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(54) **SHOCK WAVE BALLOON CATHETER WITH INSERTABLE ELECTRODES**

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**ABSTRACT**

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A translatable shock wave treatment apparatus is suitable for use in treating calcified lesions in vascular structures having small diameters. An elongate member carrying a collapsed angioplasty balloon is first inserted into the occluded blood vessel. The angioplasty balloon is inflated with a conducting fluid to pre-dilate the narrow blood vessel prior to introducing electrodes and applying shock wave therapy. After the blood vessel is at least partially opened, a translatable electrode carrier equipped with one or more shock wave emitters is advanced into the angioplasty balloon. Shock waves are then propagated through the fluid to impart energy to calcified plaques along the vessel walls, thereby softening the calcified lesions. Following the shock wave treatment, multiple inflation and deflation cycles of the angioplasty balloon can be administered to gently compress the softened lesion and complete dilation of the blood vessel.

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**Publication Classification**

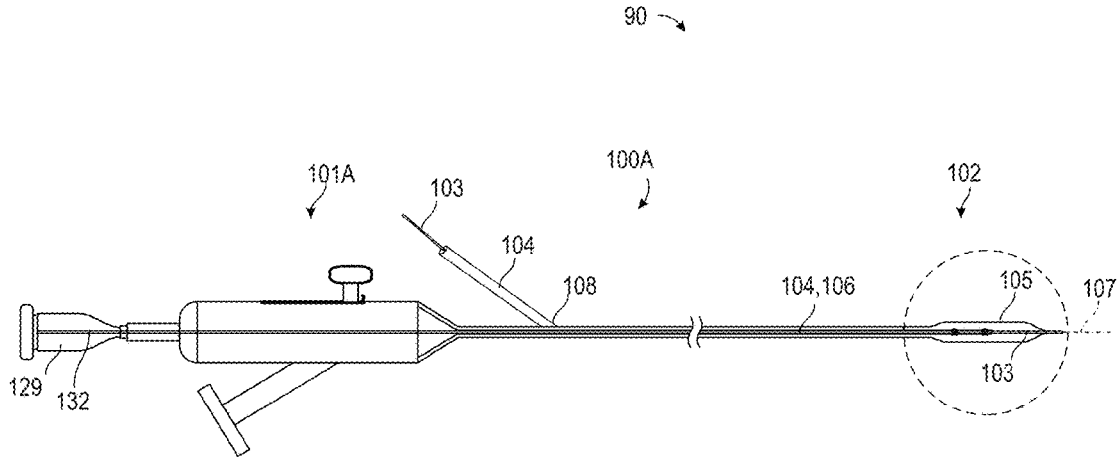
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*A61M 25/10* (2006.01)

(52) **U.S. Cl.**

CPC ..... *A61B 17/22022* (2013.01); *A61M 25/104* (2013.01); *A61M 2025/0008* (2013.01); *A61B*



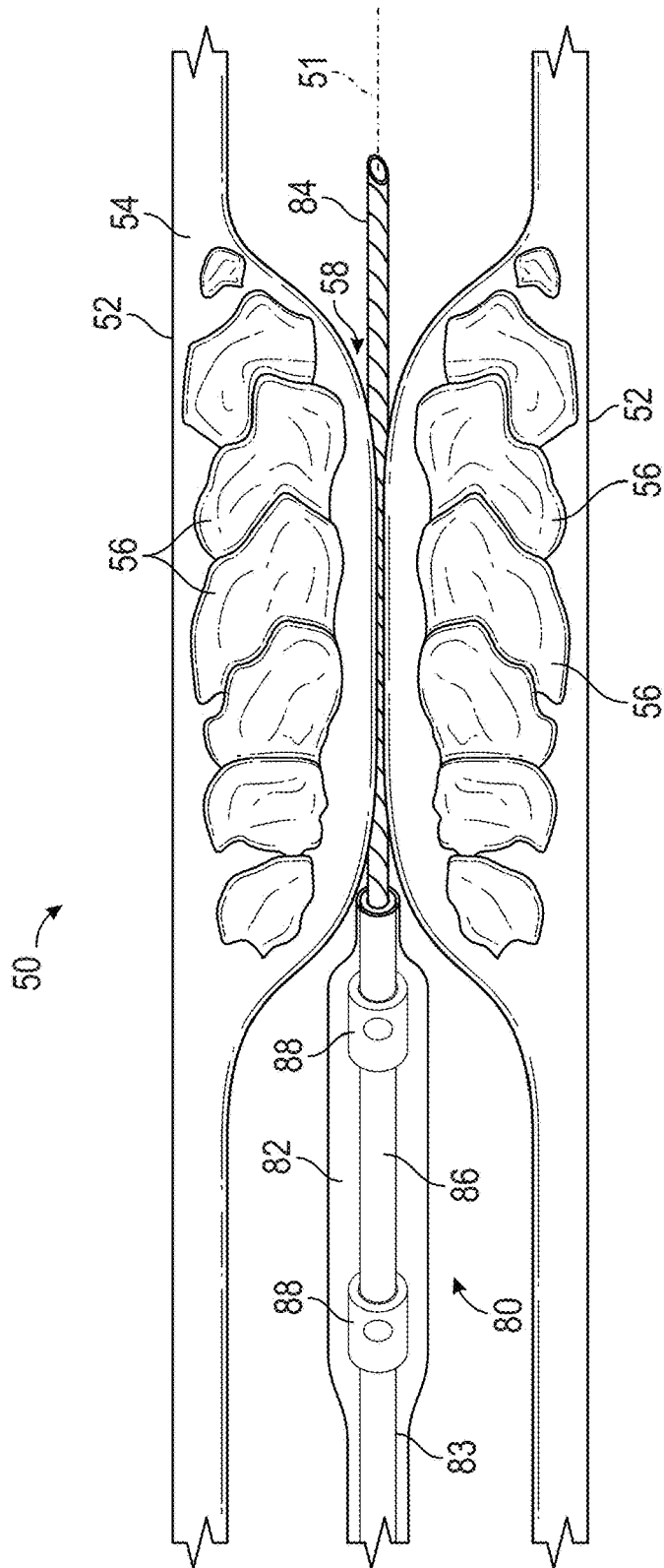


FIG. 1 (PRIOR ART)

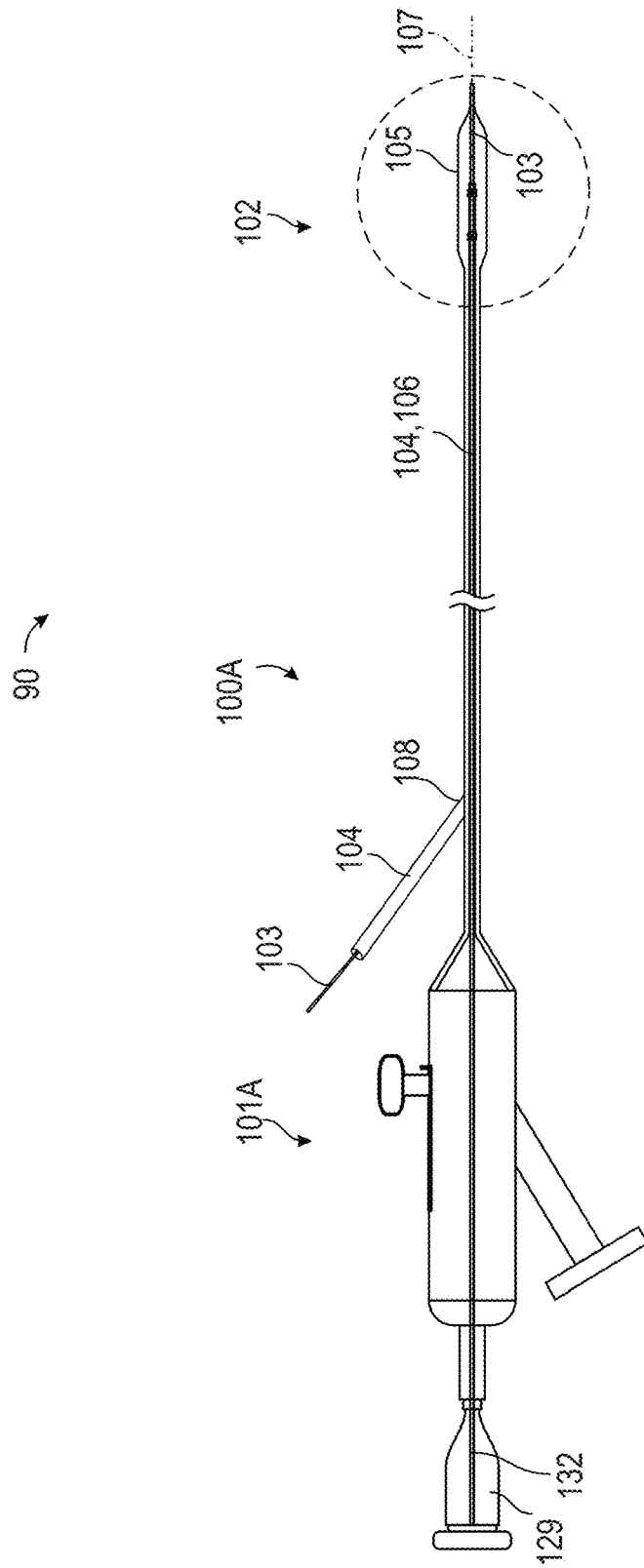


FIG. 2A

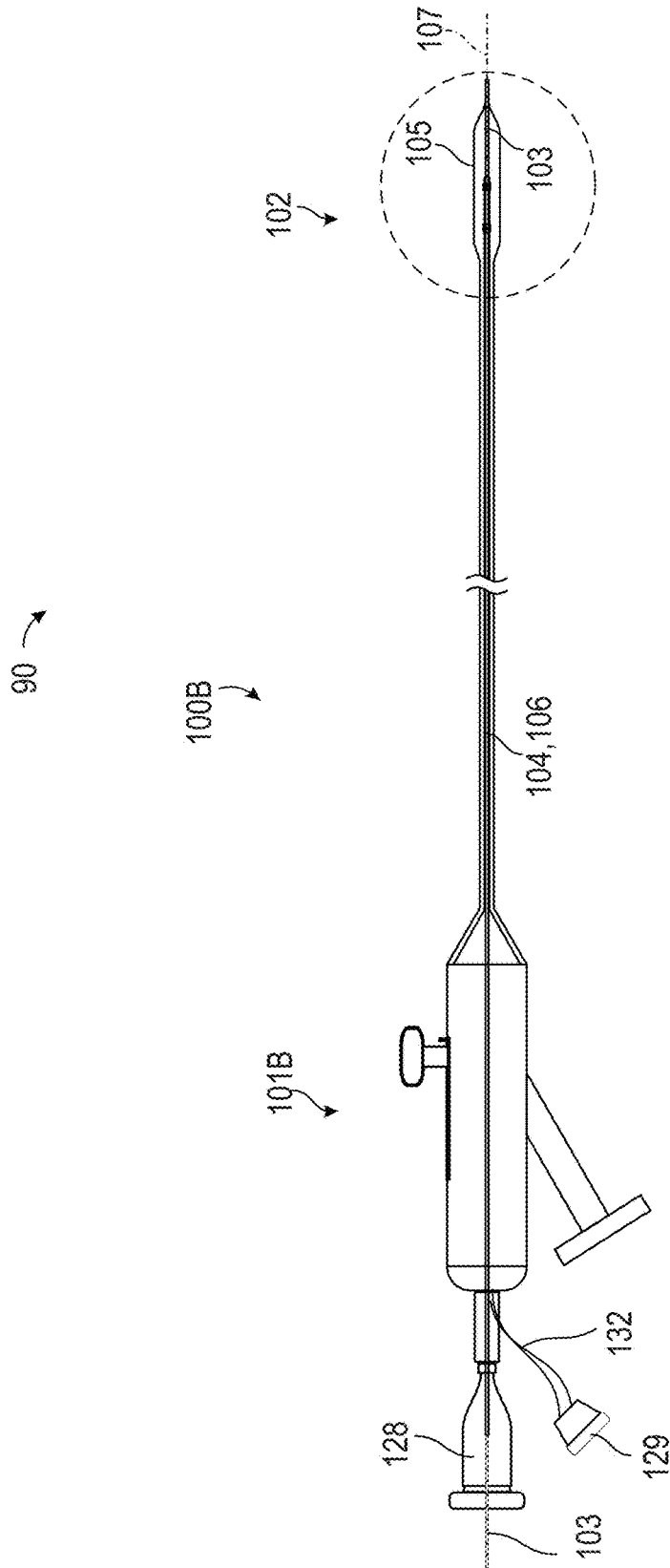


FIG. 2B

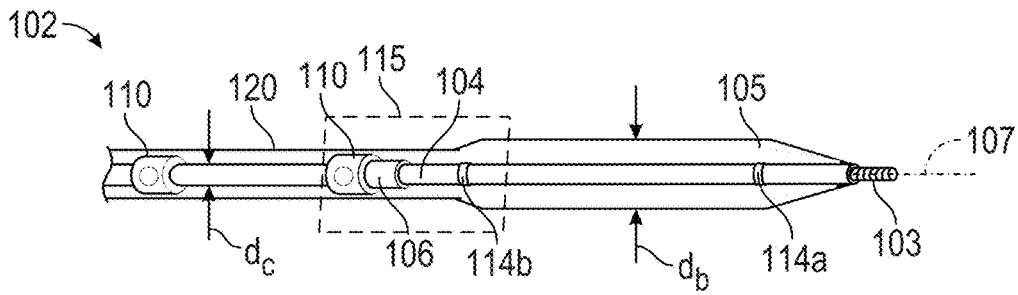


FIG. 3A

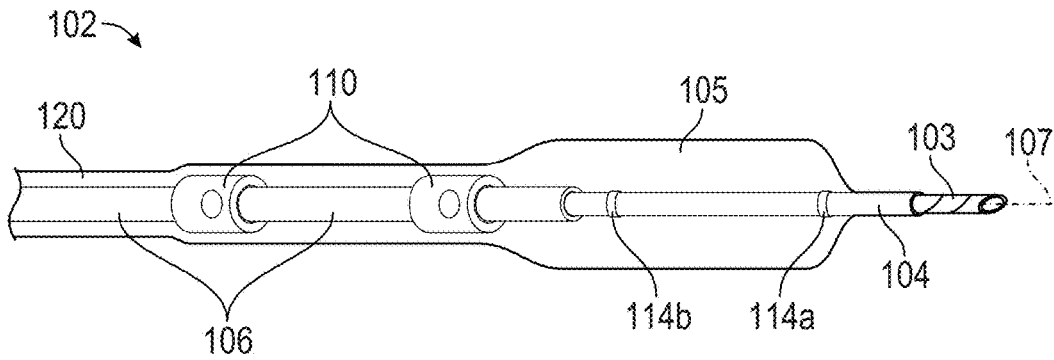


FIG. 3B

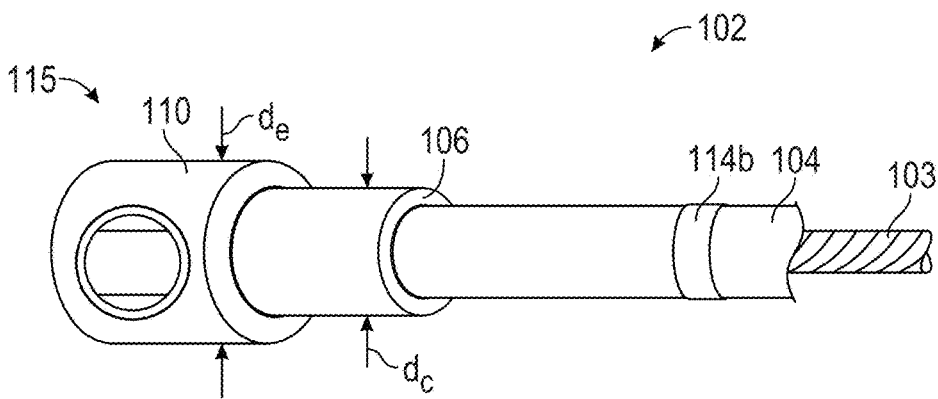


FIG. 3C

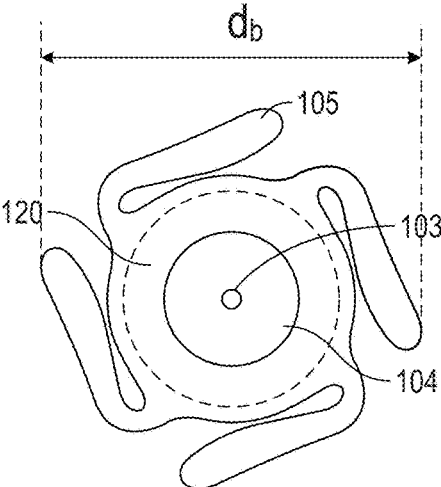


FIG. 3D

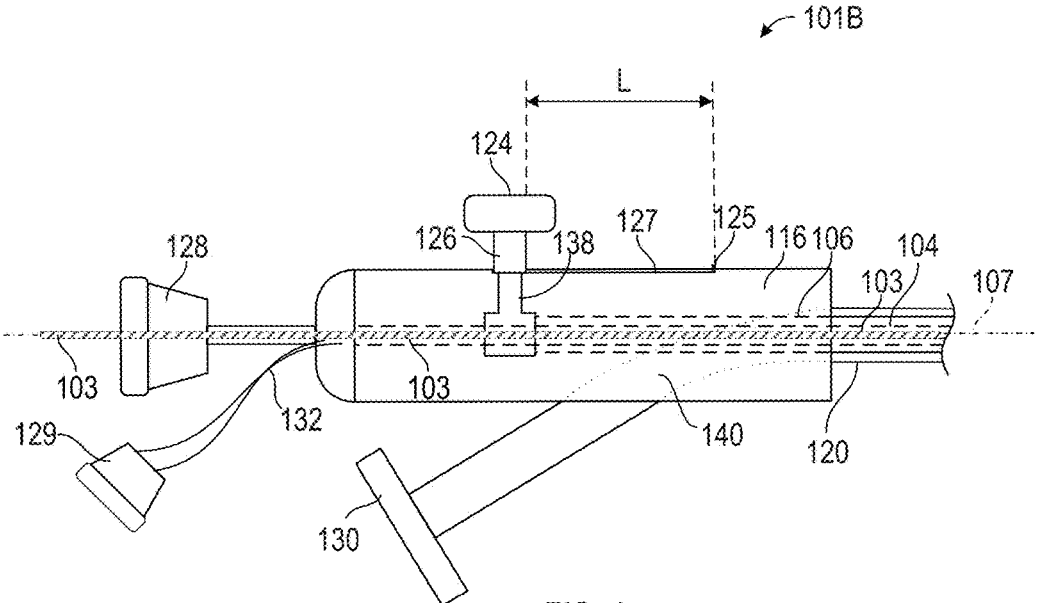


FIG. 4

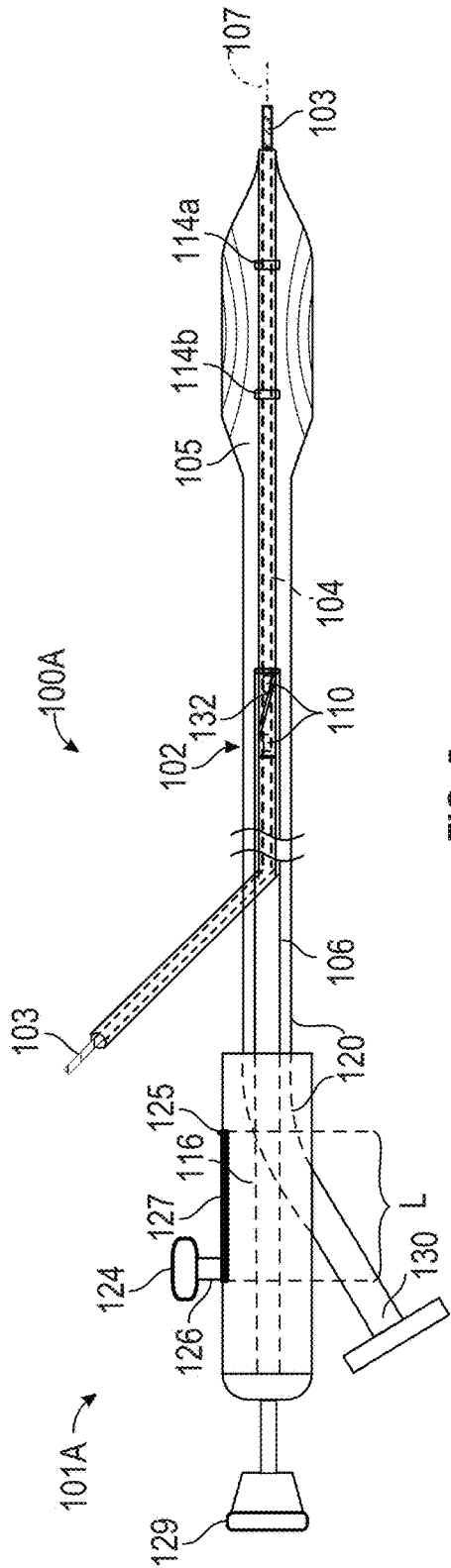


FIG. 5

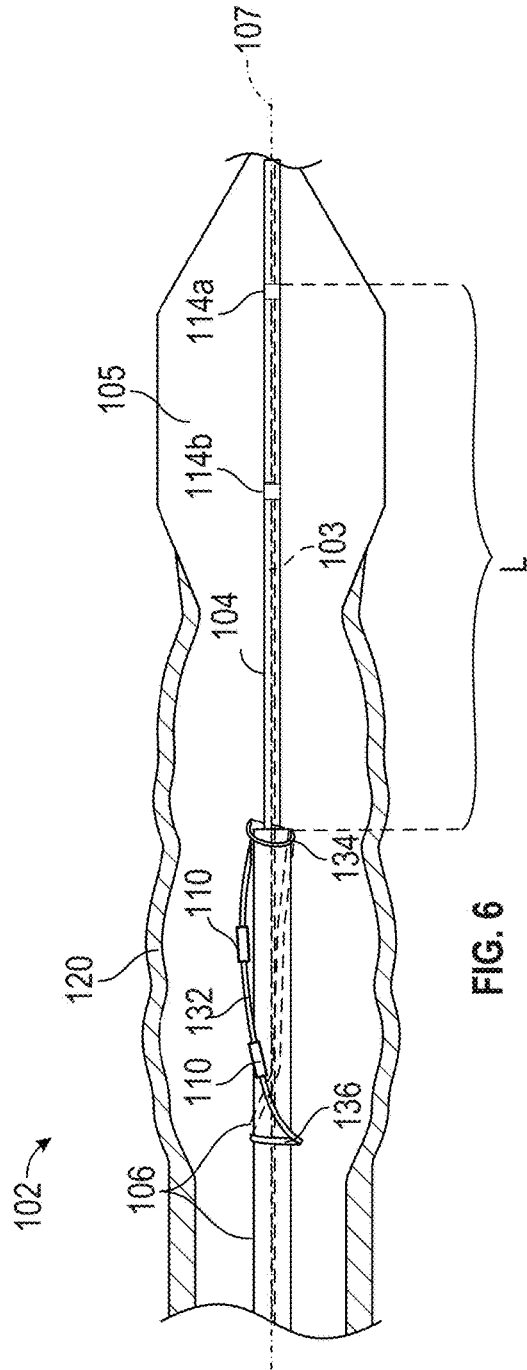
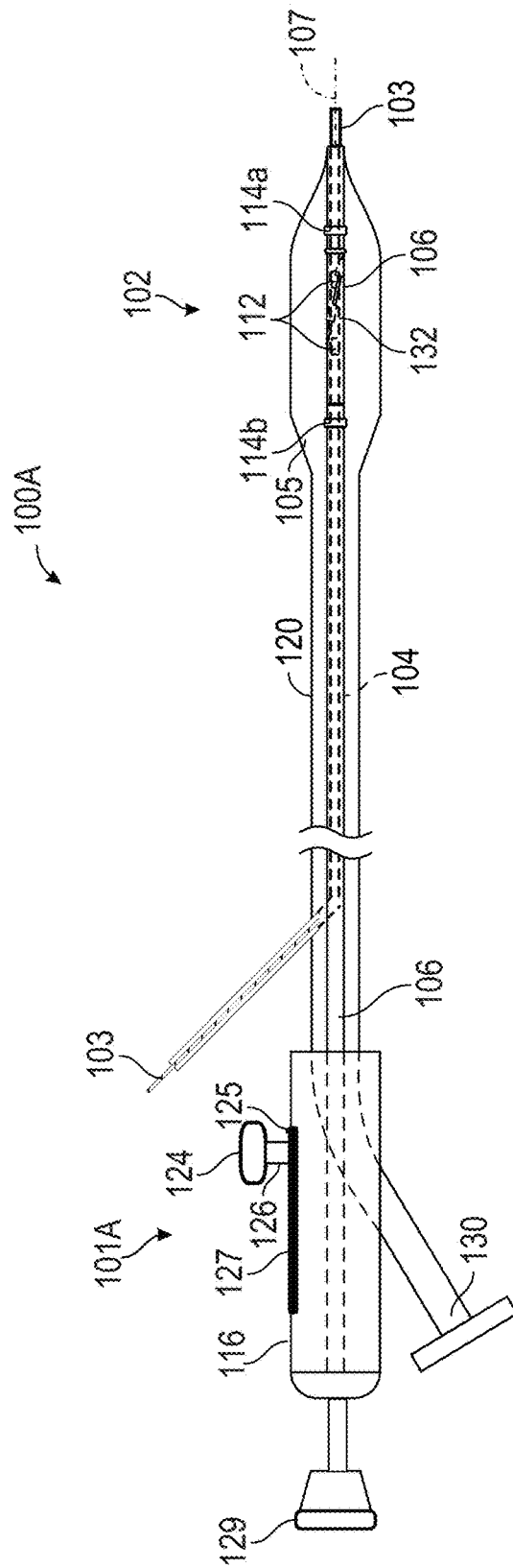


FIG. 6





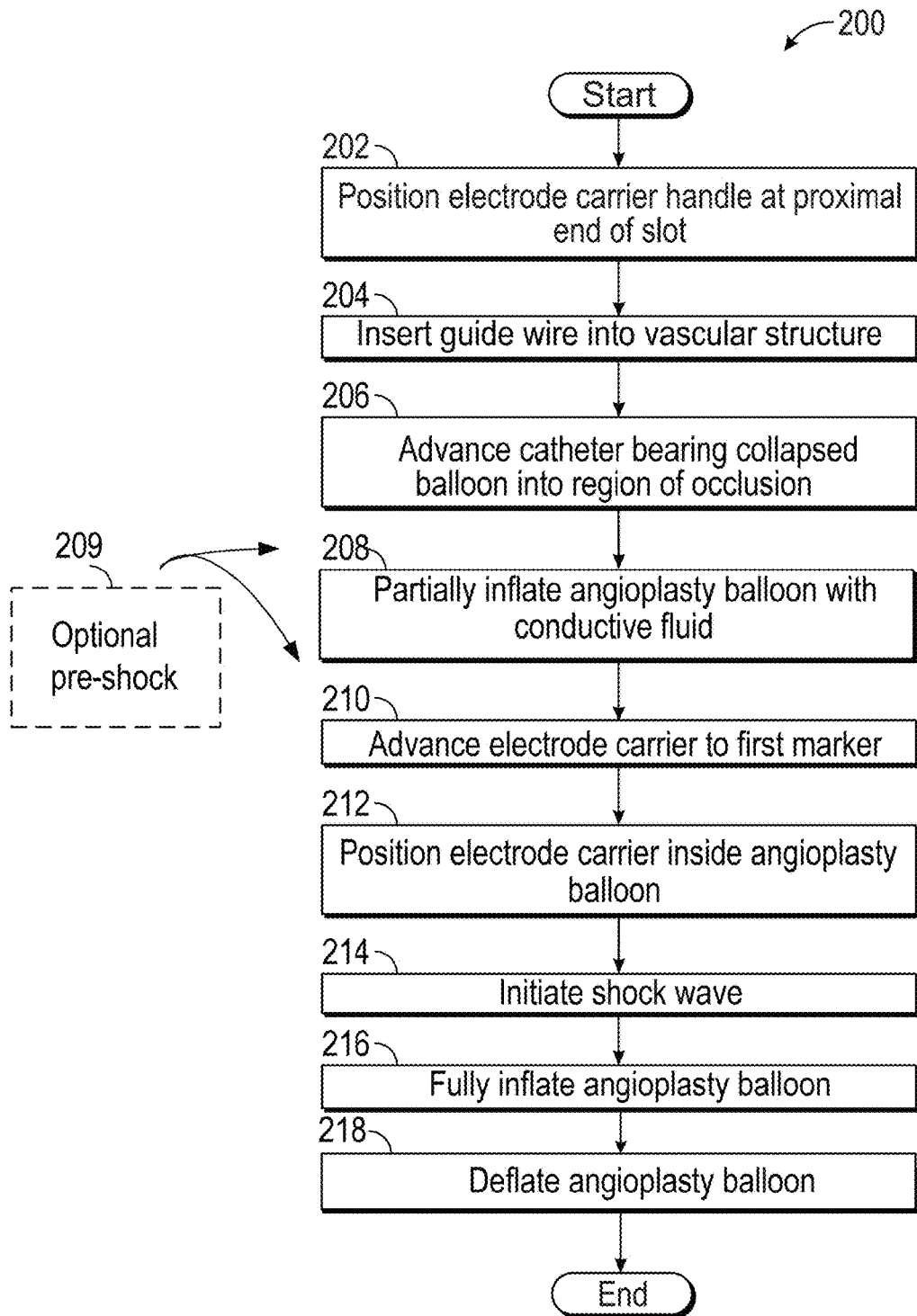


FIG. 8

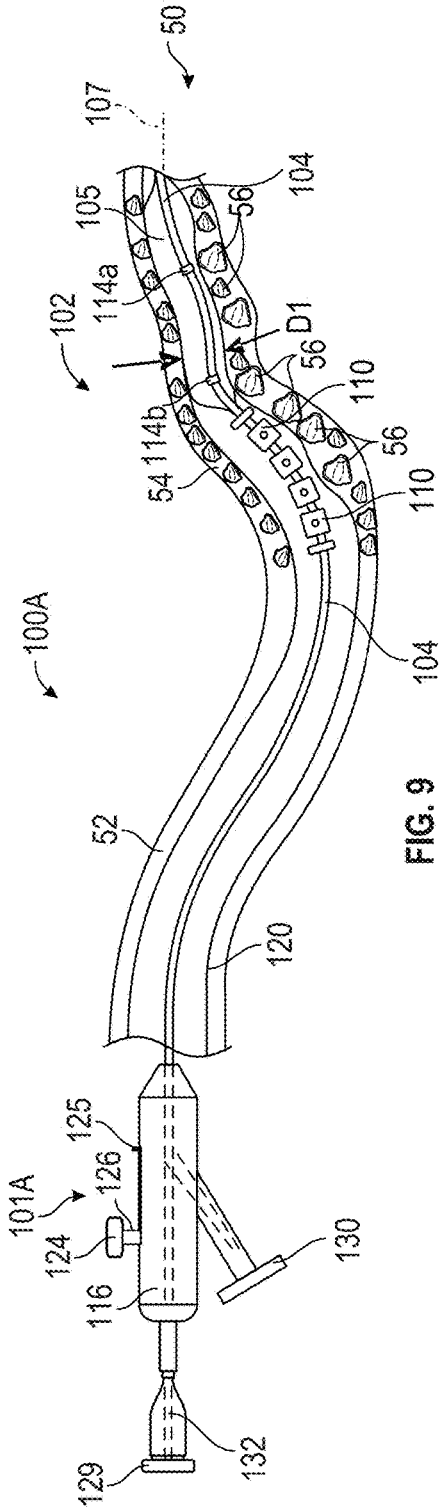


FIG. 9

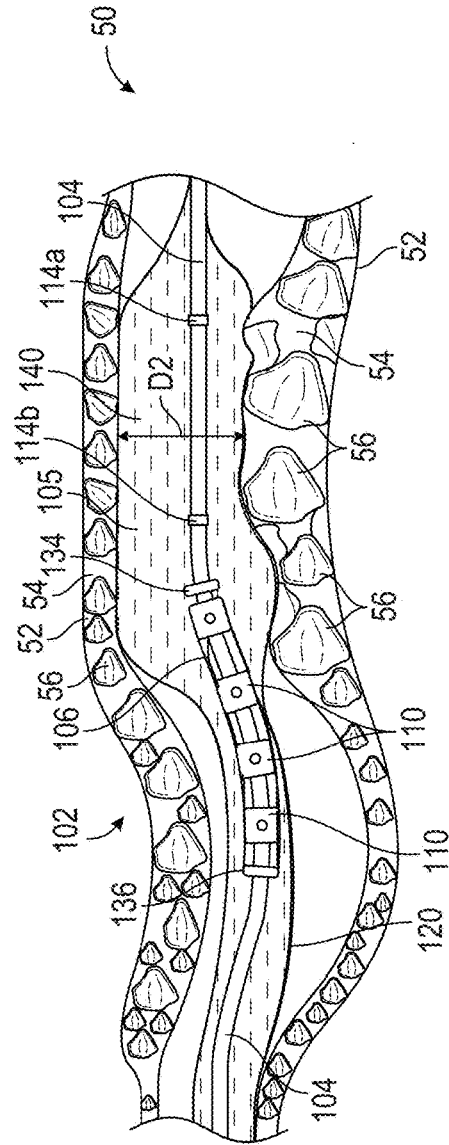


FIG. 10

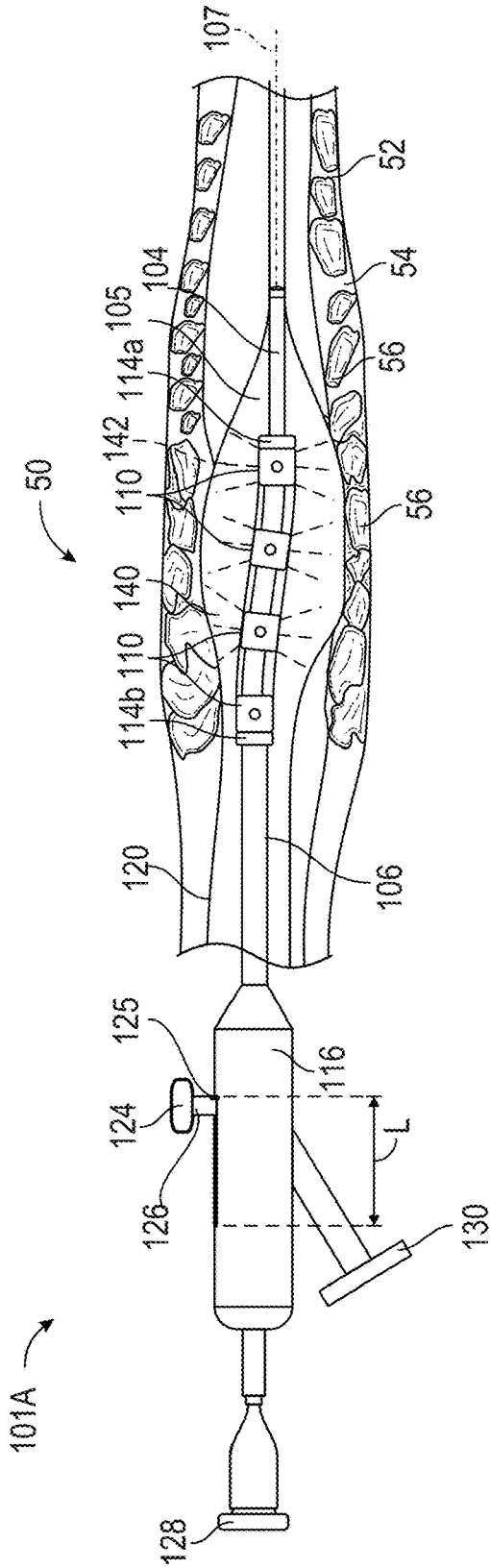


FIG. 11

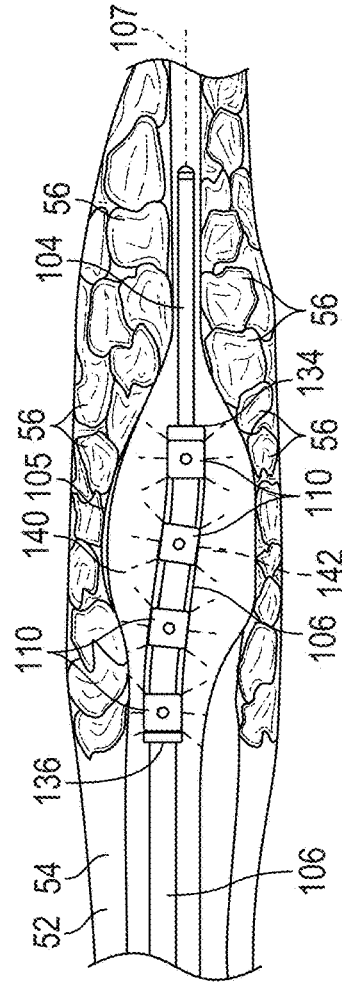
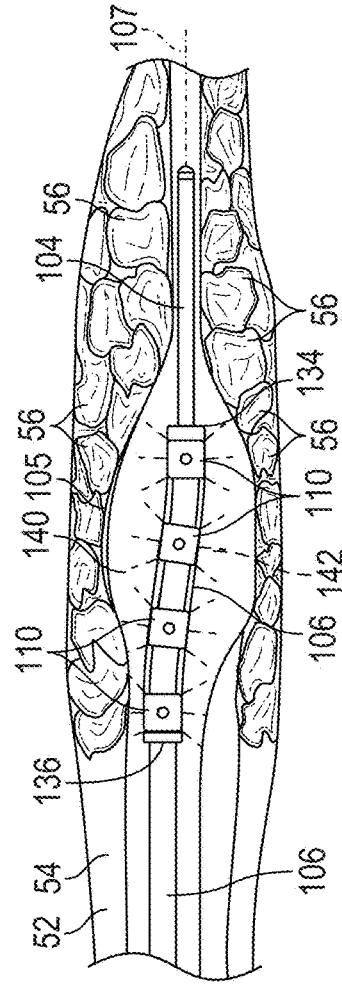


FIG. 12



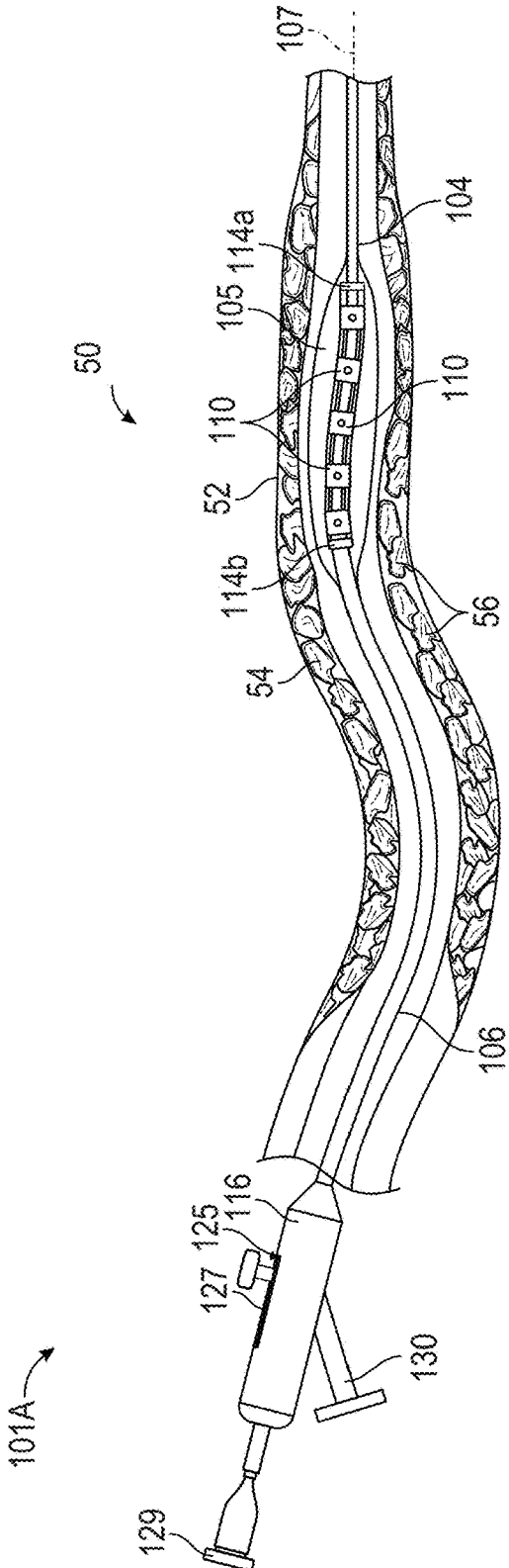


FIG. 13

## SHOCK WAVE BALLOON CATHETER WITH INSERTABLE ELECTRODES

### FIELD

[0001] The present disclosure relates generally to occlusions in human vascular structures and, in particular, to the use of shock wave therapy in the treatment of calcified lesions.

### BACKGROUND

[0002] Balloon angioplasty is a well-known, standard treatment that restores blood flow in blocked arteries. Blockages occur when plaque accumulates in the walls of the blood vessels, forming lesions. In a conventional balloon angioplasty procedure, a catheter carrying an angioplasty balloon is inserted into the blood vessel along a guide wire to position the angioplasty balloon adjacent to a lesion. Progress of the guide wire may be tracked using fluoroscopy or x-rays. Inflating the angioplasty balloon compresses soft lesions on the wall of the vessel, thereby dilating the blood vessel and allowing blood to flow through a larger portion thereof. However, when plaque is hardened, or calcified, gentle compression may not be effective. In such cases, rapid expansion of the angioplasty balloon may occur when the calcified lesions break, so as to permit increasing the inner diameter of the blood vessel. Conventional balloon angioplasty techniques used to treat such calcified lesions may impart high stress that can damage vessel walls. Soft tissue damage often includes dissections or perforations that require placement of a stent to restore structural integrity to the blood vessel wall.

[0003] An improved electrohydraulic dilation technique has been used to treat calcified plaques using shock waves. Lithoplasty® technology is described in U.S. Pat. Nos. 8,976,371 and 8,888,788, assigned to Shockwave, Inc., of Fremont, Calif., both of which are incorporated by reference herein in their entireties. In this technique, electrodes are disposed inside the angioplasty balloon. The angioplasty balloon is inflated with a conductive fluid, for example, a saline solution, which will propagate shock waves, i.e., high energy pressure waves. When high voltage pulsed signals are applied to a bipolar emitter, i.e., a pair of emitter electrodes, a resulting plasma arc creates a rapidly expanding and collapsing gas bubble that emits a shock wave through the fluid. When a unipolar emitter is used, the high voltage signal arcs between a single emitter electrode and the fluid itself. Such shock waves have been shown to effectively break up, dislodge, or pulverize hardened plaques, thereby softening the lesion while preserving the integrity of the vessel walls. Following shock wave treatment, a conventional low-pressure angioplasty procedure can be used effectively to gently compress the softened lesions and dilate the blood vessel.

### BRIEF SUMMARY

[0004] While existing cardiovascular intervention therapies are appropriate for treating calcified lesions in larger blood vessels, e.g., leg arteries having diameters of about 5.0-10.0 mm, smaller vascular structures, or those that are severely blocked may not have a sufficient diameter to accommodate a Lithoplasty® apparatus. Such smaller vascular structures include, for example, cerebral and coronary arteries having diameters less than about 3.0 mm.

[0005] A translatable shock wave treatment apparatus is suitable for use in treating small diameter blood vessels that contain calcified lesions. According to a new procedure, an elongate member, or catheter, carrying a folded or collapsed angioplasty balloon is first inserted into the narrow blood vessel. The collapsed angioplasty balloon has a small diameter that will fit into the narrow blood vessel. The angioplasty balloon is then inflated with a conducting fluid to pre-dilate the narrow blood vessel prior to introducing electrodes and applying shock wave therapy. After the blood vessel is at least partially opened, a translatable electrode carrier equipped with one or more shock wave emitters is advanced along the catheter from an initial position outside the balloon to a destination position inside the balloon. Shock waves are then propagated through the fluid to impart energy to calcified plaques along the vessel walls, thereby softening the calcified lesions. Following the shock wave treatment, the angioplasty balloon can be further inflated to gently compress the softened lesion and complete dilation of the blood vessel. In heavily occluded blood vessels, shock wave therapy can be used multiple times—first, to pre-dilate the blood vessel, and then, alternating with inflation of the angioplasty balloon, to open the blood vessel.

### DESCRIPTION OF THE FIGURES

[0006] For a better understanding of the various described embodiments, reference should be made to the Description of Embodiments below, in conjunction with the following drawings in which like reference numerals refer to corresponding parts throughout the figures.

[0007] FIG. 1 is a cross-sectional view of an existing shock wave balloon catheter apparatus, according to the prior art.

[0008] FIG. 2A is a side view of a translatable shock wave treatment apparatus according to some embodiments of the present disclosure, as described herein.

[0009] FIG. 2B is a side view of a translatable shock wave treatment apparatus according to some embodiments of the present disclosure, as described herein.

[0010] FIGS. 3A, 3B, 3C, and 3D show side views, magnified views, and an end view, respectively, of a translatable shock wave treatment apparatus according to some embodiments of the present disclosure, as described herein.

[0011] FIG. 4 is a magnified side elevation view of a handle assembly of the translatable shock wave treatment apparatus shown in FIG. 2B.

[0012] FIG. 5 is a side elevation view of the translatable shock wave treatment apparatus of FIGS. 3A-3D in an initial position.

[0013] FIG. 6 is a cross-sectional view of a distal end of the translatable shock wave treatment apparatus of FIGS. 3A-3D.

[0014] FIG. 7 is a side elevation view of the translatable shock wave treatment apparatus of FIGS. 3A-3D in a final position.

[0015] FIG. 8 is a flow diagram of a method of treating calcified lesions using the translatable shock wave treatment apparatus shown in FIGS. 3-7, according to some embodiments of the present disclosure as described herein.

[0016] FIGS. 9-13 are side elevation views of the translatable shock wave treatment apparatus in use at various steps of the method shown in FIG. 8.

[0017] FIG. 9 is a side elevation view of the translatable shock wave treatment apparatus in use, prior to inflating the angioplasty balloon.

[0018] FIG. 10 is a side elevation view of the translatable shock wave treatment apparatus in use, after partially inflating the angioplasty balloon with a fluid.

[0019] FIG. 11 is a side elevation view of the translatable shock wave treatment apparatus in use, during shock wave emission.

[0020] FIG. 12 is a magnified side elevation view of the translatable shock wave treatment apparatus in use, during shock wave emission.

[0021] FIG. 13 is a side elevation view of the translatable shock wave treatment apparatus in use, following treatment of calcified lesions.

#### DESCRIPTION OF EMBODIMENTS

[0022] The following description sets forth exemplary methods, parameters, and the like. It should be recognized, however, that such description is not intended as a limitation on the scope of the present disclosure but is instead provided as a description of exemplary embodiments.

[0023] Although the following description uses terms “first,” “second,” etc. to describe various elements, these elements should not be limited by the terms. These terms are only used to distinguish one element from another, not to imply a priority of one element over the other. For example, a first marker could be termed a second marker, and, similarly, a second marker could be termed a first marker, without departing from the scope of the various described embodiments. The first marker and the second marker are both markers, but they are not the same marker.

[0024] The terminology used in the description of the various described embodiments herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used in the description of the various described embodiments and the appended claims, the singular forms “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. The term “and/or” as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. The terms “includes,” “including,” “comprises,” and/or “comprising,” when used in this specification, specify the presence of stated features, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, steps, operations, elements, components, and/or groups thereof.

[0025] The term “if” may be construed to mean “when” or “upon” or “in response to determining” or “in response to detecting,” depending on the context. Similarly, the phrase “if it is determined” or “if [a stated condition or event] is detected” may be construed to mean “upon determining” or “in response to determining” or “upon detecting [the stated condition or event]” or “in response to detecting [the stated condition or event],” depending on the context.

[0026] Turning now to the drawings, FIG. 1 illustrates an exemplary vascular structure, e.g., a blood vessel 50 representing an artery, having a central axis 51 and a vessel wall 52. The representative blood vessel 50 is occluded by a region of plaque, or lesion 54 that has formed in the vessel wall 52. The lesion 54 may include hardened plaque deposits e.g., calcifications 56. Such lesions 54 may be located in other types of vascular structures such as, for example, a

valve in a blood vessel, or a heart valve. In the example shown in FIG. 1, lesions 54 extend from opposite vessel walls 52 far enough into the center of the blood vessel 50 that blood flow is almost fully obstructed. Only a narrow opening 58 remains along the central axis 51.

[0027] FIG. 1 further illustrates an attempt to insert an existing shock wave treatment apparatus 80 into the occluded blood vessel 50, according to an existing method of treatment. The existing shock wave treatment apparatus 80 having an angioplasty balloon 82, a shock wave guide wire lumen 83, a guide wire 84, an electrode carrier 86, and electrodes 88. The angioplasty balloon 82 and the electrode carrier 86 are coaxial with the guide wire lumen 83 and the guide wire 84. The angioplasty balloon 82 is initially folded over the guide wire lumen 83. In the example shown, the electrodes 88 are shown as cylinders, co-axial with the electrode carrier 86. Each electrode 88 may represent a uni-polar electrode or a pair of bi-polar electrodes, both of which are known in the art.

[0028] According to an existing method of treatment, a leading end of the guide wire 84 is inserted through the narrow opening 58, followed by the shock wave treatment apparatus 80 bearing the folded angioplasty balloon 82. Once the shock wave treatment apparatus 80 is positioned adjacent to the calcifications 56 to be treated, treatment can be initiated. However, in the situation shown in FIG. 1, the opening 58 is very narrow. Consequently, the shock wave treatment apparatus 80 is too large, relative to the opening 58, to be safely advanced into the occluded region, even when the balloon is deflated. For example, the shock wave treatment apparatus 80 may have a diameter of about 0.044 inches, or approximately 1.0 mm. This problem arises, for example, when the blood vessel 50 has a narrow diameter, e.g., a few millimeters, or whenever the lesions 54 are localized so that the diameter of the blood vessel opening 58 is abruptly reduced to about 1.0 mm or less.

[0029] FIGS. 2-7 illustrate a translatable shock wave treatment apparatus 90, according to some embodiments of the present disclosure. Two exemplary embodiments of the translatable shock wave treatment apparatus 90 are shown in FIGS. 2A, 2B, having respective catheter systems 100A,B respective handle assemblies 101A,B, an emitter assembly 102, a guide wire 103, a guide wire lumen 104, an angioplasty balloon 105, and an electrode carrier 106. The handle assembly 101A/B defines a proximal end of the translatable shock wave treatment apparatus 90. The angioplasty balloon 105 is attached to a distal end of the translatable shock wave treatment apparatus 90, opposite the handle assembly 101A/B at the proximal end. The guide wire lumen 104 is a hollow tube containing the guide wire 103. The guide wire lumen 104, or elongate member of the translatable shock wave treatment apparatus 90, extends between the distal end and the handle assembly along a central axis 107. The emitter assembly 102 is mounted to a distal end of the electrode carrier 106 for translation along the elongate member, relative to the angioplasty balloon 105. The elongate member is semi-rigid but also flexible, permitting insertion into a blood vessel. The angioplasty balloon 105 has a known structure and is made of a known material, e.g., a bio-compatible flexible material that is used in conventional angioplasty procedures. The guide wire lumen 104 and the guide wire 103 also have conventional structures and are made of biocompatible materials that may safely be introduced into a human bloodstream.

[0030] FIG. 2A illustrates a first embodiment of the translatable shock wave treatment apparatus 90, in which the guide wire 103 joins the catheter system 100A at a sealed entry port 108. The catheter system 100A is known in the art as a rapid exchange (Rx) system. The handle assembly 101A includes an electrical connector 129 that transmits electrical power to the emitter assembly 102 via wires 132. The handle assembly 101A is configured to translate the emitter assembly 102 with respect to the angioplasty balloon 105.

[0031] FIG. 2B illustrates a second embodiment of the translatable shock wave treatment apparatus 90, in which the guide wire 103 extends all the way through the catheter system 100B, including the handle assembly 101B. The catheter system 100B is known in the art as an over-the-wire system. The handle assembly 101B includes a guide wire handle 128 that can be used to extend and retract the guide wire 103. The handle assembly 101B also includes an electrical connector 129 that transmits electrical power to the emitter assembly 102 via the wires 132. Either one of the rapid exchange system 100A or the over-the-wire system 100B can be equipped with the emitter assembly 102, the electrode carrier 106, and either handle assembly 101A, or 101B to permit translation of the emitter assembly 102 into and out of the angioplasty balloon 105.

[0032] FIGS. 3A and 3B show magnified views of the distal end of the translatable shock wave treatment apparatus 90, in which the guide wire lumen 104 supports the emitter assembly 102 and the angioplasty balloon 105, according to some embodiments of the present disclosure. In FIG. 3A, the electrode carrier 106 is outside the angioplasty balloon 105. The angioplasty balloon 105 is folded over the guide wire lumen 104 so that the guide wire lumen 104 bearing the collapsed balloon has a narrow profile and a diameter  $d_b$ . The diameter  $d_b$  may be compressible. In FIG. 3B, the electrode carrier 106 is outside the angioplasty balloon 105 and the angioplasty balloon 105 is inflated.

[0033] FIG. 3C shows a magnified view of a portion 115 of the emitter assembly 102. The emitter assembly 102 includes an electrode carrier 106 and electrodes 110. The electrode carrier 106 is a moveable overtube, coaxial with the guide wire lumen 104 and the guide wire 103, aligned with the central axis 107. In some embodiments, the electrode carrier 106 is flexible, having an inner diameter  $d_c$  of about 0.025 inches. In the example shown, bipolar electrodes 110 are in the form of pairs of co-axial cylinders separated by an internal insulating layer. The electrodes 110 are wrapped around, or otherwise mounted to, the electrode carrier 106. The exemplary cylindrical electrodes 110 have outer diameters  $d_e$  of about 0.030 inches. In some embodiments, unipolar electrodes, low profile electrodes, or emitter electrodes of any other suitable design may be used. The electrodes 110 are powered via the electrical wires 132 that extend along the electrode carrier 106, e.g., in a groove formed on an outside surface of the electrode carrier 106, as is known in the art (see, for example, U.S. Pat. No. 8,888,788, which shows similar wiring grooves on an outside surface of a catheter). The electrical wires 132 are coupled by the connector 129 to an external generator, e.g., an external high voltage pulse generator. There may be slack in the electrical wires at the connector 129 to allow advancement of the electrode carrier 106. Two markers, e.g., marker bands 114a,b, are provided on a surface of the guide wire lumen 104, marking destination locations inside the angioplasty balloon 105. In some embodiments, the marker bands

114a,b are crimped onto the guide wire lumen 104. In some embodiments, the marker bands 114a,b are glued onto the guide wire lumen 104.

[0034] FIG. 3D illustrates an end view from the distal end of the translatable shock wave treatment apparatus 100, showing the guide wire 103, the guide wire lumen 104, and the folded angioplasty balloon 105. The angioplasty balloon 105 may be wrapped in a clockwise or counterclockwise arrangement to facilitate unobstructed inflation, as is known in the art. In some embodiments, the guide wire lumen 104 has an outer diameter equal to about 0.023 inches and the guide wire 103, the guide wire lumen 104, and the folded angioplasty balloon 105, together have an outer diameter  $d_b$  that is as small as 0.032 inches, i.e., less than 1.0 mm.

[0035] FIG. 4 shows a magnified view of an exemplary handle assembly 101B, according to some embodiments of the present disclosure. The handle assembly 101B, like the handle assembly 101A, is operable to move the emitter assembly 102 relative to the angioplasty balloon 105. In the over-the-wire embodiment of the translatable shock wave treatment apparatus 90, the handle assembly 101B is further operable to move the guide wire 103 relative to a receiving vascular structure. The handle assemblies 101A,B include a housing 116, an inflation lumen 120, an electrode carrier handle 124, a stop 125, a post 126, a slot 127 of length L, and the connector 129. The handle assembly 101B further includes the guide wire handle 128. The housing 116 is generally cylindrical, but may have a cross-section of arbitrary shape e.g., a round cylinder, a square cylinder, a triangular cylinder, or the like. The inflation lumen 120 is operable to inflate the angioplasty balloon 105, via a channel, with a fluid, e.g., a conducting fluid 140. The conducting fluid 140 may be, for example, saline solution or another electrolytic solution. Inflation of the angioplasty balloon 105 occurs when an inflation port 130 pressurizes the conducting fluid, causing the conducting fluid to flow through the inflation lumen 120. The inflation lumen 120 may be, for example, a tube or channel that extends through the housing 116 and along the central axis 107, into the angioplasty balloon 105. The inflation lumen 120 has a volume that is in fluid communication with an interior volume of the angioplasty balloon 105, as shown in FIGS. 3A and 3D. The inflation lumen 120 may be coaxial with the guide wire lumen 104 and the guide wire 103 as shown in FIG. 4, or the inflation lumen 120 may be within the guide wire lumen 104, alongside the guide wire 103, as is known in the art.

[0036] In some embodiments, the guide wire handle 128 is attached to the proximal end of the guide wire 103. The guide wire 103 is inserted into a vascular structure by manually pushing the guide wire handle 128 toward the housing 116, as is known in the art. The connector 129 is attached to wires 132. The connector 129 couples the external generator that supplies electrical power, e.g., in the form of high voltage pulses, to the emitter assembly 102 via the wires 132. The electrode carrier handle 124 is used to align the emitter assembly 102 with respect to the angioplasty balloon 105. The emitter assembly 102 is initially positioned outside the angioplasty balloon 105. As the electrode carrier handle 124 is manually advanced through the slot 127 toward the stop 125, the emitter assembly 102 translates along the guide wire lumen 104 to a position inside the angioplasty balloon 105, as will be described in greater detail below. In some embodiments, when the electrode carrier handle 124 is moved all the way to the stop 125

through the distance  $L$ , the electrode carrier **106** extends between the marker bands **114a,b**, which are also separated by a distance approximately equal to  $L$ . The distance  $L$  may be about 15 mm.

[0037] A position of the electrode carrier handle **124** opposite the stop **125** corresponds to a position of the emitter assembly **102** that is outside the inflated angioplasty balloon **105**. The electrode carrier handle **124** is coupled to the electrode carrier **106** by a pusher **138**, made of a semi-rigid material. In some embodiments, the pusher **138** is a nitinol rod having a diameter of about 0.010 inches. The pusher **138** is internal to the housing **116**. As the post **126** slides through the slot **127** toward the stop **125**, the pusher **138** causes the emitter assembly **102** to translate forward along the central axis **107**, relative to the angioplasty balloon **105**.

[0038] FIG. 5 shows the translatable shock wave treatment apparatus **100** after advancing the guide wire lumen **104** and at least partially inflating the angioplasty balloon **105**, according to some embodiments of the present disclosure. As the angioplasty balloon **105** inflates, it unfolds to form a volume surrounding the guide wire lumen **104**. The inflated angioplasty balloon **105** may be elongated as shown, or it may have a more spherical shape. In FIG. 5, the emitter assembly **102** is shown in an initial position outside the inflated angioplasty balloon **105**. The angioplasty balloon **105** may be inflated just enough to allow the emitter assembly **102** to be inserted into the balloon. In some embodiments, the emitter assembly **102** includes one or more wires **132** e.g., copper leads, of a flexible circuit that wraps around the electrode carrier **106**, e.g., in a spiral configuration. Emitters may be stationed at locations along the wires **132** instead of being in the form of cylindrical electrodes **110**.

[0039] FIG. 6 shows a magnified cut view of the distal end of the guide wire lumen **104**, according to some embodiments of the present disclosure. The emitter assembly **102** may reside within or adjacent to the inflation lumen **120**, and is positioned outside the inflated angioplasty balloon **105**. The emitter assembly **102** has a distal end **134** that will align with a first marker band **114a** after the electrode carrier **106** is moved inside the angioplasty balloon **105**. The emitter assembly **102** also has a proximal end **136** that will align with a second marker band **114b** when the electrode carrier **106** is moved inside the angioplasty balloon **105**.

[0040] FIG. 7 shows the translatable shock wave treatment apparatus **100**, in which the electrode carrier **106** has been moved inside the angioplasty balloon **105**, so that the ends of the electrode carrier **106** coincide with the marker bands **114a,b**. Accordingly, the electrode carrier handle **124** has been moved along the slot **127** to a position that coincides with the stop **125**. The electrodes **110** may be of the design shown in FIG. 6 or of the design shown in FIG. 3B.

[0041] FIG. 8 shows a sequence of steps illustrating a shock wave therapy technique, according to some embodiments of the present disclosure. The shock wave therapy technique entails executing a method **200** using the translatable shock wave treatment apparatus **100**, as described below and illustrated in FIGS. 9-13.

[0042] At step **202**, the translatable shock wave treatment apparatus **100** is prepared for insertion into the blood vessel **50**. The guide wire handle **128** is pulled behind the housing **116** to a retracted position, and the electrode carrier handle **124** slides to its initial position at the proximal end of the slot **127**, opposite the stop **125**.

[0043] At step **204**, the guide wire **103** is inserted into the target vascular structure, e.g., the blood vessel **50**, as shown in FIG. 9.

[0044] At step **206**, the guide wire **103** is advanced ahead of the guide wire lumen **104**, through the blood vessel **50** using the guide wire handle **128**. The tip of the guide wire lumen **104** bearing the folded angioplasty balloon **105** is positioned in an occluded region of the blood vessel **50** that has lesions **54** and, in particular, calcifications **56**, as shown in FIG. 9. The guide wire lumen **104** is then advanced until the marker bands **114a,b** are aligned with the occluded region to be treated. In the occluded region, the smallest diameter,  $D_1$  of the blood vessel **50** may accommodate the guide wire lumen **104** and the folded balloon **105**, while being too small to accommodate insertion of the electrode carrier **106**. Accordingly, the electrode carrier handle **124** remains at an initial position opposite the stop **125** so that the electrode carrier **106** temporarily remains outside the angioplasty balloon **105**.

[0045] At step **208**, the angioplasty balloon **105** is inflated, at least partially, expanding outward from its folded position around the guide wire lumen **104**, as shown in FIG. 10. Inflation occurs as the angioplasty balloon **105** is filled with the conducting fluid **140** by pumping the conducting fluid **140** through the inflation lumen **120** using the inflation port **130**. The inflated angioplasty balloon **105** pre-dilates the occluded region of the blood vessel **50** by compressing soft portions of the lesion **54**, while the calcifications **56** resist inflation of the angioplasty balloon **105**. Inflation of the angioplasty balloon **105** opens the interior diameter of the blood vessel **50** to a diameter  $D_2$  that exceeds the diameter  $d_c$  of the electrode carrier **106** bearing the electrodes **110**.

[0046] At step **210**, the guide wire lumen **104** is advanced further into the pre-dilated blood vessel **50** so as to align the distal end **134** of the emitter assembly **102** with the second marker band **114b**. Optionally, the angioplasty balloon **105** may be further inflated one or more times after advancing the guide wire lumen **104**. Steps **208-210** may be repeated to ensure that the diameter  $D_2$  will accommodate the electrode carrier **106** and the electrodes **110**.

[0047] At step **212**, once the diameter  $D_2$  is enlarged, the electrode carrier handle **124** is advanced by sliding the post **126** along the slot **127** through the full distance  $L$ , to the stop **125**. The distal end **134** of the emitter assembly **102** is then aligned with the first marker band **114a** and the proximal end **136** of the emitter assembly **102** is aligned with the second marker band **114b**, as shown in FIG. 11. The electrode carrier **106** thus is positioned inside the angioplasty balloon **105** between the first and second marker bands **114a, 114b**, which are stationed at destination locations along the guide wire lumen **104**. Optionally, the electrode carrier **106** may be rotated to align one or more of the emitters closer to the calcifications **56** in a target area of the vessel wall **52**. Once the electrode carrier **106** is in position, the angioplasty balloon **105** may be deflated for about 30 seconds to allow blood to flow, followed by re-inflating the angioplasty balloon **105** to a pressure of about four atmospheres.

[0048] At step **214**, a shock wave is initiated by applying an electrical signal, e.g., a high voltage pulsed signal, to the electrodes **110**. The high voltage pulsed signal causes the emitters to arc, either to one another or to the conducting fluid **140**, depending on a relative polarity and spacing between the emitters. In some embodiments, the electrodes **110** are unipolar and the conducting fluid acts as a second



pole. In some embodiments, pairs of emitters, or bipolar electrodes, are positioned close to one another, e.g., spaced apart about 4-15 millimeters along the wires **132**. A pulsing gap between negative and positive poles within each pair may be in the range of about 0.0005-0.02 inches so that an arc occurs across the pulsing gap. Heat from the arcing event vaporizes and then ionizes a small volume of the conducting fluid **140**, creating a rapidly expanding region of plasma around the energized electrodes **110**. Such rapid expansion initiates a shock wave **142** that propagates out from each electrode **110** through the conducting fluid **140**, as shown in FIGS. **11** and **12**. As the shock waves **142** in the conducting fluid **140** impinge upon the vessel walls **52**, shock wave energy is transmitted to the lesions **54**. The shock wave energy breaks apart the calcifications **56**, thereby softening the lesions **54**. In some embodiments of the method **200**, the high voltage pulsed signal may include, for example, between five and twenty pulses.

**[0049]** At step **216**, the angioplasty balloon **105** is fully inflated to compress the softened lesions **54** against the vessel wall **52**, thus restoring blood flow within the blood vessel **50**, as shown in FIG. **13**. The angioplasty balloon **105** may be deflated for about 30 seconds, and then re-inflated to a pressure of about six atmospheres for about 30 seconds. Steps **214** and **216** may be repeated one or more times until the calcifications **56** are broken into small pieces and blood flow within the blood vessel **50** is restored to about 90%. In some embodiments of the method **200**, 8-10 such cycles are performed so as not to interrupt blood flow for an extended period of time. When treating coronary arteries, performing the angioplasty procedure in short cycles may prevent syncope. When treating peripheral arteries performing the angioplasty procedure in short cycles may prevent swelling.

**[0050]** At step **218**, following treatment, the angioplasty balloon **105** is deflated by de-pressurizing the conducting fluid **140** using the inflation port **130**. The guide wire lumen **104** is removed from the blood vessel **50** and the guide wire handle **128** is then pulled away from the housing **116** to retract the guide wire **103**.

**[0051]** In some instances, the blood vessel **50** is so occluded that shock waves **142** are needed to create an opening that permits full inflation of the angioplasty balloon **105** and, subsequently, full insertion of the electrode carrier **106** into the angioplasty balloon **105**. In such cases, an additional step **209** may be inserted before or after step **208** in the method **200**. At step **209**, an optional pre-shock treatment may be applied from a position slightly outside the balloon **105**, or outside the severely obstructed region, as shown in FIG. **12**. The pre-shock treatment is carried out in a similar fashion as the shock treatment described above in step **214**. The optional pre-shock treatment dilates the blood vessel **50** so that the electrode carrier **106** can be slidably advanced further into the occluded region in an incremental fashion, to allow repeated application of the shock waves **142**. By alternating shock wave therapy with inflation of the angioplasty balloon **105**, it is possible to treat an extended calcified lesion **54** along the length of the blood vessel **50**.

**[0052]** The foregoing description, for purpose of explanation, has been made with reference to specific embodiments. However, the illustrative discussions above are not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The embodiments were chosen and described in order to best explain the principles of the

techniques and their practical applications. Others skilled in the art are thereby enabled to best utilize the techniques and various embodiments with various modifications as are suited to the particular use contemplated.

**[0053]** Although the disclosure and examples have been fully described with reference to the accompanying drawings, it is to be noted that various changes and modifications will become apparent to those skilled in the art. Such changes and modifications are to be understood as being included within the scope of the disclosure and examples as defined by the claims.

1. An apparatus, comprising:
  - an elongate member having a distal end and a proximal end;
  - a balloon attached to the distal end of the elongate member; and
  - an electrode carrier, slidable along a length of the elongate member from an initial position outside the balloon to a destination position inside the balloon.
2. The apparatus of claim **1**, further comprising an inflation device operable to inflate the balloon to a diameter exceeding that of the elongate member.
3. The apparatus of claim **1**, further comprising a channel configured to direct fluid into the balloon.
4. The apparatus of claim **1**, further comprising a handle coupled to the electrode carrier, the handle being operable to slide the electrode carrier along the length of the elongate member.
5. The apparatus of claim **4** wherein the handle is disposed at the proximal end of the elongate member.
6. The apparatus of claim **1** wherein the elongate member is suitable for introduction into a blood vessel.
7. The apparatus of claim **6** wherein a diameter of the elongate member is less than 2.0 mm.
8. The apparatus of claim **1** wherein the electrode carrier further comprises emitters stationed at surface locations of the electrode carrier.
9. The apparatus of claim **8**, further comprising a high voltage pulse generator electrically coupled to the emitters.
10. The apparatus of claim **9** wherein each emitter, when energized by the high voltage pulse generator, transmits a current by arcing.
11. The apparatus of claim **1**, further comprising one or more markers stationed at destination locations along the distal end of the elongate member.
12. A method, comprising:
  - providing a balloon attached to a distal end of an elongate member;
  - providing an electrode carrier slidably mounted on the elongate member at a position outside of, and proximal to, the balloon, the electrode carrier including an emitter attached thereto;
  - advancing the balloon into a portion of a vascular structure to be treated;
  - partially inflating the balloon with a fluid;
  - translating the electrode carrier along the elongate member to a position at least partially inside the balloon; and
  - initiating a shock wave in the fluid by energizing the emitter.
13. The method of claim **12** wherein translating the electrode carrier entails, prior to the initiating step, sliding the electrode carrier along a length of the elongate member so that the electrode carrier is fully inside the balloon.

**14.** The method of claim **12** wherein the elongate member is a catheter.

**15.** The method of claim **12** wherein translating the electrode carrier further includes aligning the electrode carrier with a marker.

**16.** The method of claim **12** wherein inflating the balloon increases an inside diameter of the vascular structure.

**17.** The method of claim **12**, further comprising, prior to inflating the balloon, rotating the electrode carrier so as to position the emitter adjacent to a target area of the vascular structure.

**18.** The method of claim **12** wherein the vascular structure includes one or more of a coronary artery, a peripheral artery, and a valve.

**19.** The method of claim **12**, further comprising further inflating the balloon after initiating the shock wave.

**20.** The method of claim **19**, further comprising when the electrode carrier is only partially inside the balloon, translating the electrode carrier further inside the balloon and repeating initiating the shock wave.

**21.** A device for use in an angioplasty procedure, the device comprising:

an elongate member having a distal end and a proximal end, the elongate member extending linearly along a central axis;

a balloon attached to the distal end of the elongate member;

an inflation pump attached to the proximal end of the elongate member, the inflation pump in fluid communication with the balloon;

an electrode carrier translatable along the elongate member from the proximal end of the elongate member outside the balloon to a position within the balloon;

a plurality of electrodes attached to the electrode carrier; and

a high voltage pulse generator electrically coupled to the electrodes, the high voltage pulse generator causing the electrodes to arc and propagate a shock wave within the balloon.

**22.** The device of claim **21**, further comprising a marker at a destination position on the elongate member.

**23.** The device of claim **21**, further comprising a handle coupled to the electrode carrier.

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