal region.

33. The apparatus of claim 31, wherein the tubular body conductive surface and the inner core conductive surface are electrically connected to opposite poles of a power supply.

34. The apparatus of claim 31, further comprising a plurality of ultrasound radiating members positioned between the tubular body and the inner core.

35. The apparatus of claim 34, further comprising an insulating sleeve positioned between the tubular body and the inner core in regions between the plurality of ultrasound radiating members.

36. The apparatus of claim 31, wherein the conductive surfaces comprise metallic fibers disposed on the central lumen surface or the inner core outer surface.

37. The apparatus of claim 36, wherein the metallic fibers comprise copper.

38. An ultrasound catheter comprising:

an elongate tubular body having a proximal region and a distal region opposite the proximal region, the tubular body defining a central lumen having a central lumen diameter;

an elongate, hollow inner core extending through the central lumen and having an inner core outer diameter that is less than or equal to the central lumen diameter;

an ultrasound radiating member positioned within the distal region of the tubular body and between the tubular body and the inner core;

a temperature sensor positioned adjacent the distal region of the elongate tubular body; and

at least one temperature sensor wire extending between the tubular body proximal region and the tubular body distal region, wherein at least a portion of the at least one temperature sensor wire is positioned between the tubular body and the inner core, and wherein the at least one temperature sensor wire is electrically connected to the temperature sensor.

* * * * *

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申请(专利权)人(译)	WILSON理查德· 亚伯拉罕TIM OLIVER LEONARD R.		
当前申请(专利权)人(译)	EKOS CORPORATION		
[标]发明人	WILSON RICHARD R ABRAHAMSON TIM OLIVER LEONARD R		
发明人	WILSON, RICHARD R. ABRAHAMSON, TIM OLIVER, LEONARD R.		
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摘要(译)

超声导管包括细长管状主体。细长管状主体具有近端区域和与近端区域相对的远端区域。管状主体限定了具有中心内腔直径的中央内腔。超声导管还包括延伸穿过中央内腔的细长中空内芯。细长的中空内芯的内芯外径小于或等于中心内腔直径。超声导管还包括超声辐射构件，其定位在管状主体的远端区域内并位于管状主体和内芯之间。超声导管还包括在管状主体近端区域和管状主体远端区域之间延伸的至少两个电导体。至少两个电导体位于管状主体和内芯之间。至少两个电导体电连接到超声辐射构件。至少两个电导体在超声辐射构件和管状体近端区域之间的区域中多次缠绕内芯。

