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(54) **BARREL ELECTRODES FOR A BASKET CATHETER, AND METHODS OF THE SAME**

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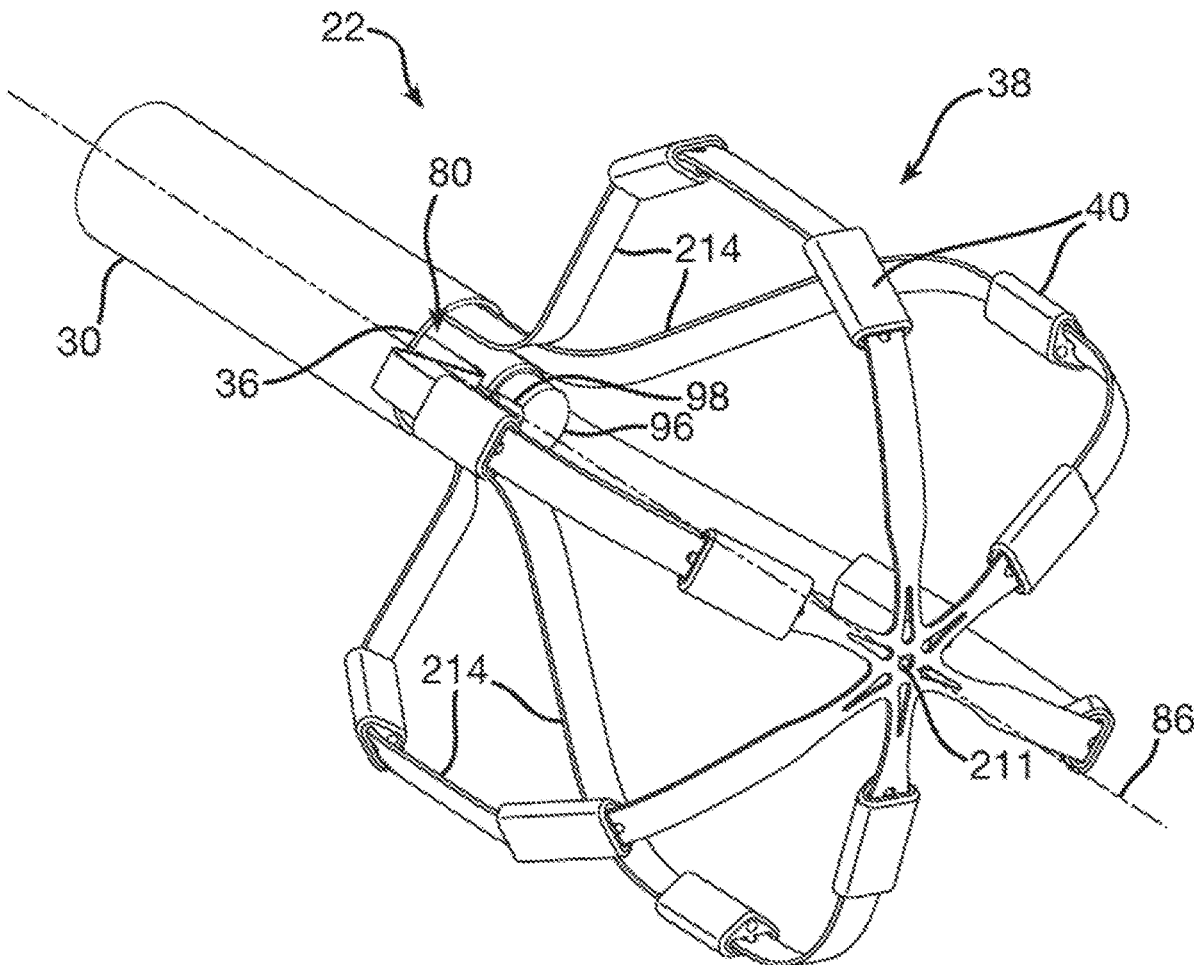
(57) **ABSTRACT**

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The disclosed technology includes an electrode for a medical probe having an elongated body. At least a portion of the elongated body can be electrically conductive. The elongated body can define a lumen that extends through the elongated body along a longitudinal axis of the elongated body. The electrode can include a locking stub that extends at least partially into the lumen so that the locking stub is locked to a member inserted into the lumen.

**Related U.S. Application Data**

(60) Provisional application No. 63/336,072, filed on Apr. 28, 2022.



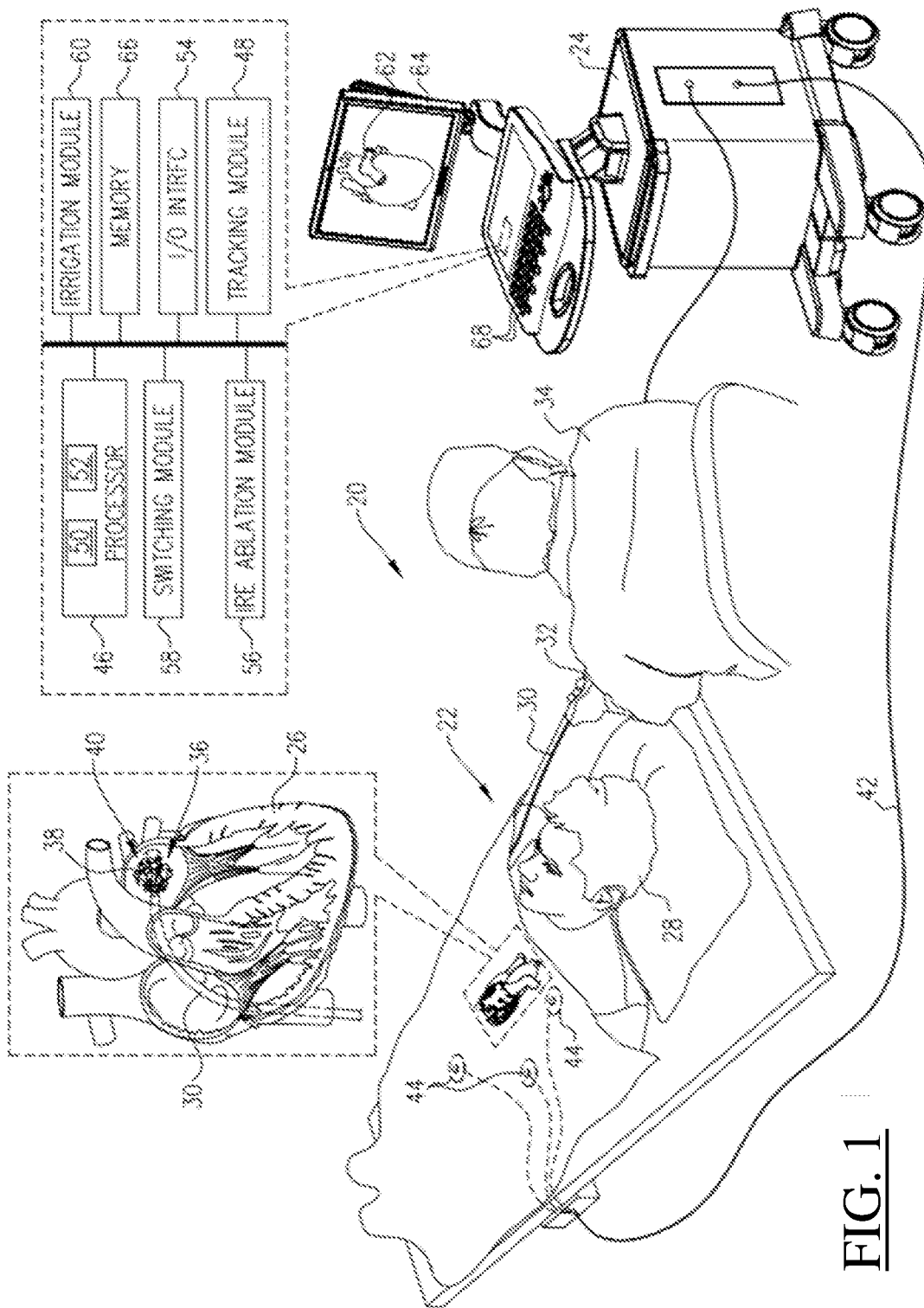


FIG. 1

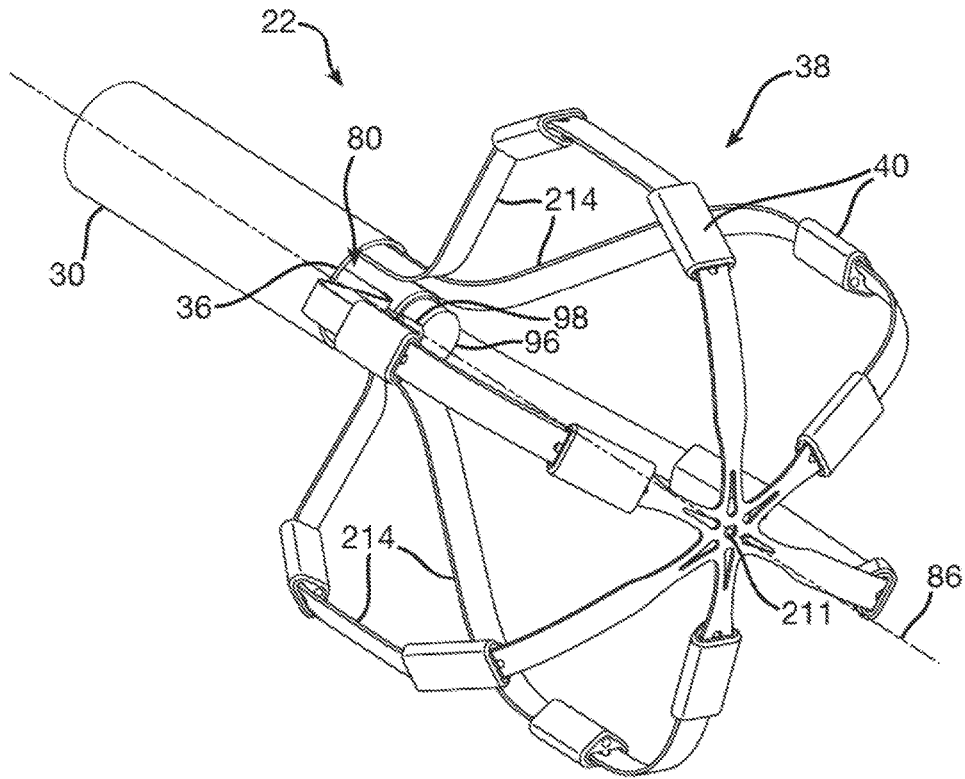


FIG. 2A

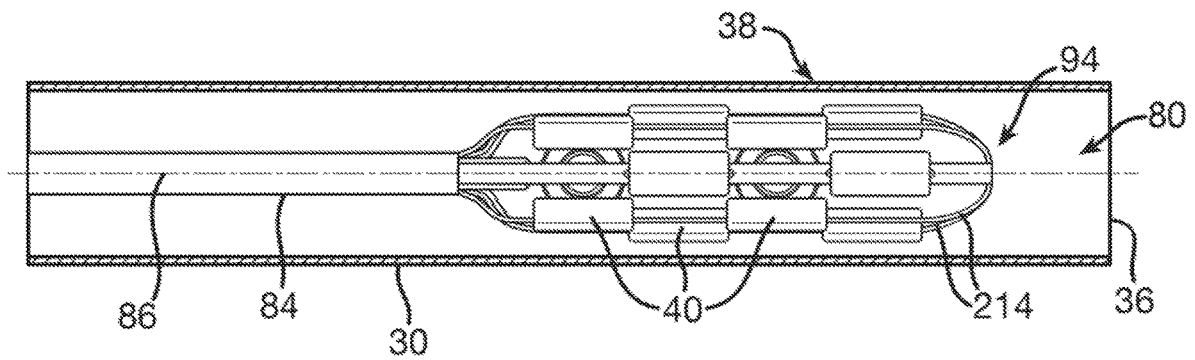
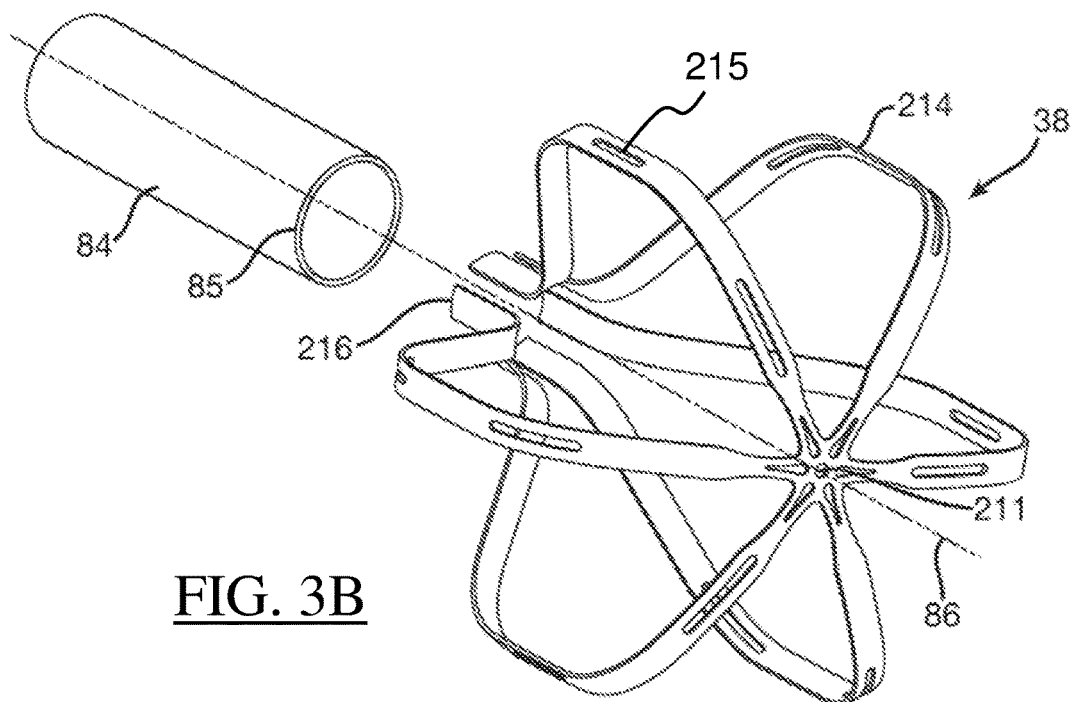
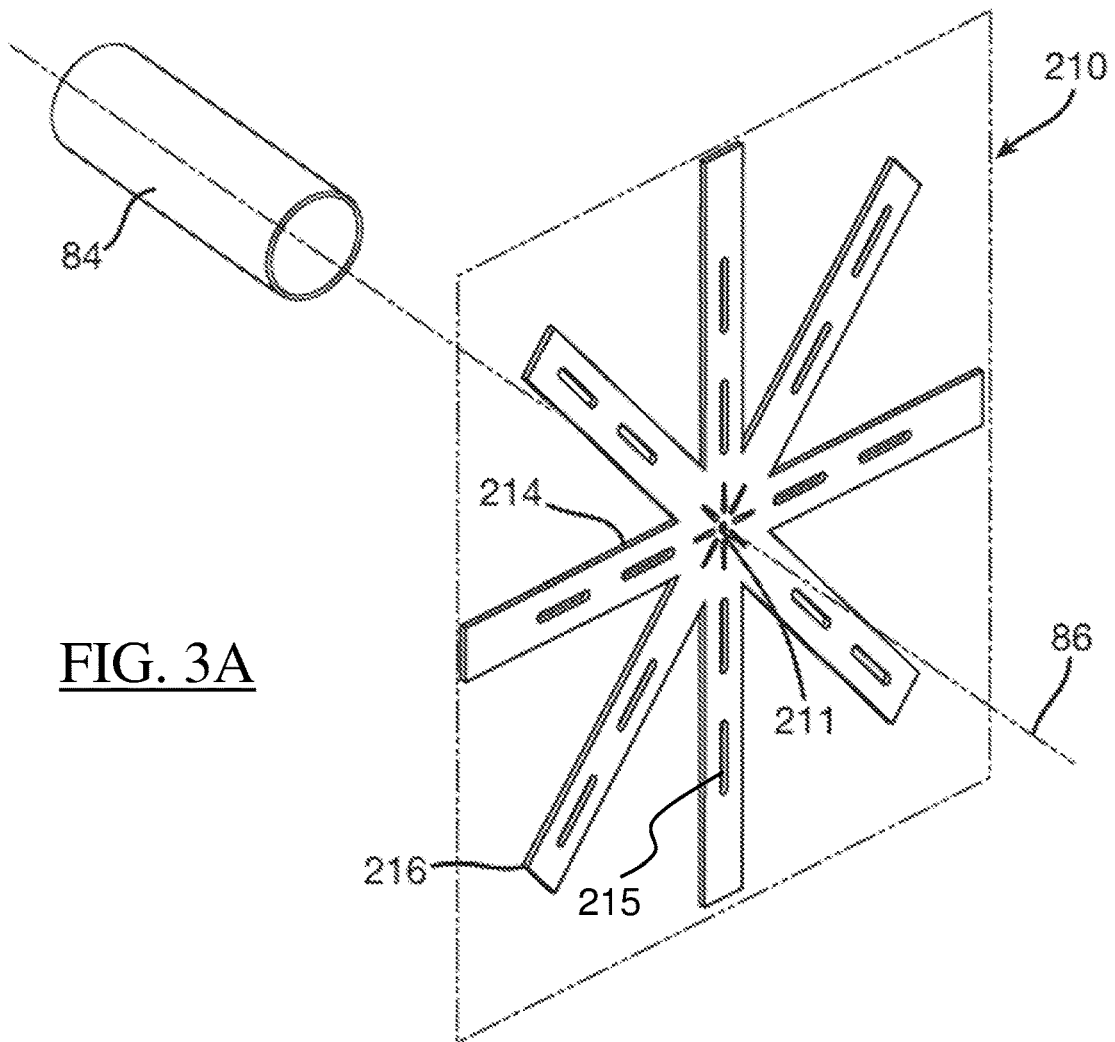


FIG. 2B



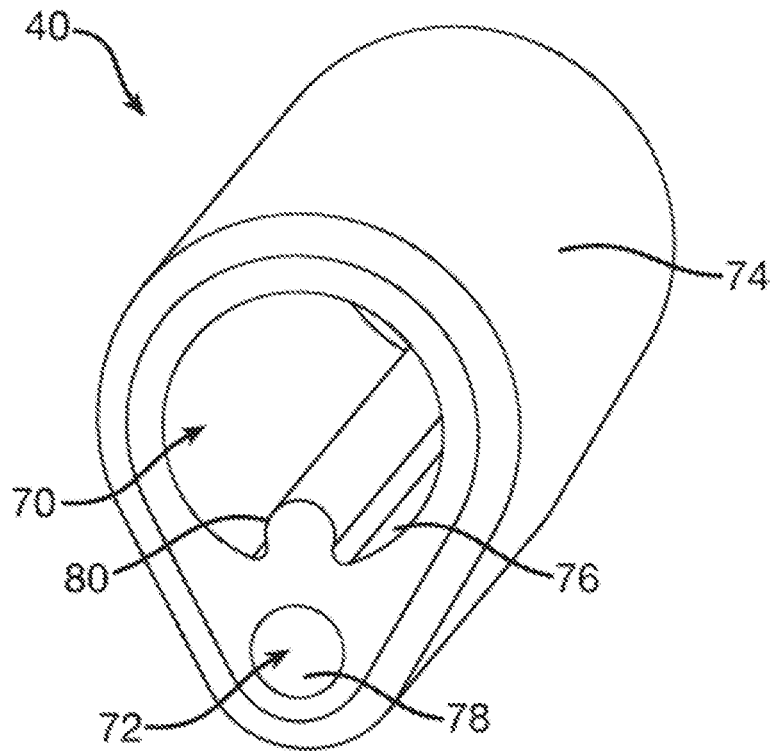


FIG. 4A

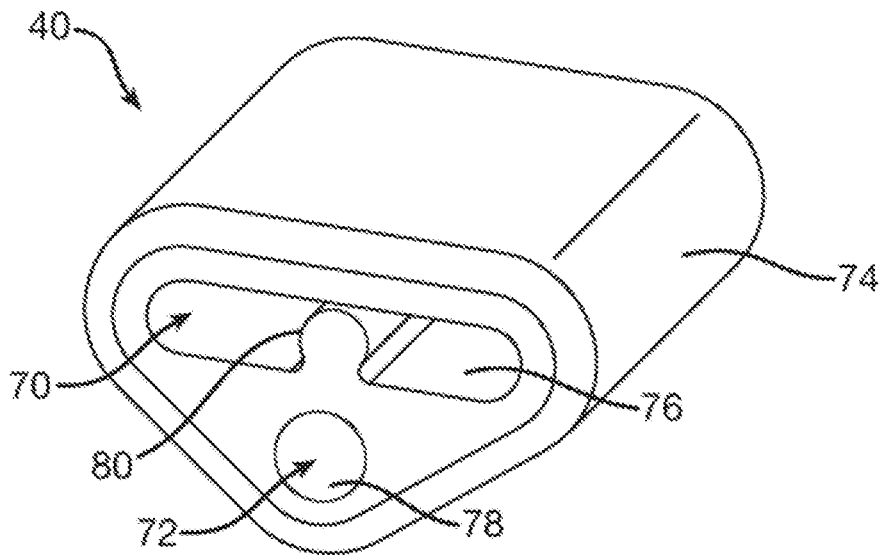


FIG. 4B

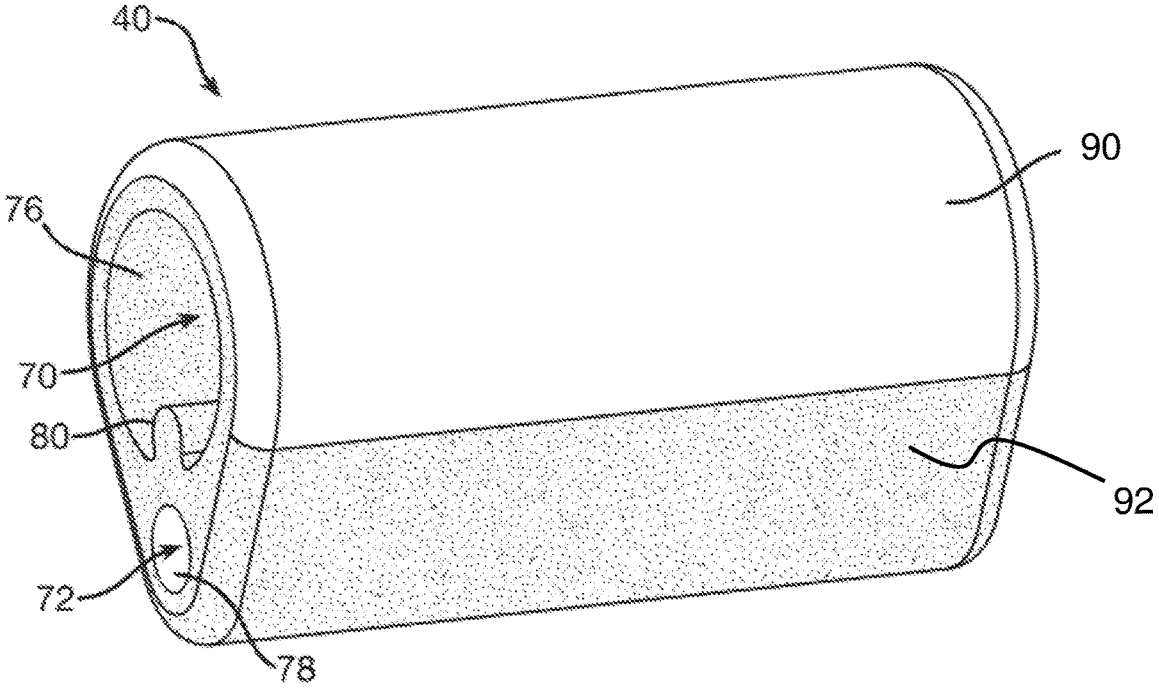


FIG. 5A

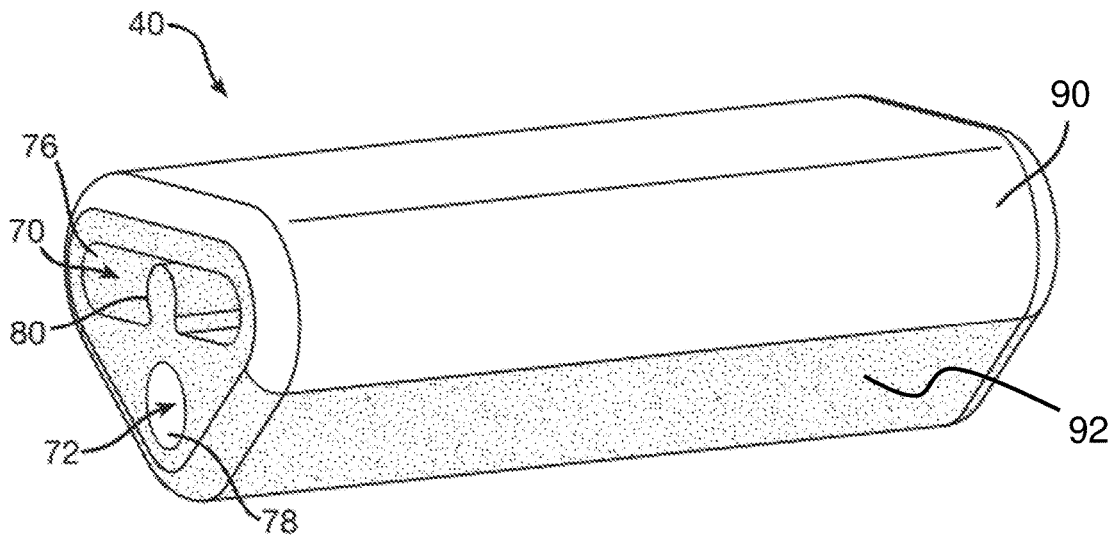
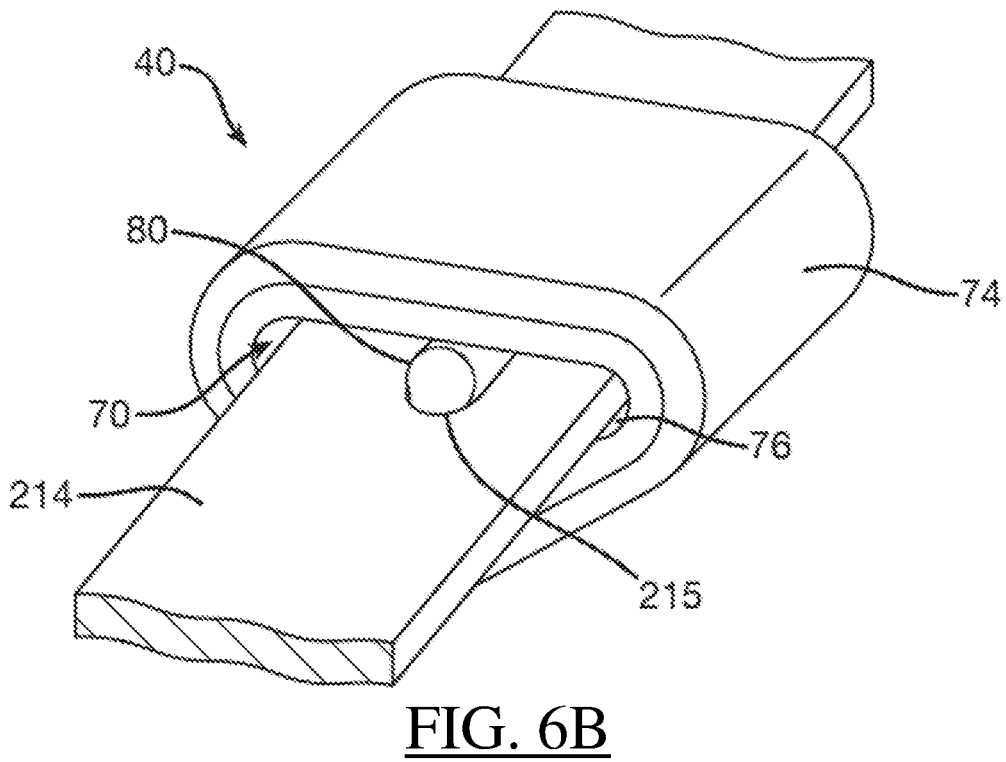
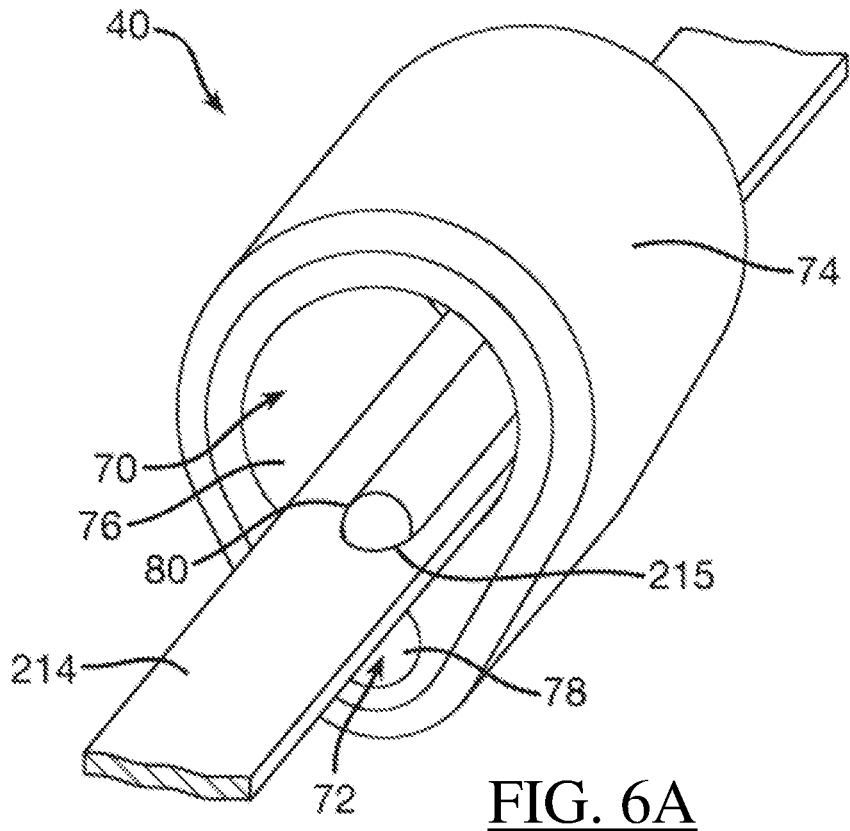


FIG. 5B



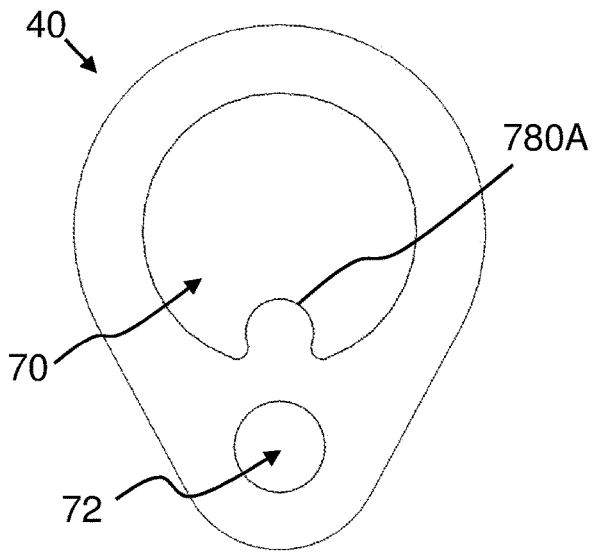


FIG. 7A

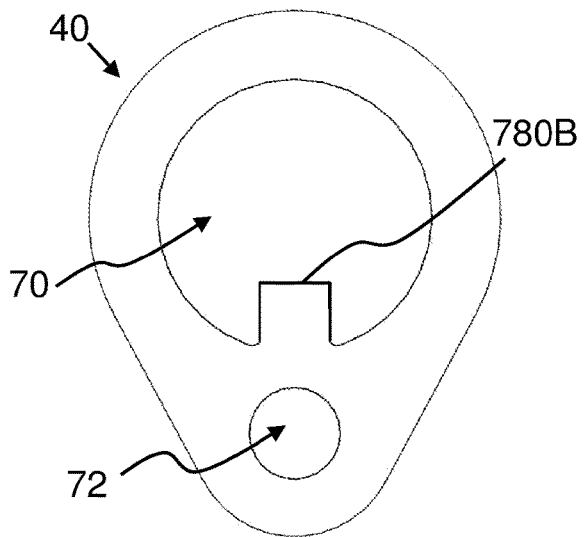


FIG. 7B

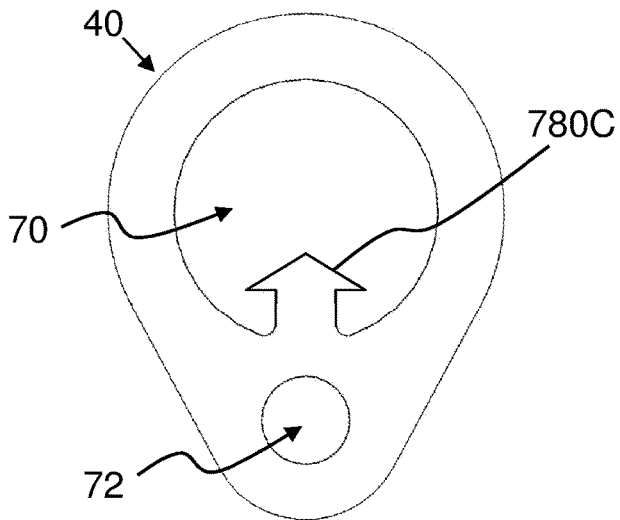


FIG. 7C



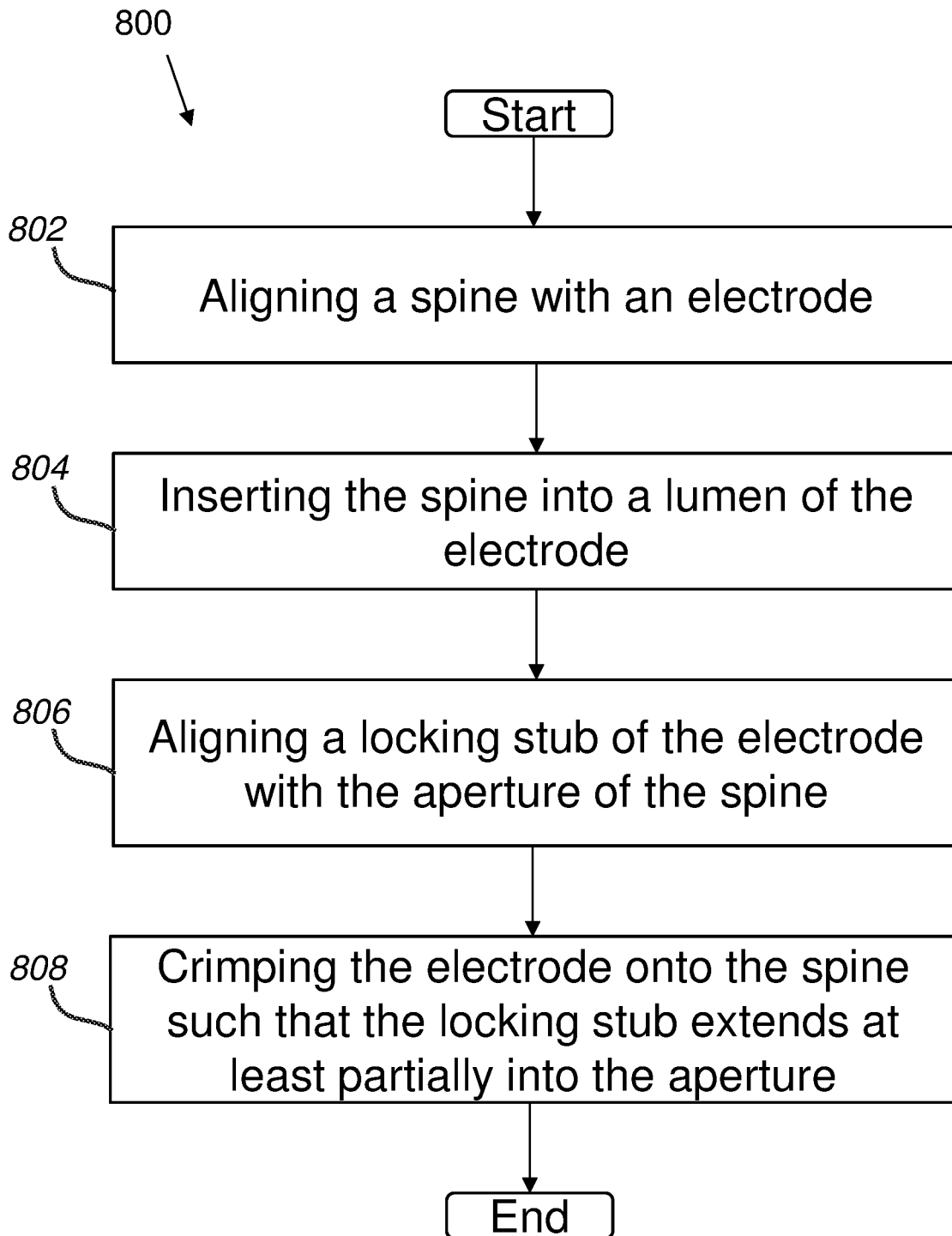


FIG. 8

## BARREL ELECTRODES FOR A BASKET CATHETER, AND METHODS OF THE SAME

### CLAIM OF PRIORITY

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 to U.S. Provisional Patent Application No. 63/336,072 filed on Apr. 28, 2022, which is hereby incorporated by reference as if set forth in full herein.

### FIELD

[0002] The present invention relates generally to medical devices, and in particular catheters with electrodes, and further relates to, but not exclusively, catheters suitable for use to induce irreversible electroporation (IRE) of cardiac tissues.

### BACKGROUND

[0003] Cardiac arrhythmias, such as atrial fibrillation (AF), occur when regions of cardiac tissue abnormally conduct electric signals to adjacent tissue. This disrupts the normal cardiac cycle and causes asynchronous rhythm. Certain procedures exist for treating arrhythmia, including surgically disrupting the origin of the signals causing the arrhythmia and disrupting the conducting pathway for such signals. By selectively ablating cardiac tissue by application of energy via a catheter, it is sometimes possible to cease or modify the propagation of unwanted electrical signals from one portion of the heart to another.

[0004] Many current ablation approaches in the art utilize radiofrequency (RF) electrical energy to heat tissue. RF ablation can have certain risks related to thermal heating which can lead to tissue charring, burning, steam pop, phrenic nerve palsy, pulmonary vein stenosis, and esophageal fistula.

[0005] Cryoablation is an alternative approach to RF ablation that generally reduces thermal risks associated with RF ablation. Maneuvering cryoablation devices and selectively applying cryoablation, however, is generally more challenging compared to RF ablation; therefore cryoablation is not viable in certain anatomical geometries which may be reached by electrical ablation devices.

[0006] Some ablation approaches use irreversible electroporation (IRE) to ablate cardiac tissue using nonthermal ablation methods. IRE delivers short pulses of high voltage to tissues and generates an unrecoverable permeabilization of cell membranes. Delivery of IRE energy to tissues using multi-electrode catheters was previously proposed in the patent literature. Examples of systems and devices configured for IRE ablation are disclosed in U.S. Patent Pub. No. 2021/0161592A1, 2021/0169550A1, 2021/0169567A1, 2021/0169568A1, 2021/0177503A1, 2021/0186604A1 and 2021/0196372A1, each of which is incorporated by reference in its entirety into this application as if set forth in full and is attached in the appendix to priority application U.S. 63/336,072.

[0007] Regions of cardiac tissue can be mapped by a catheter to identify the abnormal electrical signals. The same or different catheter can be used to perform ablation. Some example catheters include a number of spines with electrodes positioned thereon. The electrodes are generally attached to the spines and secured in place by soldering, welding, or using an adhesive. Due to the small size of the spines and the electrodes, however, soldering, welding, or

adhering the electrodes to the spines can be a difficult task, increasing the manufacturing time and cost and the chances that the electrode fails due to an improper bond or misalignment. What is needed, therefore, are systems and methods of attaching an electrode to a spine of a basket assembly without the need for soldering, welding, or using adhesive.

### SUMMARY

[0008] There is provided, in accordance with an example of the present invention, an electrode for a medical probe having an elongated body. At least a portion of the elongated body can be electrically conductive. The elongated body can define a lumen that extends through the elongated body along a longitudinal axis of the elongated body. The electrode can include a locking stub that extends at least partially into the lumen so that the locking stub is locked to a member inserted into the lumen. In this way, the presently disclosed technology can be used to secure the electrodes to the spines without requiring solder, weld, or adhesives.

[0009] The electrode can be crimped towards the longitudinal axis. The electrode can include a substantially rounded outer surface prior to being crimped and a substantially flat outer surface after being crimped.

[0010] The locking stub can have a substantially rounded cross section, a substantially rectangular cross section, and/or at least a portion of the locking stub can include a substantially triangular cross section.

[0011] The locking stub can extend a length of the elongated body.

[0012] The elongated body can further include an insulative material that can be configured to electrically isolate the electrode from the member inserted into the lumen.

[0013] The lumen can be a first lumen and the elongated body can further define a second lumen configured to receive a wire. The wire can be electrically coupled to the electrode.

[0014] There is provided, in accordance with another example of the present invention, a medical probe. The medical probe can include a tubular shaft having a proximal end and a distal end. The tubular shaft can extend along a longitudinal axis. The medical probe can include an expandable basket assembly coupled to the distal end of the tubular shaft.

[0015] The expandable basket assembly can include a plurality of electrodes. Each electrode of the plurality of electrodes can define a lumen extending therethrough and a locking stub extending at least partially into the lumen.

[0016] The expandable basket assembly can include a plurality of spines extending along the longitudinal axis and configured to bow radially outward from the longitudinal axis when the expandable basket assembly is transitioned from a collapsed form to an expanded form. Each spine of the plurality of spines can pass through a lumen of an electrode of the plurality of electrodes. Each spine of the plurality of spines can define an aperture that extends therethrough from a first side of the spine to a second side of the spine. The aperture can be configured to receive the locking stub of the electrode such that when the electrode is mechanically coupled to the spine, the locking stub extends through the aperture preventing the electrode from sliding distally or proximally along the spine.

[0017] Each electrode of the plurality of electrodes can be crimped to the spine. Each electrode of the plurality of electrodes can have a substantially rounded outer surface

prior to being crimped to the spine and a substantially flat outer surface after being crimped to the spine.

**[0018]** The locking stub can have a substantially rounded cross section, a substantially rectangular cross section, and/or at least a portion of the locking stub can include a substantially triangular cross section.

**[0019]** Each electrode can include an insulative material that can be configured to electrically isolate the electrode from the spine. Alternatively, or in addition, each spine can include an insulative material and/or an insulative material can be disposed between the electrode and the spine to electrically isolate the electrode from the spine.

**[0020]** The lumen of each electrode can be a first lumen and each electrode can further define a second lumen that is configured to receive a wire of the medical probe. The wire can be electrically coupled to the electrode. The wire can be insulated from the spine.

**[0021]** Each spine can include a first electrode and a second electrode both mechanically coupled to the spine. The spine can define a first aperture configured to receive a locking stub of the first electrode and a second aperture configured to receive a locking stub of the second electrode. The first and second apertures can be configured to prevent the first and second electrodes from sliding proximally or distally along a length of the spine when the first and second electrodes are mechanically coupled to the spine, respectively. An interface between the locking stub of the electrode and the spine at the aperture can include an interference fitting.

**[0022]** The spine can include a material selected from a group consisting of nitinol, cobalt chromium, stainless steel, titanium and combinations thereof. Alternatively, or in addition, the spine can include a polymer material.

**[0023]** The plurality of electrodes can be configured to deliver electrical pulses for irreversible electroporation. The pulses can have a peak voltage of at least 900 volts (V). The plurality of electrodes can be configured for mapping electrophysiological characteristics of cardiac tissue.

**[0024]** The medical probe can include spray ports that can be configured to deliver an irrigation fluid to the plurality of electrodes.

**[0025]** The disclosed technology can include a method of constructing a medical probe. The method can include aligning a spine of an expandable basket assembly with an electrode of the expandable basket assembly. The spine can include a proximal end, a distal end, and define an aperture extending therethrough. The method can include inserting the spine into a lumen of the electrode and aligning a locking stub of the electrode with the aperture. The method can include crimping the electrode onto the spine such that the locking stub extends at least partially into the aperture to prevent the electrode from sliding proximally or distally along the spine.

**[0026]** The electrode can have a substantially rounded outer surface prior to being crimped to the spine and a substantially flat outer surface after being crimped to the spine.

**[0027]** The locking stub can have a substantially rounded cross section, a substantially rectangular cross section, and/or at least a portion of the locking stub can include a substantially triangular cross section.

**[0028]** The electrode can include an insulative material configured to electrically isolate the electrode from the spine. Alternatively, or in addition, the spine can include an

insulative material or an insulative material can be disposed between the electrode and the spine to electrically isolate the electrode from the spine.

**[0029]** The lumen can be a first lumen and the method can further include aligning a wire of the medical probe with a second lumen of the electrode, inserting the wire into the second lumen, and coupling the wire to the electrode such that the wire is in electrical communication with the electrode. The wire can be insulated from the spine.

**[0030]** An interface between the locking stub of the electrode and the spine at the aperture can be an interference fitting. The spine can be a material selected from a group consisting of nitinol, cobalt chromium, stainless steel, titanium. Alternatively, or in addition, the spine can include a polymer material.

**[0031]** The aperture of the spine can be a first aperture. The spine can further define a second aperture. The method can further include aligning the spine with a second electrode of the expandable basket assembly, inserting the spine into a lumen of the second electrode, aligning a locking stub of the second electrode with the second aperture, and crimping the second electrode onto the spine such that the locking stub extends at least partially into the second aperture to prevent the second electrode from sliding proximally or distally along the spine.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0032]** FIG. 1 is a schematic pictorial illustration of a medical system including a medical probe whose distal end includes a basket assembly with electrodes, in accordance with an embodiment of the present invention;

**[0033]** FIG. 2A is a schematic pictorial illustration showing a perspective view of a medical probe in an expanded form, in accordance with an embodiment of the present invention;

**[0034]** FIG. 2B is a schematic pictorial illustration showing a side view of a medical probe in a collapsed form, in accordance with the disclosed technology;

**[0035]** FIGS. 3A and 3B are schematic pictorial illustrations showing exploded views of a tubular shaft and spines of the basket assembly to illustrate how the spines can be assembled together with the tubular shaft, in accordance with an embodiment of the present invention;

**[0036]** FIG. 4A is a schematic pictorial illustration showing a front perspective view of an electrode before being crimped while FIG. 4B is a schematic pictorial illustration showing a front perspective view of an electrode after being crimped, in accordance with an embodiment of the present invention;

**[0037]** FIG. 5A is a schematic pictorial illustration showing a side perspective view of an electrode before being crimped while FIG. 5B is a schematic pictorial illustration showing a side perspective view of an electrode after being crimped, in accordance with an embodiment of the present invention;

**[0038]** FIG. 6A is a schematic pictorial illustration showing a front perspective view of an electrode and a spine before the electrode is crimped to the spine while FIG. 6B is a schematic pictorial illustration showing a front perspective view of an electrode and a spine after the electrode is crimped to the spine, in accordance with an embodiment of the present invention;

**[0039]** FIGS. 7A-7C illustrate side views of electrodes, in accordance with embodiments of the present invention; and

[0040] FIG. 8 is a flowchart illustrating a method of constructing a medical probe, in accordance with embodiments of the present disclosure.

#### DETAILED DESCRIPTION

[0041] The following detailed description should be read with reference to the drawings, in which like elements in different drawings are identically numbered. The drawings, which are not necessarily to scale, depict selected embodiments and are not intended to limit the scope of the invention. The detailed description illustrates by way of example, not by way of limitation, the principles of the invention. This description will clearly enable one skilled in the art to make and use the invention, and describes several embodiments, adaptations, variations, alternatives and uses of the invention, including what is presently believed to be the best mode of carrying out the invention.

[0042] As used herein, the terms “about” or “approximately” for any numerical values or ranges indicate a suitable dimensional tolerance that allows the part or collection of components to function for its intended purpose as described herein. More specifically, “about” or “approximately” may refer to the range of values  $\pm 10\%$  of the recited value, e.g. “about 90%” may refer to the range of values from 81% to 99%. In addition, as used herein, the terms “patient,” “host,” “user,” and “subject” refer to any human or animal subject and are not intended to limit the systems or methods to human use, although use of the subject invention in a human patient represents a preferred embodiment. As well, the term “proximal” indicates a location closer to the operator or physician whereas “distal” indicates a location further away to the operator or physician.

[0043] As discussed herein, vasculature of a “patient,” “host,” “user,” and “subject” can be vasculature of a human or any animal. It should be appreciated that an animal can be a variety of any applicable type, including, but not limited thereto, mammal, veterinarian animal, livestock animal or pet type animal, etc. As an example, the animal can be a laboratory animal specifically selected to have certain characteristics similar to a human (e.g., rat, dog, pig, monkey, or the like). It should be appreciated that the subject can be any applicable human patient, for example.

[0044] As discussed herein, “operator” can include a doctor, surgeon, technician, scientist, or any other individual or delivery instrumentation associated with delivery of a multi-electrode catheter for the treatment of drug refractory atrial fibrillation to a subject.

[0045] As discussed herein, the term “ablate” or “ablation”, as it relates to the devices and corresponding systems of this disclosure, refers to components and structural features configured to reduce or prevent the generation of erratic cardiac signals in the cells by utilizing non-thermal energy, such as irreversible electroporation (IRE), sometimes referred to interchangeably as pulsed electric field (PEF) and pulsed field ablation (PFA). Ablating or ablation as it relates to the devices and corresponding systems of this disclosure is used throughout this disclosure in reference to non-thermal ablation of cardiac tissue for certain conditions including, but not limited to, arrhythmias, atrial flutter ablation, pulmonary vein isolation, supraventricular tachycardia ablation, and ventricular tachycardia ablation. The term “ablate” or “ablation” also includes known methods,

devices, and systems to achieve various forms of bodily tissue ablation as understood by a person skilled in the relevant art.

[0046] As discussed herein, the terms “bipolar” and “unipolar” when used to refer to ablation schemes describe ablation schemes which differ with respect to electrical current path and electric field distribution. “Bipolar” refers to ablation scheme utilizing a current path between two electrodes that are both positioned at a treatment site; current density and electric flux density is typically approximately equal at each of the two electrodes. “Unipolar” refers to ablation scheme utilizing a current path between two electrodes where one electrode having a high current density and high electric flux density is positioned at a treatment site, and a second electrode having comparatively lower current density and lower electric flux density is positioned remotely from the treatment site.

[0047] As discussed herein, the terms “tubular” and “tube” are to be construed broadly and are not limited to a structure that is a right cylinder or strictly circumferential in cross-section or of a uniform cross-section throughout its length. For example, the tubular structures are generally illustrated as a substantially right cylindrical structure. However, the tubular structures may have a tapered or curved outer surface without departing from the scope of the present disclosure.

[0048] The present disclosure is related to systems, method or uses and devices for IRE ablation of cardiac tissue to treat cardiac arrhythmias. Ablative energies are typically provided to cardiac tissue by a tip portion of a catheter which can deliver ablative energy alongside the tissue to be ablated. Some example catheters include three-dimensional structures at the tip portion and are configured to administer ablative energy from various electrodes positioned on the three-dimensional structures. Ablative procedures incorporating such example catheters can be visualized using fluoroscopy.

[0049] Ablation of cardiac tissue using application of a thermal technique, such as radio frequency (RF) energy and cryoablation, to correct a malfunctioning heart is a well-known procedure. Typically, to successfully ablate using a thermal technique, cardiac electropotentials need to be measured at various locations of the myocardium. In addition, temperature measurements during ablation provide data enabling the efficacy of the ablation. Typically, for an ablation procedure using a thermal technique, the electropotentials and the temperatures are measured before, during, and after the actual ablation. RF approaches can have risks that can lead to tissue charring, burning, steam pop, phrenic nerve palsy, pulmonary vein stenosis, and esophageal fistula. Cryoablation is an alternative approach to RF ablation that can reduce some thermal risks associated with RF ablation. However maneuvering cryoablation devices and selectively applying cryoablation is generally more challenging compared to RF ablation; therefore cryoablation is not viable in certain anatomical geometries which may be reached by electrical ablation devices.

[0050] While RF ablation and cryoablation, are based on thermal energy transfer to induce local tissue necrosis, the solution of this disclosure can resolve these and other problems by utilizing irreversible electroporation (IRE), sometimes referred to interchangeably as pulsed electric field (PEF) ablation and pulsed field ablation (PFA). IRE as discussed in this disclosure is a non-thermal cell death

technology that can be used for ablation of atrial arrhythmias. To ablate using IRE/PEF, biphasic voltage pulses are applied to disrupt cellular structures of myocardium. The biphasic pulses are non-sinusoidal and can be tuned to target cells based on electrophysiology of the cells. In contrast, to ablate using RF, a sinusoidal voltage waveform is applied to produce heat at the treatment area, indiscriminately heating all cells in the treatment area. IRE therefore has the capability to spare adjacent heat sensitive structures or tissues which would be of benefit in the reduction of possible complications known with ablation or isolation modalities. Additionally, or alternatively, monophasic pulses can be utilized.

[0051] Electroporation can be induced by applying a pulsed electric field across biological cells to cause reversible (temporary) or irreversible (permanent) creation of pores in the cell membrane. The cells have a transmembrane electrostatic potential that is increased above a resting potential upon application of the pulsed electric field. While the transmembrane electrostatic potential remains below a threshold potential, the electroporation is reversible, meaning the pores can close when the applied pulse electric field is removed, and the cells can self-repair and survive. If the transmembrane electrostatic potential increases beyond the threshold potential, the electroporation is irreversible, and the cells become permanently permeable. As a result, the cells die due to a loss of homeostasis and typically die by apoptosis. Generally, cells of differing types have differing threshold potential. For instance, heart cells have a threshold potential of approximately 500 V/cm, whereas for bone it is 3000 V/cm. These differences in threshold potential allow IRE to selectively target tissue based on threshold potential.

[0052] The solution of this disclosure includes systems and methods for applying electrical signals from catheter electrodes positioned in the vicinity of myocardial tissue to generate a pulsed electric field effective to induce electroporation in the myocardial tissue. The systems and methods can be effective to ablate targeted tissue by inducing irreversible electroporation. In some examples, the systems and methods can be effective to induce reversible electroporation as part of a diagnostic procedure. Reversible electroporation occurs when the electricity applied with the electrodes is below the electric field threshold of the target tissue allowing cells to repair. Reversible electroporation does not kill the cells but allows a physician to see the effect of reversible electroporation on electrical activation signals in the vicinity of the target location. Example systems and methods for reversible electroporation is disclosed in U.S. Patent Publication 2021/0162210, the entirety of which is incorporated by reference in its entirety into this application as if set forth in full and is attached in the appendix to priority application U.S. 63/336,072.

[0053] The pulsed electric field, and its effectiveness to induce reversible and/or irreversible electroporation, can be affected by physical parameters of the system and biphasic pulse parameters of the electrical signal. Physical parameters can include electrode contact area, electrode spacing, electrode geometry, etc. examples presented herein generally include physical parameters adapted to effectively induce reversible and/or irreversible electroporation. Biphasic pulse parameters of the electrical signal can include voltage amplitude, pulse duration, pulse interphase delay, inter-pulse delay, total application time, delivered energy, etc. In some examples, parameters of the electrical signal

can be adjusted to induce both reversible and irreversible electroporation given the same physical parameters. Examples of various systems and methods of ablation including IRE are presented in U.S. Patent Publications 2021/0161592A1, 2021/0169550A1, 2021/0169567A1, 2021/0169568A1, 2021/0177503A1, 2021/0186604A1 and 2021/0196372A1, each of which is incorporated by reference in its entirety into this application as if set forth in full and is attached in the appendix to priority application U.S. 63/336,072.

[0054] To deliver pulsed field ablation (PFA) in an IRE (irreversible electroporation) procedure, electrodes should contact the tissue being ablated with a sufficiently large surface area. As described hereinbelow, the medical probe includes a flexible insertion tube having proximal and distal ends, and a basket assembly at the distal end of the flexible insertion tube.

[0055] The basket assembly includes at least one spine and a plurality of electrodes, each given electrode having a lumen therethrough fitting a given spine. The electrodes are crimped to the spine and locked in place with a locking stub to prevent the electrodes from sliding proximally or distally along the length of the spine.

[0056] FIG. 1 is a schematic, pictorial illustration of a medical system 20 including a medical probe 22 and a control console 24, in accordance with an embodiment of the present invention. Medical system 20 may be based, for example, on the CARTO® system, produced by Biosense Webster Inc. of 31 Technology Drive, Suite 200, Irvine, CA 92618 USA. In embodiments described hereinbelow, medical probe 22 can be used for diagnostic or therapeutic treatment, such as for performing ablation procedures in a heart 26 of a patient 28. Alternatively, medical probe 22 may be used, mutatis mutandis, for other therapeutic and/or diagnostic purposes in the heart or in other body organs.

[0057] Medical probe 22 includes a flexible insertion tube 30 and a handle 32 coupled to a proximal end of the insertion tube. During a medical procedure, a medical professional 34 can insert probe 22 through the vascular system of patient 28 so that a distal end 36 of the medical probe enters a body cavity such as a chamber of heart 26. Upon distal end 36 entering the chamber of heart 26, medical professional 34 can deploy a basket assembly 38 affixed to distal end 36. Basket assembly 38 can include a plurality of electrodes 40 affixed to a plurality of spines, as described in the description referencing FIGS. 2A and 2B hereinbelow. To start performing a medical procedure such as irreversible electroporation (IRE) ablation, medical professional 34 can manipulate handle 32 to position distal end 36 so that electrodes 40 engage cardiac tissue at a desired location or locations. Upon positioning the distal end 36 so that electrodes 40 can engage cardiac tissue, the medical professional 34 can activate the medical probe 22 such that electrical pulses are delivered by the electrodes 40 to perform the IRE ablation.

[0058] In the configuration shown in FIG. 1, control console 24 is connected, by a cable 42, to body surface electrodes, which typically include adhesive skin patches 44 that are affixed to patient 28. Control console 24 includes a processor 46 that, in conjunction with a tracking module 48, determines location coordinates of distal end 36 inside heart 26. Location coordinates can be determined based on electromagnetic position sensor output signals provided from the distal portion of the catheter when in the presence of a generated magnetic field. Location coordinates can addition-

ally, or alternatively be based on impedances and/or currents measured between adhesive skin patches 44 and electrodes 40 that are affixed to basket assembly 38. In addition to being used as location sensors during a medical procedure, electrodes 40 may perform other tasks such as ablating tissue in the heart.

[0059] As described hereinabove, in conjunction with tracking module 48, processor 46 may determine location coordinates of distal end 36 inside heart 26 based on impedances and/or currents measured between adhesive skin patches 44 and electrodes 40. Such a determination is typically after a calibration process relating the impedances or currents to known locations of the distal end has been performed. While embodiments presented herein describe electrodes 40 that are (also) configured to deliver IRE ablation energy to tissue in heart 26, configuring electrodes 40 to deliver any other type of ablation energy to tissue in any body cavity is considered to be within the spirit and scope of the present invention. Furthermore, although described in the context of being electrodes 40 that are configured to deliver IRE ablation energy to tissue in the heart 26, one skilled in the art will appreciate that the disclosed technology can be applicable to electrodes used for mapping and/or determining various characteristics of an organ or other part of the patient's 28 body.

[0060] Processor 46 may include real-time noise reduction circuitry 50 typically configured as a field programmable gate array (FPGA), followed by an analog-to-digital (A/D) signal conversion integrated circuit 52. The processor can be programmed to perform one or more algorithms and uses circuitry 50 and circuit 52 as well as features of modules to enable the medical professional 34 to perform the IRE ablation procedure.

[0061] Control console 24 also includes an input/output (I/O) communications interface 54 that enables control console 24 to transfer signals from, and/or transfer signals to electrodes 40 and adhesive skin patches 44. In the configuration shown in FIG. 1, control console 24 additionally includes an IRE ablation module 56 and a switching module 58.

[0062] IRE ablation module 56 is configured to generate IRE pulses having peak power in the range of tens of kilowatts. In some examples, the electrodes 40 are configured to deliver electrical pulses having a peak voltage of at least 900 volts (V). The medical system 20 performs IRE ablation by delivering IRE pulses to electrodes 40. Preferably, the medical system 20 delivers biphasic pulses between electrodes 40 on the spine. Additionally, or alternatively, the medical system 20 delivers monophasic pulses between at least one of the electrodes 40 and a skin patch.

[0063] In order to dissipate the heat and to improve the efficiency of the ablation process, system 20 supplies irrigation fluid (e.g., a saline solution) to distal end 36 via a channel (not shown) in insertion tube 30. Control console 24 includes an irrigation module 60 to monitor and control irrigation parameters, such as the pressure and the temperature of the irrigation fluid.

[0064] Based on signals received from electrodes 40 and/or adhesive skin patches 44, processor 46 can generate an electroanatomical map 62 that shows the location of distal end 36 in the patient's body. During the procedure, processor 46 can present map 62 to medical professional 34 on a display 64, and store data representing the electroanatomical map in a memory 66. Memory 66 may include any suitable

volatile and/or non-volatile memory, such as random-access memory or a hard disk drive.

[0065] In some embodiments, medical professional 34 can manipulate map 62 using one or more input devices 68. In alternative embodiments, display 64 may include a touch-screen that can be configured to accept inputs from medical professional 34, in addition to presenting map 62.

[0066] FIG. 2A is a schematic pictorial illustration showing a perspective view of a medical probe 22 having a basket assembly 38 in an expanded form when unconstrained, such as by being advanced out of an insertion tube lumen 80 at a distal end 36 of an insertion tube 30. FIG. 2B shows the basket assembly in a collapsed form within insertion tube 30. In the expanded form (FIG. 2A), the spines 214 bow radially outwardly from a longitudinal axis 86 of the medical probe 22 and in the collapsed form (FIG. 2B) the spines are arranged generally along the longitudinal axis 86 of the medical probe 22.

[0067] As shown in FIG. 2A, basket assembly 38 includes a plurality of flexible spines 214 that are formed at the end of a tubular shaft 84 and are connected at both ends. During a medical procedure, medical professional 34 can deploy basket assembly 38 by extending tubular shaft 84 from insertion tube 30 causing the basket assembly 38 to exit the insertion tube and transition to the expanded form. Spines 214 may have elliptical (e.g., circular) or rectangular (that may appear to be flat) cross-sections, and include a flexible, resilient material (e.g., a shape-memory alloy such as nickel-titanium (also known as Nitinol), cobalt chromium, stainless steel, titanium, or any other suitable material or combinations of materials).

[0068] In embodiments described herein, electrodes 40 can be configured to deliver ablation energy (RF and/or IRE) to tissue in heart 26. For example, the electrodes 40 can be configured to deliver 20-30 amps of electrical current to cardiac tissue to facilitate ablation of the cardiac tissue. Furthermore, the electrodes 40 can be configured for bipolar or unipolar ablation schemes depending on the particular application. Alternatively, or in addition, the electrodes can be used to determine the location of basket assembly 38 and/or to measure a physiological property such as local surface electrical potentials at respective locations on tissue in heart 26.

[0069] Examples of materials ideally suited for forming electrodes 40 include gold, platinum, and palladium (and their respective alloys). These materials also have high thermal conductivity which allows the minimal heat generated on the tissue (i.e., by the ablation energy delivered to the tissue) to be conducted through the electrodes to the back side of the electrodes (i.e., the portions of the electrodes on the inner sides of the spines), and then to the blood pool in heart 26.

[0070] Basket assembly 38 has a distal end 94 and includes a stem 96 that extends longitudinally from a distal end 36 of shaft 84 towards distal end 94 of basket assembly 38. As described supra, control console 24 includes irrigation module 60 that delivers irrigation fluid to distal end 36. Stem 96 includes multiple spray ports 98, wherein each given spray port 98 can be angled to aim delivery of the irrigation fluid to either a given electrode 40 or to tissue in heart 26.

[0071] Since electrodes 40 do not include spray ports that deliver irrigation fluid, the configuration described hereinabove enables heat to be transferred from the tissue (i.e.,

during an ablation procedure) to the portion of the electrodes **40** on the inner side of the spines **214**, and the electrodes **40** can be cooled by aiming the irrigation fluid, via spray ports **98**, at the portion of the electrodes **40** on the inner side of the spines **214**.

[0072] FIGS. 3A and 3B are schematic pictorial illustrations showing exploded views of a tubular shaft **84** and spines **214** of the basket assembly **38** to provide one example of how the spines **214** can be assembled together with the tubular shaft **84**, in accordance with an embodiment of the present invention. As shown in FIG. 3A, the spines **214** can form a spine assembly **210**. The spines **214** can be formed from a single sheet of planar material to form a generally star shape. In other words, the spines **214** can be formed from the single sheet of planar material such that the spines **214** converge toward a central intersection **211**. The intersection **211** can be a solid piece of material or include one or more apertures.

[0073] The spines **214** can be folded or otherwise bent such that a proximal end **216** of the spines **214** can be inserted into the distal end **85** of the tubular shaft **84** as shown in FIG. 3B. Although not shown in FIGS. 3A and 3B, it will be appreciated that the electrodes **40** can be attached to the spines **214** before the spines are inserted into the tubular shaft **84** to form the basket assembly **38**. As stated previously, the spines **214** can include a flexible, resilient material (e.g., a shape-memory alloy such as nickel-titanium, also known as Nitinol) that can enable the basket assembly **38** to transition from its collapsed form (as shown in FIG. 2B) to its expanded form (as shown in FIG. 2A) when the basket assembly **38** is deployed from the insertion tube **30**.

[0074] The spines **214** can each define an aperture **215** that can be sized and positioned to receive a locking stub **80** of the electrode **40** as will be described in greater detail herein. By receiving the locking stub **80**, the aperture **215** can help to prevent the electrode **40** from sliding proximally or distally along the length of the spine **214**. In other words, the aperture **215** can help to secure the electrode **40** to the spine **214** when the locking stub **80** extends through the aperture **215**, without requiring a weld, a fastener, adhesive, or other fastening devices or methods. As a non-limiting example, the spines **214** can include at least two apertures **215** positioned on a length of the spine **214** between a proximal end of the spine **214** and a distal end of the spine **214**. In this way, the basket assembly **38** can have at least two electrodes **40** along each length of spine **214** extending between the proximal end to the distal end of the basket assembly **38** such that the basket assembly **38** can have a total of twelve electrodes.

[0075] As will be appreciated by one skilled in the art with the benefit of this disclosure, the basket assembly **38** shown in FIGS. 2A-3B having spines **214** formed from a single sheet of planar material and converging at a central intersection is offered merely for illustrative purposes and the disclosed technology can be applicable to other configurations of basket assemblies **38**. For example, the disclosed technology can be applicable to basket assemblies **38** formed from a single spine **214** or multiple spines **214** with each spine **214** being attached at both ends. In other examples, the basket assembly **38** can include a central hub connecting the multiple spines **214** together at a distal end **94** of the basket assembly **38**. In yet other examples, the basket assembly **38** can include a single spine **214** configured to

form a spiral, multiple spines **214** configured to form a spiral, multiple spines **214** configured to form a tripod or multiple tripods, or any other shape of basket assembly **38**. As well, the spine assembly **210** can be formed by laser cutting a cylindrical hollow stock material whereby the laser is mounted for rotation about the longitudinal axis (and translation thereto) of the cylindrical stock while cutting. Thus, although FIGS. 2A-3B illustrate a specific configuration of basket assembly **38**, the disclosed technology should not be construed as so limited.

[0076] FIG. 4A is a schematic pictorial illustration showing a front perspective view of an electrode **40** before being crimped while FIG. 4B is a schematic pictorial illustration showing a front perspective view of an electrode **40** after being crimped, in accordance with an embodiment of the present invention. Similarly, FIG. 5A is a schematic pictorial illustration showing a side perspective view of an electrode **40** before being crimped while FIG. 5B is a schematic pictorial illustration showing a side perspective view of an electrode **40** after being crimped, in accordance with an embodiment of the present invention. As shown in FIGS. 4A-5B, the electrode **40** can have an elongated body that has a cross sectional shape that extends along the length of the electrode **40**. The electrode **40** can be made from a malleable and conductive material such as gold, platinum, and palladium (and their respective alloys) as described previously. As will be appreciated, by forming the electrode **40** from a malleable material, the electrode **40** can be crimped or otherwise plastically deformed to transition from a first shape (i.e., FIGS. 4A and 5A) that is uncrimped to a second shape (i.e., FIGS. 4B and 5B) that is crimped. As will be described in greater detail herein, the electrode **40** can be crimped around a spine **214** to secure the electrode **40** to the spine **214** without requiring solder, weld, or adhesives.

[0077] The electrode **40** can define a first lumen **70** and a second lumen **72** which both extend through an elongated body of the electrode **40** from a first end to a second end of the electrode **40**. The electrode **40** can have an outer surface **74** facing outwardly from the electrode **40**, a first inner surface **76** facing inwardly toward the electrode **40** where the first lumen **70** is formed through the electrode **40**, and a second inner surface **78** facing inwardly toward the electrode **40** where the second lumen **72** is formed through the electrode. The first lumen **70** can be sized and configured to receive a spine **214**, as shown in FIG. 6A, such that the spine **214** can pass through the first lumen **70**. Although not shown, the second lumen **72** can be sized to receive a wire of the medical probe **22** such that the electrode **40** can be attached to the wire. The wire can be electrically insulated from the spine **214**. In some examples, the first lumen **70** and/or the second lumen **72** can each pass through the electrode **40** in a generally longitudinal direction of the electrode **40**. In other examples, the first lumen **70** and/or the second lumen **72** can pass through the electrode **40** in a generally transverse direction of the electrode **40**. Furthermore, the first lumen **70** and/or the second lumen **72** can be positioned in the electrode **40** nearer a bottom surface, nearer at top surface, or nearer a middle of the electrode **40** depending on the particular configuration.

[0078] By including a first lumen **70** that is sized to receive the spine **214** of the medical probe **22**, the disclosed technology can ensure the electrodes **40** are secured to the spines **214** and prevented from breaking free. Thus, even if the electrodes **40** become dislodged, the electrodes **40** will

remain attached to the spines 214 by nature of the strut 430 passing through the first lumen 70.

[0079] The electrode 40 can further include a locking stub 80 that can extend inwardly into the first lumen 70. The locking stub 80 can extend longitudinally along the length of the electrode 40 from a first end of the electrode 40 to a second end of the electrode 40. The locking stub 80 can be sized to extend at least partially through an aperture 215 of the spines 214 when the electrode 40 is coupled to the spine 214.

[0080] As illustrated in FIGS. 4A-6B, the electrode 40 can be crimped from a first shape (i.e., as illustrated in FIGS. 4A, 5A, and 6A) to a second shape (i.e., as illustrated in FIGS. 4B, 5B, and 6B). For example, the electrodes 40 can be crimped toward a longitudinal axis of the elongated body of the electrode 40 and have a substantially rounded outer surface 74 prior to being crimped and a substantially flat outer surface 74 after being crimped. The electrodes 40 can be crimped by using a tool to press the electrode 40 until the electrode 40 plastically deforms from the first shape to the second shape. As illustrated in FIGS. 6A and 6B, a spine 214 can be inserted into the electrode 40 and an aperture 215 of the spine 214 can be aligned with the locking stub 80 of the electrode 40. Once the locking stub 80 is aligned with the aperture 215, the electrode 40 can be crimped until a distance between the locking stub 80 and the first lumen inner surface 76 is reduced and the spine 214 is secured in place. In other words, the spine 214 can be inserted into the first lumen 70 and then the electrode 40 can be crimped until electrode 40 is tightly secured around the spine 214. When the electrode 40 is crimped around the spine 214, the locking stub 80 can extend through the aperture 215 of the spine 214 and the electrode 40 can be prevented from moving proximally or distally along the length of the spine 214. Stated otherwise, once the electrode 40 is crimped to spine 40, the locking stub 80 can contact an inner surface of the aperture 215 of the spine 214 and the first lumen inner surface 76 can contact the spine 214 such that the spine 214 cannot be removed from the electrode 40 without deforming the electrode 40. In some examples, the locking stub 80 can form an interference fit with the spine 214 at the aperture 215 to secure the electrode 40 in place.

[0081] FIGS. 7A-7C illustrate side views of electrodes 40 having locking stubs 780A-780C of different shapes. As shown in FIG. 7A, a locking stub 780A can comprise a generally rounded or circular cross section. Alternatively, as shown in FIG. 7B, a locking stub 780B can comprise a generally rectangular cross section or, as shown in FIG. 7C, a locking stub 780C can comprise at least a portion that has a generally triangular shape. As will be appreciated, a generally rounded locking stub 780A can help to permit the locking stub 780A to slide into the aperture 215 of the spine 214 and form an interference fit with the spine 215. Alternatively, a locking stub 780B having a generally rectangular shape may be able to form a tighter interference fit. Furthermore, a locking stub 780C having a generally triangular shape may be able to lock the spine 214 onto the locking stub 80 with the triangular shape to further secure the electrode 40 to the spine 214. As will be appreciated, FIGS. 7A-7C are offered for explanatory purposes and the disclosed technology should not be limited to the specific examples of locking stubs 780A-780C illustrated and described herein. For example, the locking stub 80 can include a generally trapezoidal, pentagonal, hexagonal, octagonal, elliptical, cross,

curved, or other suitable shape. Furthermore, the locking stub 80 can have a changing cross section along the length of the locking stub 80 from one end of the locking stub 80 to another end of the locking stub 80. For example, the locking stub 80 can have a thicker cross section at either end of the locking stub 80 or a thicker cross section at the middle of the locking stub 80. Furthermore, although described as extending from one side of the electrode 40 to a second side of the electrode 40, the locking stub 80 can extend less than the full length of the electrode 40 or may have a portion removed between the first end and second end (e.g., the locking stub 80 can have portions of material at either end of the electrode 40 with no material at the middle of the electrode 40). Further still, although a single locking stub 80 is shown and described herein, the electrode 40 can include more than one locking stub 80 and the locking stub 80 can extend into the first lumen 70 from a portion of the first lumen 70 other than the lower portion of the lumen 70 (e.g., an upper portion of the lumen 70). Accordingly, the disclosed technology should not be construed as limited to the particular configurations shown and described herein.

[0082] Returning now to FIGS. 5A and 5B, the electrode 40 can include a conductive portion 90 and an insulative portion 92. The conductive portion 90 can be configured to permit electricity to pass therethrough (i.e., for ablation or mapping of the cardiac tissue) and can face generally outward from the basket assembly 80 to face cardiac tissue when in use. The insulative portion 92, on the other hand, can be configured to prevent electricity from passing therethrough to help electrically isolate the spine 214 from the electrode 40. In this way, the insulative portion 92 can prevent a short circuit from forming between the electrode 40 and the spine 214. Furthermore, the insulative portion 92 can direct/focus current during pulsed field ablation. Alternatively, or in addition, the spine 214 can be made from an insulative material or have an insulative coating or sleeve added thereto to electrically isolate the electrode 40 from the spine 214. As yet another example, an electrically insulating material can be placed between the electrode 40 and the spine 214 to electrically isolate the electrode 40 from the spine 214.

[0083] FIG. 8 is a flowchart illustrating a method 800 of constructing a medical probe 22, in accordance with embodiments of the present disclosure. The method 800 can include aligning 802 a spine (i.e., spine 214) with an electrode (i.e., electrode 40). Aligning 802 the spine with the electrode, for example, can include aligning the lumen of the electrode (i.e., first lumen 70) with the longitudinal axis of the spine. The method 800 can include inserting 804 the spine into a lumen of the electrode and aligning 806 a locking stub (i.e., locking stub 80) with the aperture (i.e., aperture 215) of the spine. The method can further include crimping 808 the electrode onto the spine such that the locking stub extends at least partially into the aperture to secure the electrode to the spine. Crimping 808 the electrode onto the spine can include using a handheld crimp tool, an electrical crimp tool, a hydraulic crimp tool, a pneumatic crimp tool, or other suitable crimping tool for the application.

[0084] As will be appreciated by one skilled in the art, the method 800 can include any of the various features of the disclosed technology described herein and can be varied depending on the particular configuration. For example, the method 800 can further include inserting a wire into the



second lumen 72 and electrically connecting the wire to the electrode 40. As another example, the method 800 can include placing an electrically insulative material between the spine 214 and the electrode 40. Furthermore, the method 800 can be repeated as many times as necessary to attach the appropriate number of electrodes 40 to the spine 214 for the particular application.

[0085] The disclosed technology described herein can be further understood according to the following clauses:

[0086] Clause 1: An electrode for a medical probe, the electrode comprising: an elongated body, at least a portion of the elongated body being electrically conductive, the elongated body defining a lumen extending through the elongated body along a longitudinal axis of the elongated body; and a locking stub extending at least partially into the lumen so that the locking stub is locked to a member inserted into the lumen.

[0087] Clause 2: The electrode of clause 1, the electrode configured to be crimped towards the longitudinal axis.

[0088] Clause 3: The electrode of clause 2 further comprising a substantially rounded outer surface prior to being crimped and a substantially flat outer surface after being crimped.

[0089] Clause 4: The electrode according to any of clauses 1-3, the locking stub having a substantially rounded cross section.

[0090] Clause 5: The electrode according to any of clauses 1-3, the locking stub having a substantially rectangular cross section.

[0091] Clause 6: The electrode according to any of clauses 1-3, at least a portion of the locking stub comprising a substantially triangular cross section.

[0092] Clause 7: The electrode according to any of clauses 1-6, wherein the locking stub extends a length of the elongated body.

[0093] Clause 8: The electrode according to any of clauses 1-7, the elongated body further comprising an insulative material configured to electrically isolate the electrode from the member inserted into the lumen.

[0094] Clause 9: The electrode according to any of clauses 1-8, the lumen being a first lumen, wherein the elongated body further defines a second lumen configured to receive a wire.

[0095] Clause 10: The electrode according to clause 9, wherein the wire is electrically coupled to the electrode.

[0096] Clause 11: A medical probe, comprising: a tubular shaft having a proximal end and a distal end, the tubular shaft extending along a longitudinal axis; and an expandable basket assembly coupled to the distal end of the tubular shaft, the expandable basket assembly comprising: a plurality of electrodes, each electrode of the plurality of electrodes defining a lumen extending therethrough and a locking stub extending at least partially into the lumen; and a plurality of spines extending along the longitudinal axis and configured to bow radially outward from the longitudinal axis when the expandable basket assembly is transitioned from a collapsed form to an expanded form, each spine of the plurality of spines passing through a lumen of an electrode of the plurality of electrodes, each spine of the plurality of spines defining an aperture extending therethrough from a first side of the spine to a second side of the spine, the aperture configured to receive the locking stub of the electrode such that when the electrode is mechanically coupled to the spine,

the locking stub extends through the aperture preventing the electrode from sliding distally or proximally along the spine.

[0097] Clause 12: The medical probe according to clause 11, each electrode of the plurality of electrodes being configured to be crimped to the spine.

[0098] Clause 13: The medical probe according to clause 12, each electrode of the plurality of electrodes having a substantially rounded outer surface prior to being crimped to the spine and having a substantially flat outer surface after being crimped to the spine.

[0099] Clause 14: The medical probe according to any of clauses 11-13, the locking stub having a substantially rounded cross section.

[0100] Clause 15: The medical probe according to any of clauses 11-13, the locking stub having a substantially rectangular cross section.

[0101] Clause 16: The medical probe according to any of clauses 11-13, wherein at least a portion of the locking stub comprises a substantially triangular cross section.

[0102] Clause 17: The medical probe according to any of clauses 11-16, each electrode of the plurality of electrodes further comprising an insulative material configured to electrically isolate the electrode from the spine.

[0103] Clause 18: The medical probe according to any of clauses 11-16, each spine of the plurality of spines further comprising an insulative material configured to electrically isolate the spine from the electrode.

[0104] Clause 19: The medical probe according to any of clauses 11-18, wherein the expandable basket assembly further comprises an insulative material disposed between the electrode and the spine to electrically isolate the electrode from the spine.

[0105] Clause 20: The medical probe according to any of clauses 11-19, the lumen of each electrode of the plurality of electrodes being a first lumen, each electrode of the plurality of electrodes further defining a second lumen configured to receive a wire of the medical probe.

[0106] Clause 21: The medical probe according to clause 20, wherein the wire is electrically coupled to the electrode.

[0107] Clause 22: The medical probe according to clause 21, wherein the wire is insulated from the spine.

[0108] Clause 23: The medical probe according to any of clauses 11-21, wherein each spine of the plurality of spines comprises a first electrode and a second electrode mechanically coupled to the spine, and wherein each spine defines a first aperture configured to receive a locking stub of the first electrode and a second aperture configured to receive a locking stub of the second electrode, the first aperture and the second aperture both being configured to prevent the first and second electrodes from sliding proximally or distally along a length of the spine when the first and second electrodes are mechanically coupled to the spine, respectively.

[0109] Clause 24: The medical probe according to any one of clauses 11-22, wherein an interface between the locking stub of the electrode and the spine at the aperture comprises an interference fitting.

[0110] Clause 25: The medical probe according to any of clauses 11-24, wherein the spine comprises a material selected from a group consisting of nitinol, cobalt chromium, stainless steel, titanium and combinations thereof.

[0111] Clause 26: The medical probe according to any of clauses 11-24, wherein the spine comprises a polymer material.

**[0112]** Clause 27: The medical probe according to any of clauses 11-26, wherein the plurality of electrodes is configured to deliver electrical pulses for irreversible electroporation, the pulses having a peak voltage of at least 900 volts (V).

**[0113]** Clause 28: The medical probe according to any of clauses 11-26, wherein the plurality of electrodes is configured for mapping electrophysiological characteristics of cardiac tissue.

**[0114]** Clause 29: The medical probe according to any of clauses 11-28, further comprising spray ports configured to deliver an irrigation fluid to the plurality of electrodes.

**[0115]** Clause 30: A method of constructing a medical probe, the method comprising: aligning a spine of an expandable basket assembly with an electrode of the expandable basket assembly, the spine comprising a proximal end, a distal end, and defining an aperture extending therethrough; inserting the spine into a lumen of the electrode; aligning a locking stub of the electrode with the aperture; and crimping the electrode onto the spine such that the locking stub extends at least partially into the aperture to prevent the electrode from sliding proximally or distally along the spine.

**[0116]** Clause 31: The method according to clause 30, the electrode having a substantially rounded outer surface prior to being crimped to the spine and having a substantially flat outer surface after being crimped to the spine.

**[0117]** Clause 32: The method according to any of clauses 30-31, the locking stub having a substantially rounded cross section.

**[0118]** Clause 33: The method according to any of clauses 30-31, the locking stub having a substantially rectangular cross section.

**[0119]** Clause 34: The method according to any of clauses 30-31, wherein at least a portion of the locking stub comprises a substantially triangular cross section.

**[0120]** Clause 35: The method according to any of clauses 30-34, the electrode further comprising an insulative material configured to electrically isolate the electrode from the spine.

**[0121]** Clause 36: The method according to any of clauses 30-34, the spine further comprising an insulative material configured to electrically isolate the spine from the electrode.

**[0122]** Clause 37: The method according to any of clauses 30-36, wherein the expandable basket assembly further comprises an insulative material disposed between the electrode and the spine to electrically isolate the electrode from the spine.

**[0123]** Clause 38: The method according to any of clauses 30-37, wherein the lumen comprises a first lumen, the method further comprising: aligning a wire of the medical probe with a second lumen of the electrode; inserting the wire into the second lumen; and coupling the wire to the electrode such that the wire is in electrical communication with the electrode.

**[0124]** Clause 39: The method according to clause 38, wherein the wire is insulated from the spine.

**[0125]** Clause 40: The method according to any of clauses 30-39, wherein an interface between the locking stub of the electrode and the spine at the aperture comprises an interference fitting.

**[0126]** Clause 41: The method according to any of clauses 30-40, wherein the spine comprises a material selected from a group consisting of nitinol, cobalt chromium, stainless steel, titanium.

**[0127]** Clause 42: The method according to any of clauses 30-41, wherein the spine comprises a polymer material.

**[0128]** Clause 43: The method according to any of clauses 30-42, wherein the aperture of the spine is a first aperture, the spine further defining a second aperture, the method further comprising: aligning the spine with a second electrode of the expandable basket assembly; inserting the spine into a lumen of the second electrode; aligning a locking stub of the second electrode with the second aperture; and crimping the second electrode onto the spine such that the locking stub extends at least partially into the second aperture to prevent the second electrode from sliding proximally or distally along the spine.

**[0129]** The embodiments described above are cited by way of example, and the present invention is not limited by what has been particularly shown and described hereinabove. Rather, the scope of the invention includes both combinations and sub combinations of the various features described hereinabove, as well as variations and modifications thereof which would occur to persons skilled in the art upon reading the foregoing description and which are not disclosed in the prior art.

What is claimed is:

1. An electrode for a medical probe, the electrode comprising:

an elongated body, at least a portion of the elongated body being electrically conductive, the elongated body defining a lumen extending through the elongated body along a longitudinal axis of the elongated body; and a locking stub extending at least partially into the lumen so that the locking stub is locked to a member inserted into the lumen.

2. The electrode of claim 1, the electrode configured to be crimped towards the longitudinal axis.

3. The electrode of claim 2 further comprising a substantially rounded outer surface prior to being crimped and a substantially flat outer surface after being crimped.

4. The electrode of claim 1, the locking stub having a substantially rounded cross section.

5. The electrode of claim 1, the locking stub having a substantially rectangular cross section.

6. The electrode of claim 1, at least a portion of the locking stub comprising a substantially triangular cross section.

7. The electrode of claim 1, wherein the locking stub extends a length of the elongated body.

8. The electrode of claim 1, the elongated body further comprising an insulative material configured to electrically isolate the electrode from the member inserted into the lumen.

9. The electrode of claim 1, the lumen being a first lumen, wherein the elongated body further defines a second lumen configured to receive a wire.

10. A medical probe, comprising:

a tubular shaft having a proximal end and a distal end, the tubular shaft extending along a longitudinal axis; and an expandable basket assembly coupled to the distal end of the tubular shaft, the expandable basket assembly comprising:

- a plurality of electrodes, each electrode of the plurality of electrodes defining a lumen extending therethrough and a locking stub extending at least partially into the lumen; and
- a plurality of spines extending along the longitudinal axis and configured to bow radially outward from the longitudinal axis when the expandable basket assembly is transitioned from a collapsed form to an expanded form, each spine of the plurality of spines passing through a lumen of an electrode of the plurality of electrodes, each spine of the plurality of spines defining an aperture extending therethrough from a first side of the spine to a second side of the spine, the aperture configured to receive the locking stub of the electrode such that when the electrode is mechanically coupled to the spine, the locking stub extends through the aperture preventing the electrode from sliding distally or proximally along the spine.
- 11.** The medical probe according to claim **10**, each electrode of the plurality of electrodes being configured to be crimped to the spine.
- 12.** The medical probe according to claim **11**, each electrode of the plurality of electrodes having a substantially rounded outer surface prior to being crimped to the spine and having a substantially flat outer surface after being crimped to the spine.
- 13.** The medical probe according claim **10**, each electrode of the plurality of electrodes further comprising an insulative material configured to electrically isolate the electrode from the spine.
- 14.** The medical probe according to claim **10**, each spine of the plurality of spines further comprising an insulative material configured to electrically isolate the spine from the electrode.
- 15.** The medical probe according to claim **10**, wherein each spine of the plurality of spines comprises a first electrode and a second electrode mechanically coupled to the spine, and

wherein each spine defines a first aperture configured to receive a locking stub of the first electrode and a second aperture configured to receive a locking stub of the second electrode, the first aperture and the second aperture both being configured to prevent the first and second electrodes from sliding proximally or distally along a length of the spine when the first and second electrodes are mechanically coupled to the spine, respectively.

**16.** The medical probe of claim **10**, wherein an interface between the locking stub of the electrode and the spine at the aperture comprises an interference fitting.

**17.** The medical probe according to claim **10**, wherein the plurality of electrodes is configured to deliver electrical pulses for irreversible electroporation, the pulses having a peak voltage of at least 900 volts (V).

**18.** The medical probe according to claim **10**, wherein the plurality of electrodes is configured for mapping electrophysiological characteristics of cardiac tissue.

**19.** A method of constructing a medical probe, the method comprising:

aligning a spine of an expandable basket assembly with an electrode of the expandable basket assembly, the spine comprising a proximal end, a distal end, and defining an aperture extending therethrough;

inserting the spine into a lumen of the electrode;

aligning a locking stub of the electrode with the aperture; and

crimping the electrode onto the spine such that the locking stub extends at least partially into the aperture to prevent the electrode from sliding proximally or distally along the spine.

**20.** The method according to claim **19**, wherein the lumen comprises a first lumen, the method further comprising:

aligning a wire of the medical probe with a second lumen of the electrode;

inserting the wire into the second lumen; and

coupling the wire to the electrode such that the wire is in electrical communication with the electrode.

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