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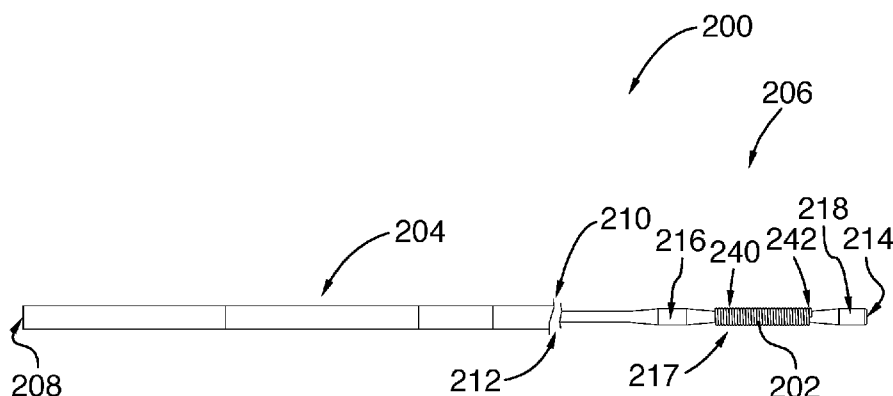


FIG. 3

(57) Abstract: There is described a device for transmitting mechanical waves, comprising: a mechanical waveguide having an elongated shape and extending between a proximal end and a distal end for propagating the mechanical waves coupled at the proximal end up to the distal end; and a radiopaque marker secured to the mechanical wave adjacent to the distal end thereof.



MECHANICAL WAVEGUIDE PROVIDED WITH A MARKER THEREON

TECHNICAL FIELD

[0001] The present invention relates to the field of mechanical waveguides, and more particularly to the field of mechanical waveguides for medical applications.

5 BACKGROUND

[0002] Minimally-invasive medical devices are attractive because they require a small incision to be made to the subject to be treated before insertion of the minimally-invasive medical device. Some minimally-invasive devices use a source of mechanical waves positioned outside the body of the subject and the mechanical waves are carried into the body
10 to the lesion to be treated with a minimally-invasive device. To achieve this, the minimally-invasive device comprises a mechanical waveguide or transmission member to deliver the mechanical waves up to the lesion.

[0003] However, it would be beneficial for a user of the minimally-invasive device to be able to visualize the mechanical waveguide, and more particularly the distal end of the
15 mechanical waveguide, while treating the lesion.

[0004] Therefore, there is a need for an improved mechanical waveguide to be used in a system for treating lesions.

SUMMARY

[0005] In accordance with a first broad aspect, there is provided a device for
20 transmitting mechanical waves, comprising: a mechanical waveguide having an elongated shape and extending between a proximal end and a distal end for propagating the mechanical waves coupled at the proximal end up to the distal end; and a radiopaque marker secured to the mechanical wave adjacent to the distal end thereof.

[0006] In one embodiment, the mechanical waveguide comprising a recessed section adjacent to the distal end and the radiopaque marker is positioned over at least a portion of the recessed section.

[0007] In one embodiment, the radiopaque marker comprises a recess receiving aperture extending therealong, the recessed section extending at least partially within the recess receiving aperture of the radiopaque marker.

[0008] In one embodiment, the mechanical waveguide comprises a proximal section and a distal section each adjacent to the recessed section, the distal section comprising the distal end of the mechanical waveguide.

10 [0009] In one embodiment, the radiopaque marker extends between a first end and a second end, the first end abutting against one of the distal and proximal sections.

[0010] In one embodiment, the second end abuts against another one of the distal and proximal sections.

[0011] In one embodiment, the mechanical waveguide has a cylindrical shape.

15 [0012] In one embodiment, the distal section comprises a first distal portion adjacent to the recessed section and having an increasing diameter, and a second distal portion having a constant diameter and extending up to the distal end of the elongated member, the second end of the radiopaque marker abutting against the first distal portion of the distal section.

20 [0013] In one embodiment, the proximal section comprises a first proximal portion adjacent to the recessed section and having a decreasing diameter, and a second proximal portion having a substantially constant diameter, the first end of the radiopaque marker abutting against the first proximal portion of the proximal section.

[0014] In one embodiment, the proximal section further comprises a third proximal portion having an increasing diameter, the second proximal portion being located between
25 the first and third proximal portions.

[0015] In one embodiment, the radiopaque marker comprises a coil wound around the recessed section.

[0016] In one embodiment, an internal diameter of the coil is substantially equal to a diameter of the recessed section of the mechanical waveguide.

5 [0017] In one embodiment, an internal diameter of the coil is greater than a diameter of the recessed section of the mechanical waveguide and less than a maximal diameter of the proximal and distal sections.

[0018] In one embodiment, the coil comprises a plurality of loops, at least one of a distal end of the coil and a proximal end of the coil being secured to an adjacent one of the
10 plurality of loops.

[0019] In one embodiment, the coil comprises a plurality of loops and at least two adjacent ones of the plurality of loops being secured together.

[0020] In one embodiment, the coil is a single layer coil.

[0021] In another embodiment, the coil is a multi-layer coil.

15 [0022] In one embodiment, the radiopaque marker is one of made of and coated with one of tungsten, platinum, gold, a gold alloy and a doped polymer.

[0023] In one embodiment, wherein the mechanical waveguide is made of one of stainless steel, aluminum, aluminum alloy, titanium, titanium alloy, nitinol and fused quartz.

[0024] In one embodiment, the titanium alloy comprises one of Ti-6Al-4V and Ti-
20 11.5Mo-6Zr-4.5Sn (Beta III titanium).

[0025] In one embodiment, at least a portion of the elongated member is coated with one of a hydrophilic coating and a hydrophobic coating.

[0026] In one embodiment, at least a portion of the elongated member is coated with polytetrafluoroethylene.

[0027] According to a second broad aspect, there is provided an assembly comprising: a mechanical waveguide comprising a first elongated structure extending along a first longitudinal axis between a proximal end and a distal end and provided with at least two protrusions projecting from an outer face of thereof adjacent to the distal end, the two protrusions being spaced apart by a given distance along the first longitudinal axis; and a radiopaque marker comprising a second elongated structure made of a radiopaque material and extending along a second longitudinal axis, the second elongated structure being hollow so as to be positioned around the first elongated structure between the two protrusions and being deformable so that an inner dimension thereof be reduced to maintain the second elongated structure between the two protrusions, wherein the inner dimension of the radiopaque marker is greater than an outer dimension of a section of the first elongated structure comprised between the two protrusions once deformed and positioned between the two protrusions.

[0028] In one embodiment, the first and second elongated structures have substantially a same cross-sectional shape.

[0029] In one embodiment, the first and second elongated structures have different cross-sectional shapes.

[0030] In one embodiment, the first elongated structure has a cylindrical shape and the second elongated structure has a tubular structure, an inner diameter of the second elongated structure being less than a transversal dimension of at least one of the two protrusions.

[0031] In one embodiment, the two protrusions extend along a portion of a circumference of the first elongated structure.

[0032] In one embodiment, at least one of the two protrusions extends along a whole circumference of the first elongated structure.

[0033] In one embodiment, the two protrusions are aligned along the longitudinal axis.

[0034] In one embodiment, the two protrusions each have one of a trapezoidal, hemispherical, cubic, and pyramidal shape.

[0035] In one embodiment, the second elongated structure is made of one of gold and platinum.

5 [0036] In one embodiment, the second elongated structure comprises a slot extending longitudinally from a proximal end thereof to a distal end thereof.

[0037] In one embodiment, the assembly further comprises a tube insertable around the radiopaque marker.

[0038] In one embodiment, the tube is made of a heat-shrinkable material.

10 [0039] According to another broad aspect, there is provided a method for making a mechanical waveguide structure, the method comprising: providing a mechanical waveguide comprising a first elongated structure extending along a first longitudinal axis and provided with at least two protrusions projecting from an outer face of thereof, the two protrusions being spaced apart by a given distance along the longitudinal axis; providing a radiopaque
15 marker comprising a second elongated structure made of a radiopaque material, extending along a second longitudinal axis and having a length being one of less than and equal to the given distance, the second elongated structure being hollow so as to be positioned around the first elongated structure between the two protrusions and being deformable so that an inner dimension thereof be reduced to maintain the second elongated structure between the two
20 protrusions; positioning the second elongated structure around the first elongated structure between the two protrusions; and mechanically deforming the second elongated structure so that the inner dimension thereof be less than a transversal dimension of the two protrusions, thereby securing the radiopaque marker to the first elongated structure between the two protrusions, wherein the inner dimension of the radiopaque marker after said mechanically
25 deforming is greater than an outer dimension of a section of the first elongated structure comprised between the two protrusions.

[0040] In one embodiment, the first and second elongated structures have substantially a same cross-sectional shape.

[0041] In one embodiment, the first and second elongated structures have different cross-sectional shapes.

[0042] In one embodiment, the first elongated structure has a cylindrical shape and the second elongated structure has a tubular structure, an inner diameter of the second elongated structure being less than a transversal dimension of at least one of the two protrusions.

[0043] In one embodiment, the two protrusions extend along a portion of a circumference of the first elongated structure.

[0044] In one embodiment, at least one of the two protrusions extends along a whole circumference of the first elongated structure.

[0045] In one embodiment, the two protrusions are aligned along the longitudinal axis

[0046] In one embodiment, the two protrusions each have one of a hemi-spherical, cubic, and pyramidal shape.

[0047] In one embodiment, the radiopaque marker is made of one of gold and platinum.

[0048] In one embodiment, said mechanically deforming comprises one of crimping and swaging the second elongated structure.

[0049] In one embodiment, the second elongated structure comprises a slot extending longitudinally from a proximal end thereof to a distal end thereof.

[0050] In one embodiment, said mechanically deforming comprises reducing a width of the slot.

[0051] In one embodiment, said reducing the width of the slot is performed until opposite sides of the slot abut each other.

[0052] In one embodiment, the method further comprises securing together the opposite sides of the slot.

[0053] In one embodiment, the method further comprises positioning a retaining tube over the radiopaque marker.

5 [0054] In one embodiment, the retaining tube is made of a heat-shrinkable material and further comprising heating the retaining tube.

[0055] For the purpose of the present description, a mechanical wave should be understood as a signal having arbitrary amplitude, duration, waveform, frequency, and/or the like. For example, a mechanical wave may have a high/low amplitude, a short/long duration,
10 different waveforms, and any frequency content.

[0056] For the purpose of the present description, a mechanical pulse should be understood as a short duration mechanical wave. The duration of a mechanical pulse is of the order of $1/f_c$, where f_c is the central frequency of the mechanical pulse, which is typically around 500 kHz, and typically within the range of 100 kHz to 1 MHz or more generally
15 from 20 kHz to 5 MHz.

[0057] Furthermore, a mechanical waveguide should be understood as a waveguide adapted to propagate mechanical waves or pulses along its length. In the present description, the expressions “waveguide”, “mechanical waveguide” and “transmission member” may be used interchangeably. The characteristics such as the shape, the dimensions, the material of
20 which it is made, and/or the like may vary as long as mechanical waves and pulses may propagate along the mechanical waveguide. For example, a mechanical waveguide may have a cylindrical shape. The diameter of the mechanical waveguide may be constant along its length. Alternatively, the diameter of the waveguide may vary along its length so as to correspond to a taper or reverse profile for example. In an example, a mechanical waveguide
25 may be a dispersive waveguide, whereby the speed of propagation of the mechanical waves depends on the modes of propagation and their frequency content. Alternatively, a mechanical waveguide may be non-dispersive.

[0058] The expression “radiopaque marker” refers to a body or device that is opaque to radiations used for imaging a subject, i.e., that prevents at least partially the propagation of the radiations therethrough. Therefore, while imaging a subject using adequate radiations, the radiopaque marker is visible on the images. Several different medical imaging techniques
5 may be used for imaging a subject, such as radiography, magnetic resonance imaging, ultrasound imaging, tomography, etc. It should be understood that at least some of the characteristics of the radiopaque marker such as the material from which it is made are chosen as a function of the chosen medical imaging technique so that the radiopaque marker be visible on the images of the subject taken using the chosen medical imaging technique.

10 BRIEF DESCRIPTION OF THE DRAWINGS

[0059] Further features and advantages of the present invention will become apparent from the following detailed description, taken in combination with the appended drawings, in which:

[0060] Figure 1 is a block diagram illustrating a system for treating a lesion located in
15 a blood vessel, in accordance with the prior art;

[0061] Figure 2 is a block diagram illustrating a cylindrical mechanical waveguide having a constant diameter therealong and having a radiopaque marker secured thereto, in accordance with an embodiment;

[0062] Figure 3 illustrates a transmission member having a coil-shaped radiopaque
20 marker secured thereon, in accordance with an embodiment;

[0063] Figure 4 illustrates a section of the transmission member of Figure 3 adjacent to a distal end thereof with the coil-shaped radiopaque marker omitted, the section comprising a coil receiving portion located between two protrusions, in accordance with an embodiment;

25 [0064] Figure 5 illustrates a distal end of the transmission member of Figure 3 having a coil-shaped radiopaque marker secured thereon;

[0065] Figure 6 illustrates a distal section of a transmission member provided with a recess for receiving a radiopaque marker thereon, in accordance with a first embodiment;

[0066] Figure 7 illustrates a distal section of a transmission member provided with a recess for receiving a radiopaque marker thereon, in accordance with a second embodiment;

5 [0067] Figure 8 illustrates an assembly formed of a mechanical waveguide and an independent radiopaque marker before securing the two together, in accordance with an embodiment;

[0068] Figure 9 illustrates the assembly of Figure 8 when the radiopaque marker is secured to the mechanical waveguide;

10 [0069] Figure 10 illustrates a slotted tubular radiopaque marker, in accordance with an embodiment;

[0070] Figure 11 illustrates a cylindrical mechanical waveguide having a diameter varying recess and a radiopaque marker secured thereto, in accordance with a first embodiment; and

15 [0071] Figure 12 illustrates a cylindrical mechanical waveguide having a diameter varying recess and a radiopaque marker secured thereto, in accordance with a second embodiment.

[0072] It will be noted that throughout the appended drawings, like features are identified by like reference numerals.

20 DETAILED DESCRIPTION

[0073] In the following, there is described a mechanical waveguide or transmission member that comprises an elongated body extending between a proximal end and a distal end. The mechanical waveguide further comprises a radiopaque body secured to the elongated body at a position adjacent to the distal end of the elongated body.

[0074] Figure 1 illustrates an exemplary system 100 for treating a lesion 102 in order to order to describe an exemplary context in which the present mechanical waveguide provided with a radiopaque marker may be used. The system 100 comprises a pulse generator 104 for generating mechanical waves or pulses and a transmission member 106 for
5 propagate the mechanical waves or pulses generated by the pulse generator 104 up to the lesion 102.

[0075] In one embodiment, the pulse generator 104 is adapted to generate a high amplitude and short duration pulse. The pulse generator 104 may comprise at least one broadband source and/or at least one narrow band source. The narrow or broad band source
10 may be an electromechanical transducer. The pulse generator 104 may comprise a spatial concentrator to focus the output of at least one source toward a focal zone at which the proximal end of the transmission member 106 is located so as to couple the generated pulse therein.

[0076] The transmission member 106 such the present mechanical waveguide
15 extends between a first or proximal end that is operatively connected to the pulse generator 104 and a second or distal end. The transmission member 106 is adapted to receive a mechanical pulse or wave at its proximal end and propagate the mechanical pulse up to its distal end. When it reaches the distal end, the mechanical pulse is at least partially transmitted to its surrounding medium to generate a transmitted pulse that propagates outside
20 of the transmission member 106. It should be understood that part of the pulse may also be reflected by the distal end and propagates back in the transmission member 106 towards the proximal end thereof. The transmitted mechanical pulse corresponds to a mechanical pulse that propagates in the medium surrounding the distal end of the transmission member 106 up to the lesion 102. The transmitted pulse further propagates into the lesion 102, which may
25 create cracks within the lesion 102, and eventually cleaves or breaks the lesion 102 into pieces.

[0077] In an embodiment in which the distal end of the transmission member 106 abuts against the lesion 102, the transmission member 106 may further be used to break the lesion 102 and/or drill a hole into the lesion 102. The transmission of the mechanical pulse at

the distal end of the transmission member 106 creates a movement of the distal end of the transmission member 106. This movement may be along the longitudinal axis of the transmission member 106. Alternatively, the movement may be perpendicular to the longitudinal axis or it may be a combination of movements both along the longitudinal axis and perpendicular to the longitudinal axis of the transmission member. During this movement, the distal end of the transmission member 106 nominally first moves towards the lesion 102 and then moves back into its initial position. It should be understood that the movement may be inversed (i.e., the distal end may first move away from the lesion 102 and then towards the lesion 102) depending on the polarity of the mechanical pulse reaching the distal end of the transmission member 106. When a plurality of distinct mechanical pulses are successively transmitted at the distal end of the transmission member 106, the movement of the distal end may be seen as a jack-hammer movement which may be used to treat the lesion 102.

[0078] In order to visualize the lesion 102 during a medical procedure, medical imaging is usually used. The transmission member comprises a radiopaque marker, as described below, that is secured adjacent to the distal end of a mechanical waveguide in order to localize the distal end of the mechanical waveguide relative to the lesion 2 to be treated on the X-ray images.

[0079] In one embodiment, the mechanical waveguide or transmission member provided with a radiopaque marker may be used to treat vascular occlusions, i.e., to cross an occlusion present in a blood vessel. In this case, at least a section of the transmission member is positioned within a blood vessel of a subject so that its distal end be adjacent to the occlusion. For example, the distal end of the transmission member may be in physical contact with the occlusion. When a mechanical pulse reaches the distal end of the transmission member, the distal end will impact onto the occlusion and transmits the mechanical pulse in the occlusion itself. If the distal end of the transmission member is not in physical contact with the occlusion, the mechanical pulse is transmitted in the medium present between the occlusion and the distal end, e.g. blood, saline fluid, contrast fluid or the like, and the transmitted mechanical pulse can propagate up to the occlusion. The mechanical pulse allows cracking, eroding cleaving, tunneling and/or breaking the occlusion and further allows the

distal end of the transmission member to cross the occlusion as the distal end is moved farther within the vessel.

[0080] Figure 2 illustrates one embodiment of a mechanical waveguide assembly 150 comprising a mechanical waveguide 152 in the shape of an elongated body that is made of a material adapted to propagate mechanical waves and/or pulses. The mechanical waveguide 152 extends longitudinally between a proximal end 154 and a distal end 156 and has a cylindrical shape. The distal end 154 of the mechanical waveguide 152 is adapted to receive mechanical waves or pulses which are then propagated along the mechanical waveguide 152 up to the distal end 156 thereof. In the illustrated embodiment, the diameter of the mechanical waveguide 152 is constant along a length thereof between the proximal and distal ends 154 and 156.

[0081] The mechanical waveguide assembly 150 further comprises a radiopaque marker 158 which has a tubular or annular shape and is mounted on the mechanical waveguide 152 adjacent to the distal end 156 thereof. The radiopaque marker 158 extends longitudinally between a proximal end 160 which faces the proximal end 154 of the mechanical waveguide 152 and a distal end 162 which faces the distal end 156 of the mechanical waveguide 152.

[0082] The radiopaque marker 158 allows locating the distal end 156 of the mechanical waveguide 152 while the mechanical waveguide 152 is inserted into the subject and images of the subject are taken. Such a marker allows visualizing the distal end 156 of the mechanical waveguide 152 with respect to an occlusion for example. Since the position of the marker 158 is known relative to that of the distal end 156 of the mechanical waveguide 152, visualizing the marker 158 allows a user to know or determine the position of the distal end 156 of the mechanical waveguide 152.

[0083] For example, when X-rays are used for imaging a subject, the marker 158 is chosen so as to be visible on X-ray images by preventing or limiting the propagation of the X-rays therethrough. In this case, the maker 158 may be made of or coated with a dense material such as tungsten, platinum, gold, gold alloys, doped polymer, or the like.

[0084] It should be understood that any adequate methods for securing the radiopaque marker 158 to the mechanical waveguide 152 may be used. For example, adhesive may be used. In another example, the radiopaque marker 158 may be welded to the mechanical waveguide 152. In a further example and as described below, protrusions
5 projecting from the mechanical waveguide 152 or a recess formed into the mechanical waveguide 152 may be used to retain the radiopaque marker secured to the mechanical waveguide 152.

[0085] In one embodiment, the mechanical waveguide 152 may be made of a material adapted to minimize damping of mechanical waves such as stainless steel, aluminum or aluminum alloys, titanium or titanium alloys such as, Ti-6Al-4V or, Ti-11.5Mo-
10 6Zr-4.5Sn (Beta III titanium), nitinol, fused quartz or the like. In one embodiment, a heat treatment such as annealing may be applied to at least a portion of the mechanical waveguide 152.

[0086] While it extends along the whole circumference of the mechanical waveguide 152, the radiopaque marker 158 may extend along only a section of the circumference of the mechanical waveguide 152. The radiopaque marker 158 may be fixedly
15 secured to the mechanical waveguide 152. Alternatively, the radiopaque marker 158 may be movably secured to the mechanical waveguide 152. For example, the radiopaque marker 158 may have a single degree of freedom. For example, when secured to the mechanical
20 waveguide 152, the radiopaque marker 158 may rotate around the mechanical waveguide 152 about the longitudinal axis thereof while being preventing from any other movements such as translating along the longitudinal axis of the mechanical waveguide 152 or translating along the transverse axis, i.e., the axis orthogonal to the longitudinal axis.

[0087] While in the illustrated embodiment, the distal end 162 of the radiopaque
25 marker 158 is located at a given distance from the distal end 156 of the mechanical waveguide 152, it should be understood that the distal end 162 of the radiopaque marker 158 and the distal end 156 of the mechanical waveguide 152 may be coplanar.

[0088] While in the illustrated embodiment the internal diameter of the radiopaque marker 158 substantially corresponds to the external diameter of the mechanical

waveguide 152, it should be understood that the internal diameter of the radiopaque marker 158 may be greater than the external diameter of the mechanical waveguide. In this case, screws may be used for securing the radiopaque marker 158 to the mechanical waveguide 152 for example.

- 5 [0089] As described below, the shape, size and position of the radiopaque marker 158 may vary as long as it may be secured to the mechanical waveguide 152 adjacent to the distal end 156 thereof.

- 10 [0090] While the mechanical waveguide 152 has a constant diameter along a length thereof, it should be understood that other configurations are possible. For example, the mechanical waveguide may comprise a recessed section along which the mechanical waveguide has a diameter that is less than that of the two sections that are adjacent to the recessed section. The radiopaque marker may be mounted over the recessed section of the mechanical waveguide. In another example, the mechanical waveguide may comprise at least two bumps or protrusions spaced apart by a given distance, i.e., a proximal protrusion and a
- 15 distal protrusion. The section of the mechanical waveguide comprised between the two protrusions may be seen as a recessed section relative to the two protrusions, i.e., the diameter of the section comprised between the two protrusions is less than the maximal diameter of each protrusion while being may be equal to, greater than or less than the diameter of the remaining mechanical waveguide, i.e., the section of the mechanical
- 20 waveguide which is proximal to the proximal protrusion and the section of the mechanical waveguide that is distal to the distal protrusion, if any. In an example in which the mechanical waveguide comprises a recessed section, the diameter of the recessed section may be constant therealong. In another example, the diameter of the recessed section may vary therealong.

- 25 [0091] While the mechanical waveguide 152 has a circular cross-section, it should be understood that the cross-section of the mechanical waveguide may have any other adequate shape such as oval, square, rectangular, etc. In this case, the transverse dimensions of the mechanical waveguide, i.e., the dimensions of the mechanical waveguide in a direction orthogonal to its longitudinal axis, may be constant over the length of the mechanical

waveguide. In another example, the transverse dimensions of the mechanical waveguide may vary and the mechanical waveguide may comprise a recessed section adjacent to the distal end thereof. The marker is then positioned over the recessed section of the mechanical waveguide. The recessed section extends longitudinally along a given length of the mechanical waveguide and is comprised between a proximal section and a distal section of the mechanical waveguide. The distal section extends between the recessed section and the distal end of the mechanical waveguide. The proximal section is adjacent to the recessed section and extends from the recessed section towards the proximal end of the mechanical waveguide. The transverse dimensions of the recessed section are less than those of the proximal and distal sections, i.e., the surface area of the cross-section of the recessed section is less than that of the cross-section of the distal section and that of the cross-section of the proximal section so as to form a recess.

[0092] It should be understood that the maximal transverse dimensions of the proximal section are greater than the internal transverse dimensions of the proximal end of the marker so that the marker cannot pass over the proximal section. Similarly, the maximal transverse dimensions of the distal section are greater than the internal transverse dimensions of the distal end of the marker so that the marker cannot pass over the distal section.

[0093] In one embodiment, the surface area of the cross-section of the recessed section is constant along the recessed section. In another embodiment, the surface area of the cross-section of the recessed section may vary along the recessed section as long as the maximal cross-sectional surface area of the recessed section be less than the maximal cross-sectional surface area of the distal section and the maximal cross-sectional surface area of the proximal section.

[0094] Similarly, the cross-sectional surface area of the distal section and/or proximal section adjacent to the recessed section may vary therealong as long as the maximal cross-sectional surface area of the recessed section be less than the maximal cross-sectional surface area of the distal section and the maximal cross-sectional surface area of the proximal section. For example, a cylindrical proximal section may comprise three portions: a first or proximal portion having an increasing diameter, a second or distal section having a

decreasing diameter and a third or middle portion having a constant diameter and comprised between the first and second portions.

[0095] Figure 3 illustrates one embodiment of a cylindrical transmission member 200 provided with a coil shaped marker 202 having the shape of a single row or single layer coil.

5 The transmission member 200 comprises a first section 204 and a second section 206 having a tapering transition in between. The diameter of the first section 204 is greater than that of the second section 206. The proximal end 208 of the first section 204 is connectable to a source of mechanical pulses to receive mechanical pulses therefrom and may have a shape different than the one illustrated in Figure 3. The mechanical pulses propagate along the first
10 section 204 from its proximal end 208 up to its distal end 214 before propagating in the tapering section. The proximal end 212 of the second section 206 receives the mechanical pulses from the tapering section and the mechanical pulses propagate up to the distal end 214 of the second section 206.

[0096] The second section 206 comprises a distal section 218 extending from the
15 distal end 214 of the transmission member 200, a proximal section 216 and a recessed section 217 therebetween. The diameter of the recessed section 217 is less than that of the proximal and distal sections 216 and 218 so that the sections 216 and 218 appear as protrusions or bulbs relative to the recessed section 217. The sections 216 and 218 each protrude outwardly and radially from the transmission member 200 along the entire
20 circumference of the transmission member 200.

[0097] As illustrated in Figure 4, the proximal section 216 comprises three portions: a first or proximal portion 220, a second or distal portion 222 and a third or middle portion 224. The proximal portion 220 is a tapered portion having a diameter that increases therealong in direction of the recessed section 217. The middle portion 224 has a
25 substantially constant diameter therealong. The distal portion 222 is a tapered portion having a diameter that decreases towards the recessed section 217.

[0098] The distal section 218 comprises two portions: a first or proximal portion 230 and a second or distal portion 232. The proximal portion 230 is a tapered portion having a

diameter that increases therealong in direction of the distal end 214 and the distal portion 232 has a substantially constant diameter.

[0099] While in the illustrated embodiment it is substantially constant therealong, it should be understood that the diameter of the recessed section 217 could vary as long as the
5 maximal diameter of the recessed section 217 is less than the maximal diameter of the proximal section 216 and the maximal diameter of the distal section 218.

[0100] As illustrated in Figure 3, the coil shaped marker 202 is wound over the recessed section 206 between the proximal and distal sections 216 and 218. The marker 202 extends between a proximal end 240 and a distal end 242. The length and internal diameter
10 of the marker 202 are chosen so that, when positioned over the recessed section 217, the proximal end 240 of the marker 202 abuts against the proximal section 216, i.e., against the wall of the tapered portion 222, and the distal end 242 abuts against the distal section 218, i.e., against the wall of the tapered portion 230. As a result of the abutment of the ends 240 and 242 of the marker 202 against the tapered portions 222 and 230, the coil shaped
15 marker 202 is secured to the transmission member 200 and has a fixed position relative to the transmission member 200, i.e., the marker 202 cannot translate along the transmission member 200 once secured thereto. It should be understood that the marker 202 may rotate relative to the transmission member 200 about the longitudinal axis of the transmission 200 once secured thereto.

[0101] In one embodiment, the internal diameter of the coil-shaped marker 202 is substantially equal to that of the recessed section 206. In another embodiment, the internal diameter of the coil-shaped marker 202 is greater than that of the recessed section 206 while being less than the maximal diameter of the proximal and distal sections 216 and 218 so that the coil-shaped marker 202 be retained between the proximal and distal sections 216 and 218
20 while being rotatable relative to the transmission member 200.

[0102] In one embodiment, the length and the internal diameter of the marker 202 are chosen so that the coil-shaped marker 202 be movably secured to the transmission member 200, i.e., the coil-shaped marker 202 may translate along the transmission member 200 between the proximal and distal sections 216 and 218 and rotate about the

longitudinal axis of the transmission member 200. For example, if it has a length equal to or less than that of the recessed section 217 and an internal diameter greater than that of the recessed section 217, then the marker 202 may be movably secured to the transmission member and may translate along a section of the transmission member 200 between the proximal and distal sections 216 and 218.

[0103] While in the illustrated embodiment, the diameter of the central portion 224 of the proximal section 216 is equal to that of the portion 232 of the distal section 218, it should be understood that other configurations may be possible as long as the maximal internal diameter of the marker 202 is less than the maximal diameter of the proximal and distal sections 216 and 218. Similarly, while the diameter of the recessed section 217 is substantially equal to that of the section 234 of the transmission member 200 that is located between the proximal section 216 and the proximal end 212. For example, the diameter of the recessed section 217 could be less than that of the section 234. In another embodiment, the diameter of the recessed section 217 could be greater than that of the section 234 as long as it is less than the maximal diameter of the proximal and distal sections 216 and 218.

[0104] It should be understood that more than one marker may be positioned over the recessed section 217. For example, two markers may be positioned side-by-side along the length of the recessed section 217.

[0105] It should be understood that the transmission member 200 may comprise more than one recessed section in order to secure more than one coil shaped marker to the transmission member 200 at different locations along the distal section 206 of the transmission member. In one embodiment, the different recessed sections and the different markers may have different dimensions such as a different diameter and/or a different length.

[0106] In one embodiment, the coil-shaped marker 202 comprises a radiopaque wire that is coiled around and over at least a portion of the recessed section 206 comprised between the proximal and distal sections 216 and 218. The radiopaque wire may be made of radiopaque material or coated with a radiopaque material such as tungsten, platinum, gold, gold alloys, doped polymer, or the like.

[0107] In one embodiment, the coil-shaped marker 202 comprises a predefined number of loops which extend between a proximal loop adjacent to the proximal section 216 and a distal loop adjacent to the distal section 218. As illustrated in Figure 5, the end 240 of the distal loop 242, i.e., the distal loose end 240 of the wire forming the coil 202, may be secured to the second-to-last loop 244 adjacent to the distal loop 242. For example, the loose end 240 of the distal loop 242 may be spot welded to the second-to-last loop 244. Similarly, the loose end of the proximal loop (i.e., the first loop) may be secured to the second loop. Securing the loose ends of the distal and proximal loops allows preventing any unwinding of the coil during use and smoothing the edges of the coil thereby protecting the vascular anatomy during the insertion of the transmission member 200 within the body of the subject. It should be understood that loops other than the proximal and distal loops may also be secured to neighbor loops

[0108] It should be understood that the shape and dimensions of the proximal and distal sections 216 and 218 may vary as long as they allow maintaining the position of the marker 202 therebetween so as to secure the marker 202 to the transmission member 200. In the illustrated embodiment, the protrusion 216 comprises three portions: a proximal portion 220 having an increasing diameter, a distal portion 222 having a decreasing diameter, and an intermediary or central portion 224 located between the proximal and distal portion 220 and 222 and having a constant diameter. Within the proximal portion 220, the diameter of the proximal section 216 increases along a length thereof from the diameter of the section 234 of the transmission member 200 to the maximal diameter of the protrusion 216. The diameter of the central portion 224 is substantially constant along a length thereof and corresponds to the maximal diameter for the proximal section 216. Within the distal portion 222, the diameter of the protrusion 216 decreases along a length thereof from the maximal diameter of the protrusion 216 to the diameter of the recessed section 217. While the slope of the proximal and distal portions 220 and 222 is linear, it should be understood that other configurations may be possible. For example, the slope of the proximal and distal sections may be curved or may be sudden, i.e., a step.

[0109] In the illustrated embodiment, the distal section 218 comprises two portions: a proximal portion 230 having an increasing diameter and a distal portion 232 located between

the recessed section 217 and the distal end 214 of the transmission member 200. Within the proximal portion 230, the diameter of the distal section 218 increases from the diameter of the recessed section 217 to the maximal diameter of the distal section 218. The diameter of the transmission member 200 within the distal portion 232 is substantially constant and
5 corresponds to the maximal diameter for the distal section 218.

[0110] While in the illustrated embodiment, the proximal portion 220 of the proximal section 216 is substantially identical to the proximal portion 230 of the distal section 218 and the central portion 224 of the proximal section 216 is substantially identical to the central portion 232 of the distal section 218, it should be understood that other configurations may
10 be possible. For example, the maximal diameter of the proximal section 216 may be greater or less than that of the distal section 218.

[0111] In one embodiment, the diameter of the section 204 of the transmission member 200 is substantially equal to 0.33 mm and the diameter of the recessed section 217 is substantially equal to 0.404 mm. The maximal diameter of the proximal and distal
15 sections 216 and 218 is substantially equal to 0.432 mm. The length of the proximal, intermediary and distal portions 220, 224 and 222 of the proximal section 216 are each substantially equal to 0.5 mm. The length of the proximal and distal portions 230 and 232 of the distal section 218 are each substantially equal to 0.5 mm so that the distal end of the marker 202 is positioned at about 1 mm from the end 214 of the transmission member 200.
20 The length of the marker 202 is substantially equal to 10 mm.

[0112] In one embodiment, the diameter of the section 204 of the transmission member 200 is substantially equal to 0.43 mm and the diameter of the recessed section 217 is substantially equal to 0.22 mm. The maximal diameter of the proximal and distal
25 sections 216 and 218 is substantially equal to 0.28 mm. The length of the proximal, intermediary and distal portions 220, 224 and 222 of the proximal section 216 are each substantially equal to 0.5 mm. The length of the proximal and distal portions 230 and 232 of the distal section 218 are each substantially equal to 0.5 mm so that the distal end of the marker 202 is positioned at about 1 mm from the end 214 of the transmission member 200. The length of the marker 202 is substantially equal to 10 mm.

[0113] While in the illustrated embodiment, the proximal and distal sections 216 and 218 appear as protrusions relative to the section 234 of the transmission member, it should be understood that other configurations may be possible. For example, Figure 6 illustrates one embodiment of a transmission member 200' comprising a recessed section 217'. The transmission member comprises a proximal section 216' which is adjacent to the recessed section 217' and located between the recessed section 217' and the proximal end 208' of the transmission member 200'. The transmission member also comprises a distal section 218' adjacent to the recessed section 217' and located between the recessed section 217' and the distal end 214' of the transmission member 200'. The transmission member 200' further comprises a section 234' which is located between the proximal section 216' and the proximal end 208'. In this embodiment, the proximal section 216' comprises no proximal portion such as proximal portion 220 and only comprises a constant diameter central portion 224' and a decreasing diameter distal portion 222'. The maximal diameter of the proximal section 216' corresponds to the diameter of the portion 224' which is identical to that of the section 234'. The distal section 218' comprises an increasing diameter proximal portion 230' and a constant diameter distal portion 232'. The maximal diameter of the proximal section 218' corresponds to the diameter of the distal portion 232' which is identical to that of the section 234'. As a result, the transmission member 200' appears as having a constant diameter along a length thereof except for the recessed section 217', the distal portion 222' of the proximal section 216' and the proximal portion 230' of the distal section 218' which all have a diameter that is less than that of the other sections of the transmission member 200'.

[0114] While the diameter of the distal portion 232' of the distal section 218' is equal to that of the portion 224' of the proximal section 216' and the section 234', it should be understood that other configurations may be possible. For example, the diameter of the distal portion 232' of the distal section 218' may be greater than that of the portion 224' of the proximal section 216' and the section 234'.

[0115] In one embodiment, the decreasing diameter section 222, 222' and the increasing diameter section 230, 230' allows reducing the propagation losses for the mechanical waves or pulses propagating along the transmission member 200, 200'.

[0116] While Figures 4 and 6 illustrates a proximal section 216, 216' having a decreasing diameter section 222, 222' and a distal section 218, 218' having an increasing diameter section 230, 230', it should be understood that other configurations may be possible. For example, Figure 7 illustrates a transmission member 300 comprising an elongated body 302 extending between a proximal end 304 and a distal end 306. The elongated body 302 comprises a recessed section 317 adjacent to the distal end 306, a proximal section 316 adjacent to the recessed section 317 and positioned between the recessed section 317 and the proximal end 304, and a distal section 318 adjacent to the recessed section 317 and located between the recessed section 317 and the distal end 306.

[0117] In this embodiment, the proximal section 316 comprises a single portion having a diameter that is greater than that of the recessed section 317 and greater than the internal diameter of the proximal end of the marker to be inserted over the recessed section 317. The distal section 318 comprises a single portion having a diameter that is also greater than that of the recessed section 317 and further greater than the internal diameter of the proximal end of the marker to be inserted over the recessed section 317. While the diameter of the distal section 318 is greater than that of the proximal section 316, it should be understood that other configurations may be possible.

[0118] In one embodiment, the transmission member 200 is made of Ti-11.5Mo-6Zr-4.5Sn (Beta III titanium) and at least a portion of the section 204 of the transmission member is coated with polytetrafluoroethylene (PTFE) while at least a portion of the section 206 of the transmission member 200 may be coated with a hydrophilic material or a hydrophobic material to allow improved movement through the anatomy and allow devices to easily slide over the transmission member 200. In one embodiment, the distal section 206 of the transmission member 200 may have no coating. It should be understood that the marker may also be coated with any adequate coating or combination of coatings.

[0119] While the recess 217 extends along the whole circumference of the transmission member 200, it should be understood that the recess 217 may extend along only a section of the circumference of the transmission member 200.

[0120] In one embodiment, the increased diameter of the distal section 218 provides at least two functions: providing an increased drilling diameter and maintaining the position of the marker 202.

[0121] While Figures 3-7 refer to a transmission member having a circular cross-section, it should be understood that other configurations may be possible. For example, the transmission member may consist in an elongated member extending between a proximal end and a distal end and having a square or rectangular cross-section.

[0122] While Figure 3 refers to a marker 202 having a coil shape, it should be understood that other shape may be provided to the marker 202 as long as the marker consists in an elongated and hollow body mountable over the recessed section 217 and of which the distal and proximal ends of the internal cavity formed by the elongated and hollow body have transverse or cross-sectional dimensions that are less than those of the proximal and distal sections adjacent thereof. For example, the marker 202 may have a tubular shape and may surround the transmission member 200. In one embodiment, the tubular marker 202 may have an opening along a length thereof in order to position the tubular marker 202 around the transmission member 200. A tubular marker 202 may also be molded or screwed over the transmission member 200. In the case of a tubular marker comprises no opening, the tubular marker 202 may be inserted around the transmission member before the protrusion 218 be created. For example, the protrusion 218 may then be created using welding, forging, or the like.

[0123] In another example, the marker may consist in an elongated body defining an opening extending through the entire length thereof. The opening is sized and shaped for receiving at least a portion of the recessed section of the transmission member therein. The cross-section of the opening may have any adequate shape such as circular, square, rectangular, or the like as long as at least one transverse or cross-sectional dimension of the opening is less than the transverse dimension of the distal and proximal sections adjacent to the recessed section. For example, the transverse dimension of the opening may vary along the length of the marker as long as the transverse dimension of the distal and proximal ends

of the opening is less than the transverse dimension of the distal and proximal sections, respectively.

[0124] In an embodiment in which the marker 202 has a coil shape, the contact surface area between the marker 202 and the transmission member 200 may be reduced with respect to a configuration in which the marker 202 has a tubular shape for example. As a result, the propagation losses of the mechanical pulses may be reduced when a coil-shaped marker 202 is used.

[0125] In another embodiment, the marker 202 may comprise a braided sleeve whose inner diameter decreases as the length of the sleeve is increased.

10 [0126] In an embodiment in which the marker 202 has a coil shape, the marker 202 may be fixedly secured to the transmission member 200 in order to improve its mechanical integrity. For example, adhesive, soldering, welding, or the like may be used for securing the coil shaped marker 202 to the transmission member 200.

[0127] In one embodiment, the transmission member 200 is made of an alloy that can transmit mechanical waves or pulses from the proximal end 208 to the distal end 214. The distal section 206 may be more flexible than the proximal section 204. The flexibility of the distal section 206 may be achieved through a reduction in diameter of the transmission member 200 and/or the selection of an appropriate material. The reduction in diameter can be achieved using a single taper or a series of tapers in order to obtain an increased flexibility for the distal section 206. The length and/or diameter of the proximal and distal sections 216 and 218 are chosen so that the proximal and distal sections 216 and 218 do not significantly decrease the flexibility of the distal section 206. In one embodiment, the flexibility of the distal section 206 may be increased only in one direction of its cross-section. This may be achieved via a reduction of dimension only in the direction of the cross-section of the distal section 206 for which the increase of flexibility is desired.

[0128] While the coil shaped marker 202 comprises a single row/layer, it should be understood that other configurations may be possible. For example, the marker 202 may comprise at least two rows or layers of coil made from a continuous wire and wound in

alternating directions around the recess section 217. In this case, both loose ends of the coil are located at the same end of the marker 202 and they may be welded together to close the coil. In another example, the coil may be made of a continuous wire that is wound around the recessed section from a first end to a second and after making the last loop at the second end, the continuous wire may be inserted under the coil up to the first end where the two loose ends of the continuous wire are located. The two loose ends located at the first end of the coil may be secured together. In another example, the marker 202 may comprise a coil having different pitch angles along its length. In a further example, the coil may be made of a continuous wire that is wound around the recessed section of the mechanical waveguide from a first end to a second. After making the last loop at the second end, the continuous wire is coiled back, over the existing coil or within the existing coil, to the first end where the two loose ends of the continuous wire are located. The two loose ends located at the first end of the coil may then be secured together. In this case, a U-turn may be performed at the second end so that the wire is then wound around the mechanical waveguide from the second end to the first end.

[0129] As a mechanical wave or pulse propagates along the transmission member 200, some mechanical energy may leak out from the transmission member 200 into the surrounding medium. In one embodiment, the marker 202 located between the transmission member 200 and the surrounding medium may prevent or minimize mechanical energy to leak out into the surrounding medium.

[0130] In one embodiment, the material, size and shape of the marker 202 are chosen so that the marker 202 be flexible enough to allow shaping the distal tip of the transmission member.

[0131] While the above-described mechanical waveguides 200 and 300 comprises protrusions 216, 218 and 318 which extend along the whole circumference of the mechanical waveguide 200 and 330, other configurations may be possible as illustrated in Figure 8.

[0132] Figure 8 illustrates one embodiment of a mechanical waveguide assembly formed of a transmission member or mechanical waveguide 400 and a radiopaque marker 404. In Figure 8, the radiopaque marker 404 is illustrated before being secured to the

mechanical waveguide 400 and is therefore independent and separate from the mechanical waveguide 400. Figure 9 illustrates the radiopaque marker 404 when secured to the mechanical waveguide 400.

[0133] The mechanical waveguide 400 has a cylindrical or tubular shape with a local outer transversal dimension h_3 , i.e., a local outer diameter h_3 in this embodiment, and extends along a longitudinal axis between a proximal end and a distal end. When the mechanical waveguide 400 is used for propagating mechanical waves, at least a section of the mechanical waveguide 400 is adapted to be inserted into a subject such as into a blood vessel of the subject so that its distal end be positioned adjacent to a lesion to be treated in order to propagate the mechanical waves up to the lesion.

[0134] The outer surface of the mechanical waveguide 400 is provided with at least two protrusions or bumps 402 and 403 which project radially and outwardly therefrom. The two bumps 402 and 403 are spaced apart along the longitudinal axis by a distance L_1 . In the illustrated embodiment, the bumps 402 and 403 each have a hemi-spherical shape.

[0135] The transversal dimension of the first bump 402, i.e., the distance between the apex of the bump 400 and the opposite face of the mechanical waveguide 400 along the transverse axis orthogonal to the longitudinal axis, is defined as h_1 . Similarly, the transversal dimension of the second bump 403, i.e., the distance between the apex of the bump 402 and the opposite face of the mechanical waveguide 400 along the transverse axis orthogonal to the longitudinal axis, is defined as h_2 .

[0136] It should be understood that the location of the bumps 402 and 403 along the longitudinal axis of the mechanical waveguide 400 may vary. In one embodiment, the bump 403 is located adjacent to the distal end of the mechanical waveguide 400.

[0137] As described above, the assembly further comprises the radiopaque marker 404 which has a tubular shape. The radiopaque marker 404 extends linearly along a longitudinal axis. The radiopaque marker 404 is provided with an internal transversal dimension h_4 , i.e., an internal diameter h_4 in the illustrated embodiment, an external

transversal dimension h_5 , i.e., an external diameter h_5 in the illustrated embodiment, and a length L_2 .

[0138] The internal or inner diameter h_4 of the radiopaque marker is chosen to be greater than the transversal dimensions h_1 and h_2 of the first and second bumps 402 and 403, respectively, so that the mechanical waveguide 400 be inserted into the radiopaque marker 404. The length L_2 of the radiopaque marker 404 is chosen to be less than the distance L_1 between the two bumps 402 and 403.

[0139] The radiopaque marker 404 is made of a radiopaque material and the thickness and material of the radiopaque marker 404 are chosen so that the radiopaque marker 404 be ductile or deformable.

[0140] In order to secure the radiopaque marker 404 on the mechanical waveguide 400, the radiopaque marker 404 is inserted around the mechanical waveguide 400 and slid along the longitudinal axis of the mechanical waveguide 400 until it is located between the bumps 402 and 403. Once in place, the radiopaque marker 404 is mechanically deformed by crimping or swaging from its outer surface to reduce its inner dimension h_4 to a value being less than the transversal dimensions h_1 and h_2 . As a result, the deformed radiopaque marker 404 is secured to the mechanical waveguide 400 as illustrated in Figure 9. Since the final inner dimension h_4 of the radiopaque marker 404 is less than the transversal dimension h_1 of the first bump 402, the radiopaque marker 404 cannot pass over the first bump 402. Similarly, the radiopaque marker 404 cannot pass over the second bump 403 since the final inner dimension h_4 of the radiopaque marker 404 is less than the transversal dimension h_2 of the second bump 403. As a result, the radiopaque marker 404 is maintained between the two bumps 402 and 403.

[0141] In one embodiment, the length L_2 of the radiopaque marker 404 is chosen so that the proximal end of the radiopaque marker 404 abuts against the distal face of the first bump 402 and the distal end of the radiopaque marker 404 abuts against the proximal face of the second bump 403 when the radiopaque marker 404 is secured to the mechanical waveguide 400. In this case, the radiopaque marker 404 cannot slide or translate along the mechanical waveguide 400 once secured thereto between the two bumps 402 and 403.

[0142] In another embodiment, the length L2 of the radiopaque marker 404 is chosen so that the radiopaque marker 404 may slide between the two bumps 402 and 403 once secured to the mechanical waveguide 400, i.e., the radiopaque marker 404 does not abut against both bumps 402 and 403 once secured to the mechanical waveguide 400. In this case, contact between the mechanical waveguide 400 and radiopaque marker 404 is minimal, thus preventing mechanical energy leakage between the mechanical waveguide 400 and the radiopaque marker 404.

[0143] In one embodiment, the final inner dimension h4 of the radiopaque marker once secured to mechanical waveguide 400 is substantially equal to the diameter h3 of the mechanical waveguide 400 so that no transverse movement of the radiopaque marker 404 relative to the mechanical waveguide 400 be possible.

[0144] In another embodiment, the final inner dimension h4 of the radiopaque marker 404 is greater than the diameter h3 of the mechanical waveguide 400, thereby allowing a transverse movement of the radiopaque marker 404 relative to the mechanical waveguide 400. In this case, contact between the mechanical waveguide 400 and the radiopaque marker 404 is minimal, thus preventing mechanical energy leakage between the mechanical waveguide 400 and the radiopaque marker 404.

[0145] While in the illustrated embodiment the bumps 402 and 403 each have a hemi-spherical shape, it should be understood that any other adequate shape may be provided for the bumps. For example, the bumps 402 and 403 may have a trapezoidal, pyramidal or cubic shape. It should also be understood that the bumps 402 and 403 may be provided with different shapes.

[0146] While in the illustrated embodiment the bumps 402 and 403 are located at as same angular position along the circumference of the mechanical waveguide 400, it should be understood that other configurations are possible. For example, the bumps 402 and 403 may project from opposite sides of the mechanical waveguide 400.

[0147] While in the illustrated embodiment the bumps 402 and 403 each extend along a portion of the circumference of the mechanical waveguide 400, it should be understood that

at least one bump 402, 403 may extend along the whole circumference of the mechanical waveguide 400, thereby forming a ring. In this case, the transversal dimension of the bump corresponds to the external diameter of the ring.

[0148] In one embodiment, the radiopaque marker 404 is made of a sufficiently radiopaque and ductile material in order to ensure good visibility on medical images and manufacturability. For example, the radiopaque marker 404 may be made of gold or platinum.

[0149] While in the illustrated embodiment, the mechanical waveguide 400 and the radiopaque marker 404 have a cylindrical or tubular shape, it should be understood that the mechanical waveguide 400 and the radiopaque marker 404 may have different geometries. For example, the mechanical waveguide 400 and the radiopaque marker may each have a substantially rectangular or square cross-sectional shape.

[0150] While in the illustrated embodiment the mechanical waveguide 400 and the marker 404 each have substantially the same shape, i.e., a cylindrical or tubular shape, it should be understood that other configurations may be possible. For example, the mechanical waveguide 400 may have a cylindrical shape while the radiopaque marker 404 may have a rectangular or square cross-sectional shape.

[0151] It should be understood that the shape and inner dimensions of the radiopaque marker 404 before securing to the mechanical waveguide 400 may vary as long as the radiopaque marker 404 may be inserted around the mechanical waveguide 400 and over at least one bump 402, 403 to be positioned between the bumps 402 and 403. For example, the inner dimension of the radiopaque marker 404 may be greater than the transversal dimension of the second bump 403 but less than the transversal dimension of the first bump 402. In this case, the radiopaque marker 404 is inserted around the mechanical waveguide 400 from the distal end thereof and slid over the second bump 403 to be positioned between the two bumps 402 and 403. In another example, the inner dimension of the radiopaque marker 404 may be greater than the transversal dimension of the first bump 402 but less than the transversal dimension of the second bump 403. In this case, the radiopaque marker 404 is inserted around the mechanical waveguide 400 from the proximal end thereof and slid over

the first bump 402 to be positioned between the two bumps 402 and 403. In a further example, the inner dimension of the radiopaque marker 404 may be greater than the transversal dimension of both the first and second bumps 402 and 403 as described above.

[0152] It should also be understood that the radiopaque marker 404 once positioned
5 between the two bumps may be deformed in any adequate manner as long as its final maximal inner dimension be less than the transversal dimension of the two bumps 402 and 403. In one embodiment, the final inner dimension of the radiopaque marker 404 is chosen so as to minimize contact between the deformed radiopaque marker 404 and the mechanical waveguide 400.

10 [0153] The generally tubular initial geometry of the radio-opaque marker can be full or segmented. For example the radiopaque marker 404 can comprise a plurality of distinct or joined rings of uniform or varying individual length, all of generally the same cross-sectional geometry. The marker can also comprise a wire wound as a coil, or comprise a combination of distinct or joined tubes, distinct or joined rings, and coils.

15 [0154] In one embodiment, once crimped or swaged, the radiopaque marker 404 can have a regular and smooth inner and/or outer surface, or it can have an irregular inner and/or outer surface, comprising features such as folds or ridges, for example. This irregular final surface can be encouraged by manufacturing the radiopaque marker 404 with pre-formed folds or ridges that, upon crimping or swaging, are amplified into larger folds, ridges or
20 pleats, for example. This geometry may be useful to minimize contact between the radiopaque marker and the mechanical waveguide 400.

[0155] Figure 10 illustrates an embodiment of a slotted radiopaque marker 430. Similarly to the radiopaque marker 404, the radiopaque marker 430 has a tubular shape and extends along a longitudinal axis. The radiopaque marker 430 also comprises a slot or
25 aperture 432 that extends linearly along the longitudinal axis of the radiopaque marker 430 from the proximal end thereof to the distal end thereof. The width of the slot 432 is chosen so as to be greater than the lateral dimension of the mechanical waveguide 400, thereby allowing the radiopaque marker 430 to be slipped on the mechanical waveguide 400 from its side. Once positioned between the bumps 402 and 403, the slot 432 is closed by crimping or

swaging to prevent the radiopaque marker 430 from slipping out from the side of the mechanical waveguide 400. The final geometry of the crimped or swaged radiopaque marker 430 is such that the radiopaque marker 430 is also prevented from axially slipping out from its location between the two bumps 402 and 403 on the mechanical waveguide 400, while physical contact is minimized between the radiopaque marker 430 and the mechanical waveguide 400.

[0156] In one embodiment, once this slotted tubular marker is in place over the mechanical waveguide 400, the slot 432 is partially closed so that the final width of the slot 432 is not wide enough to allow the radiopaque marker 432 slipping out from the side of the mechanical waveguide 400.

[0157] In another embodiment, the slot 432 is fully closed. The closed slot 432 may be achieved by having both sides of the slot 432 abutting each other or having both sides overlapping each other.

[0158] In order to prevent the slot 432 from re-opening, the open or closed slot 432 can be partially or fully joined by welding, brazing or gluing, for example. Another method to prevent the slot 432 from re-opening consists in covering the outer circumference of the radiopaque marker 430 with a retaining tube or sleeve of the same inside dimensions as that of the outer dimensions of the radiopaque marker 430. This retaining tube can be fixed in place by welding, brazing or gluing to the radiopaque marker 430, for example. The retaining tube can also be made of a heat-shrinking material, where heat application ensures that the retaining tube is securely attached to the radiopaque marker 430.

[0159] The radiopaque marker 430 can be full or segmented. For example the radiopaque marker 430 can comprise a plurality of distinct or joined slotted rings of uniform or varying individual length, all of generally the same cross-sectional geometry. The radiopaque marker 430 can also comprise a combination of distinct or joined slotted tubes and rings.

[0160] While in the above-described mechanical waveguides provided with a recess section, the recess section has constant transverse dimensions, e.g., a constant diameter along

the length of the recessed section, it should be understood that the transverse dimensions of the recessed section may vary therealong as illustrated in Figures 11 and 12.

[0161] Figure 11 illustrates one embodiment of a mechanical waveguide assembly 500 comprising a mechanical waveguide 502 and a coil-shaped radiopaque marker 504 secured to the mechanical waveguide 502. The mechanical waveguide 502 has a generally cylindrical shape, i.e., the cross-section of the mechanical waveguide 502 is circular. The mechanical waveguide 502 extends between a proximal end (not shown) and a distal end 506, and comprises a proximal section 508 a distal section 512 and a recessed section 510 located between the proximal and distal sections 508 and 512. The proximal section 508 has a constant diameter D1 along a length thereof and the distal section 512 has also a constant diameter D2 along a length thereof. The diameter D3 of the recessed section 510 decreases from a proximal end thereof to a distal end thereof. The diameter D3 of the recessed section 510 at the proximal end is equal to the diameter D1 of the proximal section 508 while the diameter D3 of the recessed section 510 at the distal end is less than the diameter D2 of the distal section 512. The diameter D2 of the distal section 512 may be equal to, less than or greater than the diameter D1 of the proximal section 508 as long as it is greater than the diameter D3 at the distal end of the recessed section 510.

[0162] The radiopaque marker 504 comprises a coil wound around the recessed section 510 and has a substantially tubular shape. The radiopaque marker 504 extends between a proximal end and a distal end and the length of the radiopaque marker 504 is less than the length of the recessed section 510. When the radiopaque marker 504 is secured to the mechanical waveguide 500 and for each point of the radiopaque marker 504 along the length thereof, the internal diameter of the radiopaque marker 504 is substantially equal to the diameter D3 of the recessed section. The distal end of the radiopaque marker 504, i.e., the distal loop of the coil, abuts against the proximal wall 514 of the distal section 512. Since the length of the radiopaque marker 504 is less than that of the recessed section 510, the diameter of the radiopaque marker 504 at its proximal end is less than the diameter D1 of the proximal section 508.

[0163] Since the distal end of the radiopaque marker 504 abuts against the proximal wall 514 of the distal section 512 and the diameter of the proximal end of the radiopaque marker 504 is less than the maximal diameter of the recessed section 510, i.e., the diameter D1, the radiopaque marker 504 is secured to the mechanical waveguide 502 and cannot
5 translate along the longitudinal axis of the mechanical waveguide 502. In one embodiment, the radiopaque marker 504 may rotate about the longitudinal axis of the mechanical waveguide 502 once secured thereto.

[0164] It should be understood that the dimensions of the radiopaque marker 504 may vary as long as its length is less than the length of the recessed section 510, its diameter at its
10 proximal length is less than the maximal diameter of the recessed section, i.e., diameter D1, and its diameter at its distal end is less than the diameter D2 of the distal section 512. For example, for each point along the length of the radiopaque marker 504, the diameter of the radiopaque marker 504 may be greater than the diameter of the recessed section 510 as long as the diameter of the proximal end of the radiopaque marker 504 is less than D1 and the
15 diameter of the distal end of the radiopaque marker 504 is less than D2.

[0165] Figure 12 illustrates one embodiment of a mechanical waveguide assembly 600 comprising a mechanical waveguide 602 and a coil-shaped radiopaque marker 604 secured to the mechanical waveguide 602. The mechanical waveguide 602 has a generally cylindrical shape, i.e., the cross-section of the mechanical waveguide 602 is
20 circular. The mechanical waveguide 602 extends between a proximal end (not shown) and a distal end 606, and comprises a proximal section 608 a distal section 612 and a recessed section 610 located between the proximal and distal sections 608 and 612. The proximal section 608 has a constant diameter D1 along a length thereof. The distal section 612 comprises a proximal portion 614 and a distal portion 616. The diameter of the proximal
25 portion 614 increases from the recessed section 610 to the distal portion 616 and the distal portion 606 has a constant diameter D2 along a length thereof. The diameter D3 of the recessed section 610 decreases from a proximal end thereof to a distal end thereof. The diameter D3 of the recessed section 610 at the proximal end is equal to the diameter D1 of the proximal section 608 while the diameter D3 of the recessed section 610 at the distal end
30 is less than the diameter D2 of the distal portion 616. The diameter D2 of the distal

portion 616 may be equal to, less than or greater than the diameter D1 of the proximal section 608 as long as it is greater than the diameter D3 at the distal end of the recessed section 610.

[0166] The radiopaque marker 604 comprises a coil wound around the recessed section 610 and has a substantially tubular shape. The radiopaque marker 604 extends between a proximal end and a distal end and the length of the radiopaque marker 604 is less than the length of the recessed section 610. When the radiopaque marker 604 is secured to the mechanical waveguide 600 and for each point of the radiopaque marker 604 along the length thereof, the internal diameter of the radiopaque marker 604 is substantially equal to the diameter D3 of the recessed section. The distal end of the radiopaque marker 604, i.e., the distal loop of the coil, abuts against the proximal portion 614 of the distal section 612. Since the length of the radiopaque marker 604 is less than that of the recessed section 610, the diameter of the radiopaque marker 604 at its proximal end is less than the diameter D1 of the proximal section 608.

[0167] Since the distal end of the radiopaque marker 604 abuts against the proximal portion 614 of the distal section 612 and the diameter of the proximal end of the radiopaque marker 604 is less than the maximal diameter of the recessed section 610, i.e., the diameter D1, the radiopaque marker 604 is secured to the mechanical waveguide 602 and cannot translate along the longitudinal axis of the mechanical waveguide 602. In one embodiment, the radiopaque marker 604 may rotate about the longitudinal axis of the mechanical waveguide 602 once secured thereto.

[0168] It should be understood that the dimensions of the radiopaque marker 604 may vary as long as its length is less than the length of the recessed section 610, its diameter at its proximal end is less than the maximal diameter of the recessed section, i.e., diameter D1, and its diameter at its distal end is less than the diameter D2 of the distal portion 616. For example, for each point along the length of the radiopaque marker 604, the diameter of the radiopaque marker 604 may be greater than the diameter of the recessed section 610 as long as the diameter of the proximal end of the radiopaque marker 604 is less than D1 and the diameter of the distal end of the radiopaque marker 604 is less than D2.

[0169] In one embodiment, the length of the protrusions such as protrusions 216, 218, 318, 402 and 403 is chosen so as to be short in comparison to the wavelength of the mechanical waves or pulses propagating through the mechanical waveguide or transmission member in order to minimize diffraction of the travelling mechanical waves or pulses and/or propagation losses. For example, the length of the protrusion along the longitudinal axis of the mechanical waveguide may be less than $1/10^{\text{th}}$ of the wavelength of the mechanical waves or pulses to be propagated in the mechanical waveguide.

[0170] The embodiments of the invention described above are intended to be exemplary only. The scope of the invention is therefore intended to be limited solely by the scope of the appended claims.

I/WE CLAIM:

1. A device for transmitting mechanical waves, comprising:

a mechanical waveguide having an elongated shape and extending between a proximal end and a distal end for propagating the mechanical waves coupled at the proximal end up to the distal end; and

a radiopaque marker secured to the mechanical wave adjacent to the distal end thereof.

2. The device of claim 1, wherein the mechanical waveguide comprising a recessed section adjacent to the distal end and the radiopaque marker is positioned over at least a portion of the recessed section.

3. The device of claim 2, wherein the radiopaque marker comprises a recess receiving aperture extending therealong, the recessed section extending at least partially within the recess receiving aperture of the radiopaque marker.

4. The device of claim 3, wherein the mechanical waveguide comprises a proximal section and a distal section each adjacent to the recessed section, the distal section comprising the distal end of the mechanical waveguide.

5. The device of claim 4, wherein the radiopaque marker extends between a first end and a second end, the first end abutting against one of the distal and proximal sections.

6. The device of claim 5, wherein the second end abuts against another one of the distal and proximal sections.

7. The device of claim 6, wherein the mechanical waveguide has a cylindrical shape.

8. The device of claim 7, wherein the distal section comprises a first distal portion adjacent to the recessed section and having an increasing diameter, and a second distal portion having a constant diameter and extending up to the distal end of the elongated

member, the second end of the radiopaque marker abutting against the first distal portion of the distal section.

9. The device of claim 8, wherein the proximal section comprises a first proximal portion adjacent to the recessed section and having a decreasing diameter, and a second proximal portion having a substantially constant diameter, the first end of the radiopaque marker abutting against the first proximal portion of the proximal section.

10. The device of claim 9, wherein the proximal section further comprises a third proximal portion having an increasing diameter, the second proximal portion being located between the first and third proximal portions.

11. The device of claim 9 or 10, wherein the radiopaque marker comprises a coil wound around the recessed section.

12. The device of claim 11, wherein an internal diameter of the coil is substantially equal to a diameter of the recessed section of the mechanical waveguide.

13. The device of claim 11, wherein an internal diameter of the coil is greater than a diameter of the recessed section of the mechanical waveguide and less than a maximal diameter of the proximal and distal sections.

14. The device of any one of claims 11 to 13, wherein the coil comprises a plurality of loops, at least one of a distal end of the coil and a proximal end of the coil being secured to an adjacent one of the plurality of loops.

15. The device of any one of claims 11 to 14, wherein the coil comprises a plurality of loops and at least two adjacent ones of the plurality of loops being secured together.

16. The device of any one of claims 11 to 15, wherein the coil is a single layer coil.

17. The device of any one of claims 11 to 15, wherein the coil is a multi-layer coil.

18. The device of any one of claims 1 to 17, wherein the radiopaque marker is one of made of and coated with one of tungsten, platinum, gold, a gold alloy and a doped polymer.

19. The device of any one of claims 1 to 18, wherein the mechanical waveguide is made of one of stainless steel, aluminum, aluminum alloy, titanium, titanium alloy, nitinol and fused quartz.

20. The device of claim 19, wherein the titanium alloy comprises one of Ti-6Al-4V and Ti-11.5Mo-6Zr-4.5Sn (Beta III titanium).

21. The device of any one of claims 1 to 20, wherein at least a portion of the elongated member is coated with one of a hydrophilic coating and a hydrophobic coating.

22. The device of any one of claims 1 to 20, wherein at least a portion of the elongated member is coated with polytetrafluoroethylene.

23. An assembly comprising:

a mechanical waveguide comprising a first elongated structure extending along a first longitudinal axis between a proximal end and a distal end and provided with at least two protrusions projecting from an outer face of thereof adjacent to the distal end, the two protrusions being spaced apart by a given distance along the first longitudinal axis; and

a radiopaque marker comprising a second elongated structure made of a radiopaque material and extending along a second longitudinal axis, the second elongated structure being hollow so as to be positioned around the first elongated structure between the two protrusions and being deformable so that an inner dimension thereof be reduced to maintain the second elongated structure between the two protrusions,

wherein the inner dimension of the radiopaque marker is greater than an outer dimension of a section of the first elongated structure comprised between the two protrusions once deformed and positioned between the two protrusions.

24. The assembly of claim 23, wherein the first and second elongated structures have substantially a same cross-sectional shape.

25. The assembly of claim 23, wherein the first and second elongated structures have different cross-sectional shapes.

26. The assembly of claim 23 or 24, wherein the first elongated structure has a cylindrical shape and the second elongated structure has a tubular structure, an inner diameter of the second elongated structure being less than a transversal dimension of at least one of the two protrusions.

27. The assembly of claim 26, wherein the two protrusions extend along a portion of a circumference of the first elongated structure.

28. The assembly of claim 26, wherein at least one of the two protrusions extends along a whole circumference of the first elongated structure.

29. The assembly of any one of claims 23 to 28, wherein the two protrusions are aligned along the longitudinal axis.

28. The assembly of any one of claims 21 to 27, wherein the two protrusions each have one of a trapezoidal, hemi-spherical, cubic, and pyramidal shape.

30. The assembly of any one of claims 21 to 28, wherein the second elongated structure is made of one of gold and platinum.

32. The assembly of any one of claims 23 to 31, wherein the second elongated structure comprises a slot extending longitudinally from a proximal end thereof to a distal end thereof.

33. The assembly of claim 32, further comprising a tube insertable around the radiopaque marker.

34. The assembly of claim 33, wherein the tube is made of a heat-shrinkable material.

35. A method for making a mechanical waveguide structure, the method comprising:

providing a mechanical waveguide comprising a first elongated structure extending along a first longitudinal axis and provided with at least two protrusions projecting from an outer face of thereof, the two protrusions being spaced apart by a given distance along the longitudinal axis;

providing a radiopaque marker comprising a second elongated structure made of a radiopaque material, extending along a second longitudinal axis and having a length being one of less than and equal to the given distance, the second elongated structure being hollow so as to be positioned around the first elongated structure between the two protrusions and being deformable so that an inner dimension thereof be reduced to maintain the second elongated structure between the two protrusions;

positioning the second elongated structure around the first elongated structure between the two protrusions; and

mechanically deforming the second elongated structure so that the inner dimension thereof be less than a transversal dimension of the two protrusions, thereby securing the radiopaque marker to the first elongated structure between the two protrusions, wherein the inner dimension of the radiopaque marker after said mechanically deforming is greater than an outer dimension of a section of the first elongated structure comprised between the two protrusions.

36. The method of claim 35, wherein the first and second elongated structures have substantially a same cross-sectional shape.

37. The method of claim 35, wherein the first and second elongated structures have different cross-sectional shapes.

38. The method of claim 35 or 36, wherein the first elongated structure has a cylindrical shape and the second elongated structure has a tubular structure, an inner diameter of the second elongated structure being less than a transversal dimension of at least one of the two protrusions.

39. The method of claim 38, wherein the two protrusions extend along a portion of a circumference of the first elongated structure.

40. The method of claim 36, wherein at least one of the two protrusions extend along a whole circumference of the first elongated structure.

41. The method of any one of claims 35 to 40, wherein the two protrusions are aligned along the longitudinal axis
42. The method of any one of claims 35 to 41, wherein the two protrusions each have one of a hemi-spherical, cubic, and pyramidal shape.
43. The method of any one of claims 35 to 42, wherein the radiopaque marker is made of one of gold and platinum.
44. The method of any one of claims 35 to 43, wherein said mechanically deforming comprises one of crimping and swaging the second elongated structure.
45. The method of any one of claims 35 to 44, wherein the second elongated structure comprises a slot extending longitudinally from a proximal end thereof to a distal end thereof.
46. The method of claim 45, wherein said mechanically deforming comprises reducing a width of the slot.
47. The method of claim 46, wherein said reducing the width of the slot is performed until opposite sides of the slot abut each other.
48. The method of claim 47, further comprising securing together the opposite sides of the slot.
49. The method of claim 47, further comprising positioning a retaining tube over the radiopaque marker.
50. The method of claim 49, wherein the retaining tube is made of a heat-shrinkable material and further comprising heating the retaining tube.

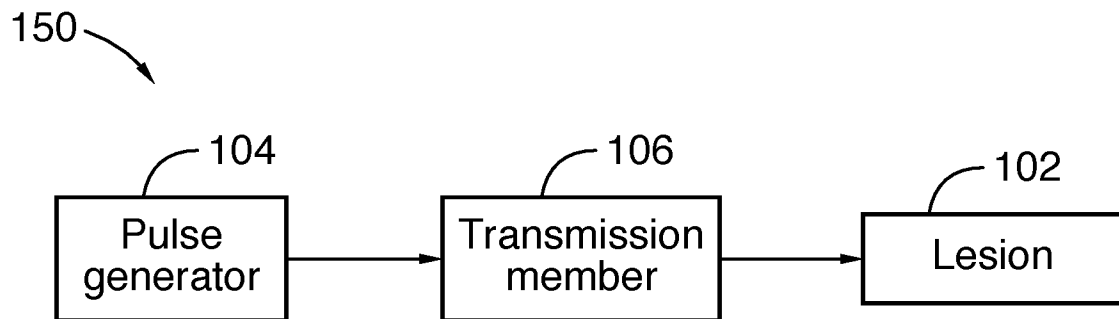


FIG.1
(PRIOR ART)

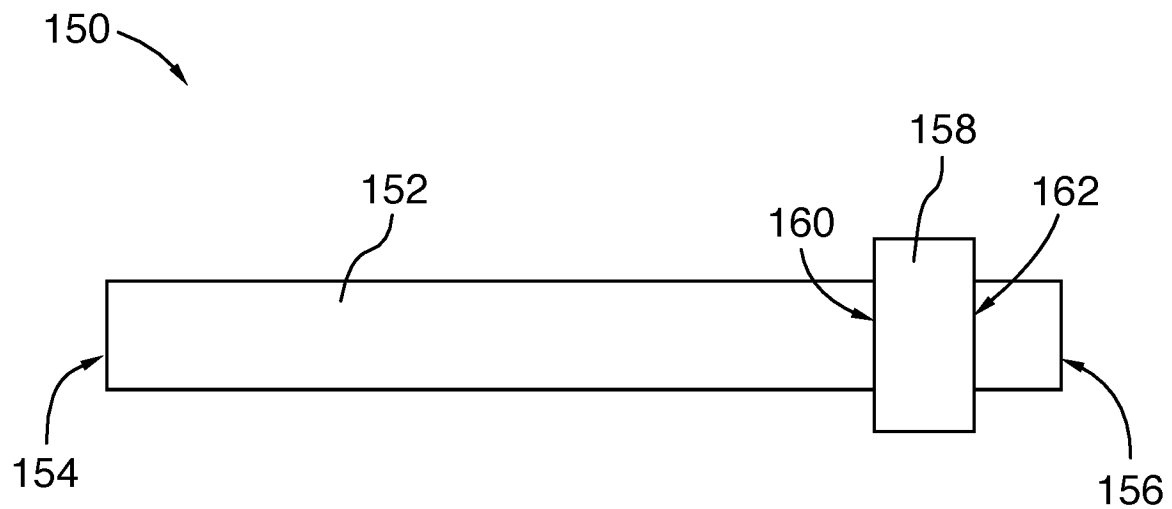


FIG.2

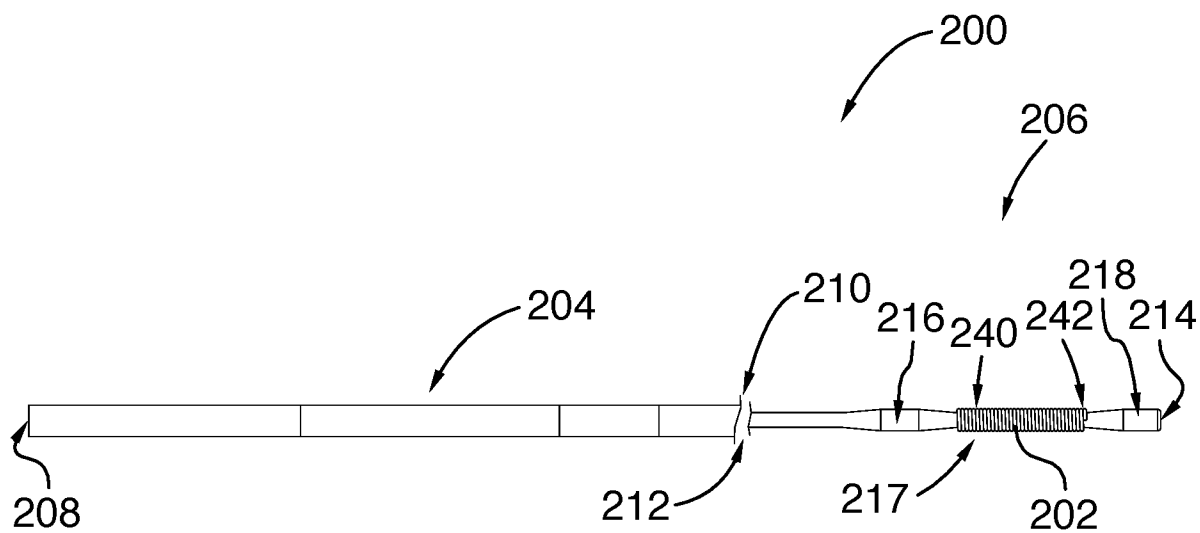


FIG. 3

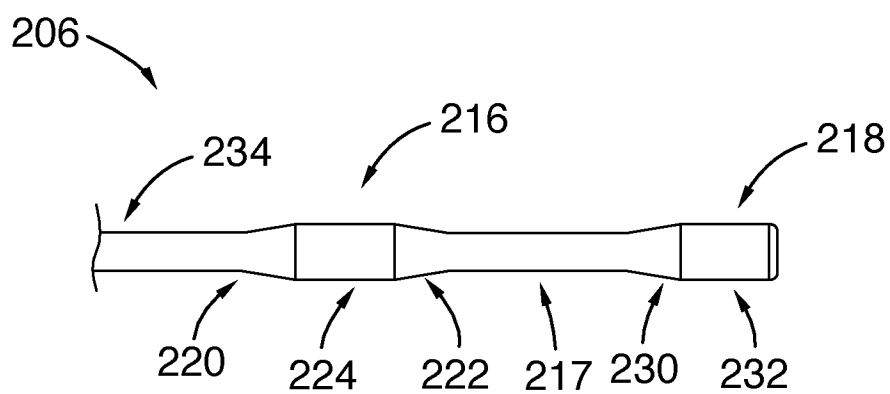


FIG. 4

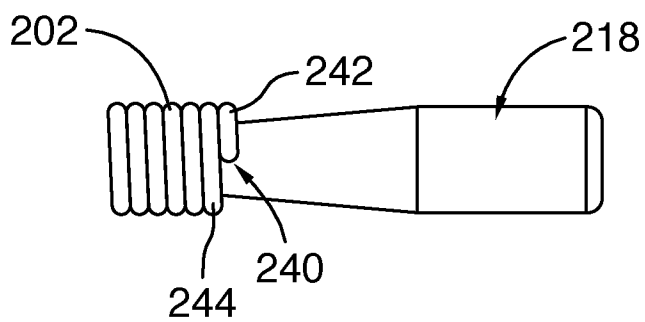


FIG. 5

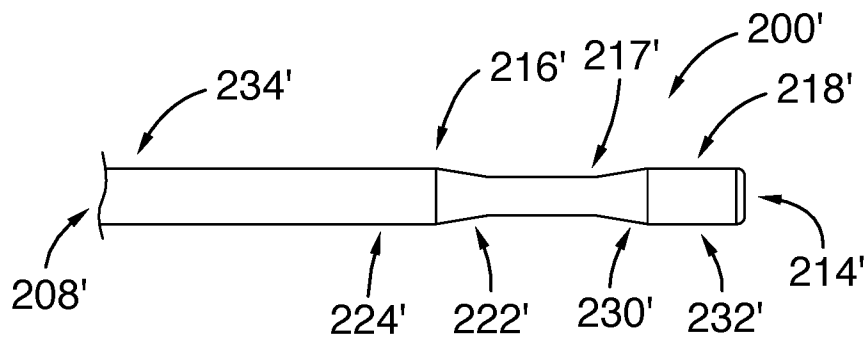


FIG. 6

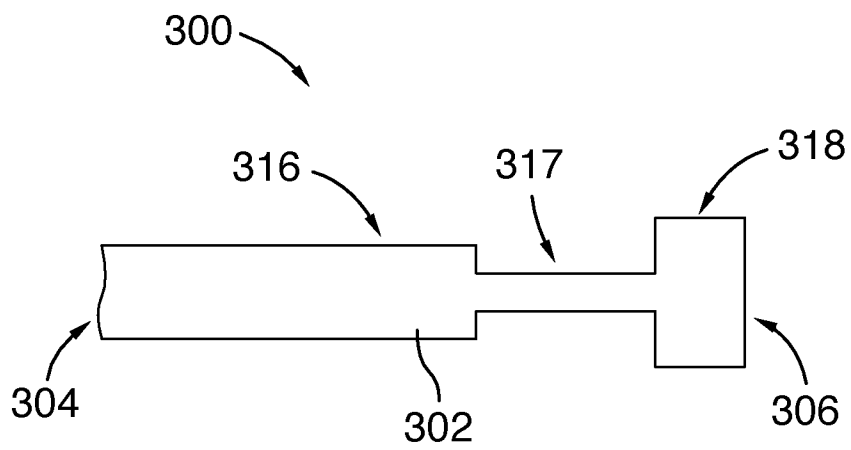


FIG. 7

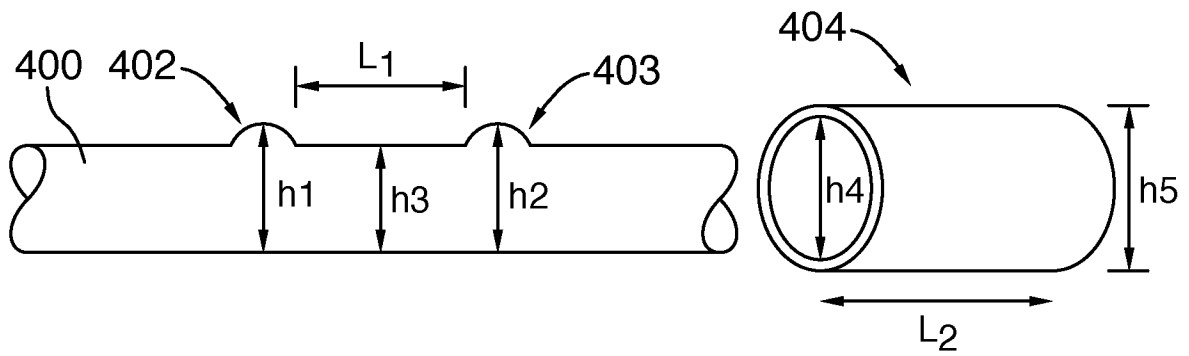


FIG. 8

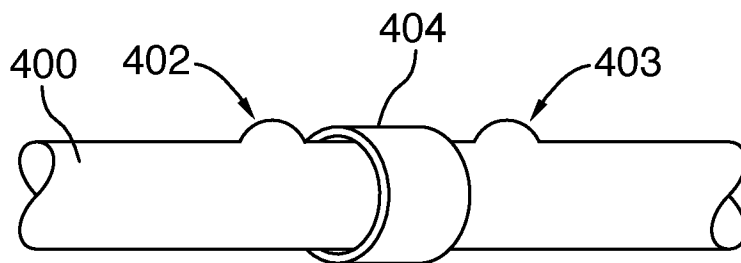


FIG. 9

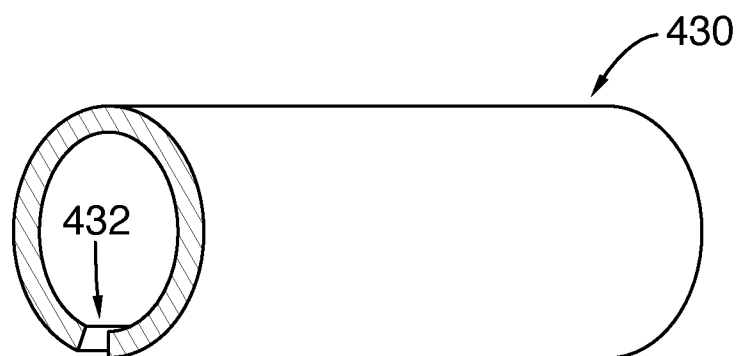


FIG. 10

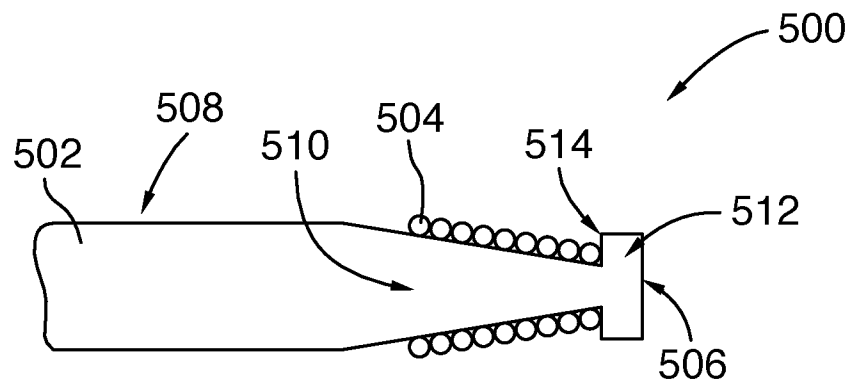


FIG.11

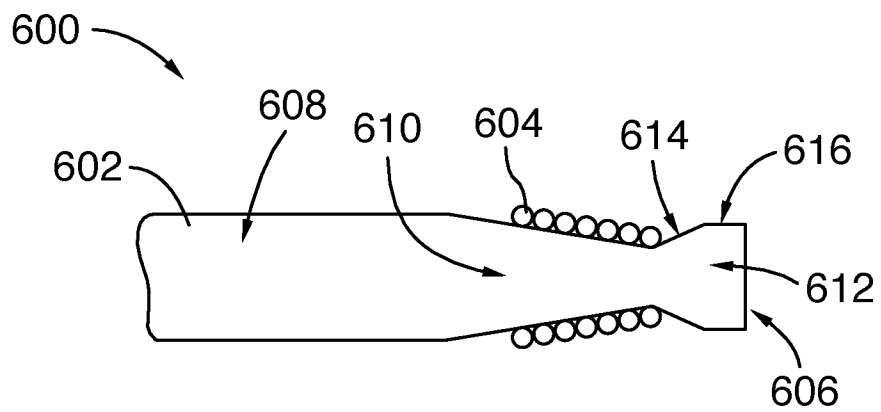


FIG.12

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2017/052387

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **B06B 3/00** (2006.01), **A61B 17/94** (2006.01), **A61B 6/12** (2006.01), **A61N 7/00** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: A61B, A61N, B06B

CPC: A61B 90/39

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)

Canadian Patent Database, Fampat (Orbit.com)

Keywords: mechanical waveguide, transmission member, radiopaque marker, acoustic, ultrasound, protrusion, bump, lump

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CA2251096 A1 (LEVIN et al.) 20 August 1998 (20-08-1998) - Description page 9, first paragraph - Description page 13, first paragraph - Description page 31, first paragraph - Claim 1 - Figures 1, 14, 29	1-3, 18, 19, 21, 22
Y	EP1985244 A2 (BALGOBIN et al.) 29 October 2008 (29-10-2008) - Paragraphs [0004], [0028] - Figure 1	18
Y	US5382228 (NITA et al.) 17 January 1995 (17-01-1995) - Abstract	19

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
17 July 2017 (17-07-2017)Date of mailing of the international search report
02 August 2017 (02-08-2017)Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
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50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 819-953-2476

Authorized officer

Philippe Perras (819) 639-3842

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2017/052387

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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