Claims

1. A steerable intracardiac ablation catheter, comprising: an elongated flexible shaft having a proximal handle and a deflectable distal section; an ultrasound imaging transducer disposed at or near the distal section configured to produce intracardiac echocardiography images; and one or more ablation electrodes on the distal section configured to deliver pulsed-field ablation energy to tissue; wherein the catheter is adapted to provide real-time ultrasound imaging and pulsed-field electrical ablation through the same catheter and includes electrical isolation features preventing interference between the ablation energy and the imaging transducer.

2. The system of claim 1, further comprising an ultrasound imaging console operatively connected to the ultrasound transducer and a pulsed-field ablation generator operatively connected to the one or more ablation electrodes, the system being configured to coordinate imaging and ablation such that the ultrasound transducer can visualize target tissue and surrounding structures during delivery of pulsed-field ablation energy.

3. A method of treating a cardiac arrhythmia, comprising: inserting a steerable catheter into a patient's heart, the catheter having an intracardiac ultrasound imaging transducer and pulsed-field ablation electrodes on a single shaft; positioning the catheter's distal end at a target tissue site within a heart chamber under guidance of real-time ultrasound images from the transducer; activating a pulsed-field ablation generator to deliver one or more high-voltage pulse trains through the ablation electrodes to create a lesion in the target tissue; and concurrently or sequentially imaging the lesion formation and adjacent anatomical structures via the ultrasound transducer, thereby monitoring the ablation in real time and adjusting the catheter or energy delivery as needed to achieve effective lesion formation while avoiding injury to non-target tissue.

4. The catheter of claim 1, wherein the ultrasound imaging transducer is a phased-array transducer comprising a plurality of piezoelectric elements capable of electronic beam steering and real-time two-dimensional imaging of cardiac structures .

5. The catheter of claim 1, wherein the ultrasound imaging transducer is a mechanical rotational transducer comprising at least one piezoelectric element mounted for rotation to sweep an imaging plane, thereby providing a 360-degree radial intracardiac ultrasound view .

6. The catheter of claim 1, wherein the ultrasound imaging transducer assembly is removably or interchangeably mounted on the catheter shaft, such that the imaging assembly can be exchanged or detached from the ablation catheter without removing the catheter from the patient (thereby allowing modular use of the imaging component).

7. The catheter of claim 1, wherein the one or more ablation electrodes are disposed on an expandable structure at the distal section, the expandable structure being selectable

from a group consisting of: an inflatable balloon carrying a plurality of electrodes (for deploying against a cardiac wall) and a flexible multielectrode basket that expands radially to contact tissue around a circumference.

8. The catheter of claim 1, further comprising an irrigation lumen within the shaft and one or more irrigation outlets near the ablation electrodes, configured to deliver cooling fluid to the tissue-electrode interface during pulsed-field ablation to mitigate any resistive heating or microbubble formation .

9. The catheter of claim 1, further comprising an electrical isolation circuit or element operatively coupled between the ablation electrodes and the ultrasound transducer's signal lines, wherein the isolation circuit prevents high-voltage ablation pulses from inducing currents or voltages in the ultrasound imaging circuitry (for example, by automatically disconnecting or shunting the imaging transducer during each ablation pulse).

10. The catheter of claim 1, wherein the distal section is deflectable via at least one pull-wire controlled by the proximal handle, allowing the catheter tip to be steered to different orientations; and wherein the catheter shaft has a multi-lumen construction carrying the pull-wire, wiring for the ultrasound transducer, and conductors for the ablation electrodes in mutually insulated lumens (as exemplified in FIG. 2).

11. The system of claim 2, wherein the system is configured such that during delivery of a pulsed-field ablation pulse or pulse train, the ultrasound imaging console temporarily blanks or suppresses reception to avoid interference, and then automatically resumes ultrasound imaging immediately after the pulse, thereby providing near-real-time visualization with protection of the imaging electronics.

12. The system of claim 2, further comprising an irrigation pump fluidly connected to the irrigation lumen of the catheter (as in claim 8) for delivering cooling saline to the ablation electrodes during energy delivery, and a control unit that coordinates the irrigation flow with the ablation generator (such that irrigation flow is activated during PFA delivery to dissipate heat).

13. The method of claim 3, wherein the target tissue site is within the left atrium and surrounds one or more pulmonary vein ostia, and wherein delivering the pulsed-field ablation energy achieves pulmonary vein isolation for treatment of atrial fibrillation.

14. The method of claim 13, further comprising the step of imaging an adjacent esophagus using the ultrasound transducer during the ablation of the posterior left atrium, and adjusting the ablation procedure (by repositioning the catheter or modulating energy) if the esophagus is determined to be at risk, thereby reducing the likelihood of esophageal injury .

15. The method of claim 13, further comprising pacing the phrenic nerve during ablation near a pulmonary vein or superior vena cava and concurrently observing diaphragmatic movement via the ultrasound imaging transducer (to ensure the phrenic nerve is not adversely affected), wherein any loss of diaphragmatic motion or abnormal motion detected causes the operator to immediately stop or reposition before continuing ablation .