Claims

1. A computer-implemented method for providing cardiac intervention guidance, the method comprising:

   – receiving multimodal cardiac data for a patient, including imaging data of a cardiac structure (selected from at least one of: magnetic resonance imaging, computed tomography, intracardiac echocardiography) and real-time procedural data (selected from at least one of: electroanatomic mapping signals, intracardiac electrograms, surface ECG, pacing lead parameters, and ablation catheter sensors);

   – analyzing the multimodal data using a trained artificial intelligence model to generate at least one of: (i) a suggested ablation lesion plan comprising one or more lesion lines or points in cardiac tissue, and (ii) a recommended pacing lead implantation depth or location for left bundle branch area pacing (LBBAP); and

   – outputting guidance information to a user interface in real time during a cardiac procedure, the guidance information including visual or textual indications of the suggested ablation lesions or lead depth recommendation, thereby assisting an operator in executing the procedure.

2. The method of claim 1, wherein the imaging data comprises a preoperative cardiac MRI scan with scar tissue delineation, and the analyzing step includes registering the MRI scan to an intraoperative electroanatomic map to identify fibrosis or scar regions as targets for the ablation lesion plan .

3. The method of claim 1, wherein analyzing the data to suggest an ablation lesion plan (aspect (i)) further comprises: detecting arrhythmogenic substrates or pathways from the data, proposing lesion lines that isolate or modify the detected substrates, and ranking the lesion lines based on predicted efficacy in terminating or preventing an arrhythmia.

4. The method of claim 1, wherein analyzing the data to recommend a pacing lead depth (aspect (ii)) includes: estimating a thickness of the interventricular septum at a target implant site from the imaging data, monitoring changes in pacing lead impedance and electrogram morphology during lead insertion, and predicting an optimal depth at which the pacing lead captures the left bundle branch conduction fibers .

5. The method of claim 1, wherein the artificial intelligence model comprises a deep learning model trained on historical patient cases, the model generating a confidence score for each suggested lesion or lead placement recommendation, and the method further comprises adjusting the guidance information based on the confidence score (only displaying suggestions above a certain confidence threshold or highlighting suggestions with lower confidence).

6. The method of claim 1, wherein outputting guidance information includes overlaying the suggested ablation lesion plan onto a three-dimensional cardiac map on an electrophysiology mapping system display, and providing an indication when a delivered ablation lesion aligns with or deviates from the suggested plan.

7. The method of claim 1, wherein outputting guidance information for the pacing lead depth includes displaying, on an intracardiac echocardiography (ICE) image, a marker indicating the model-predicted target depth within the septum and providing an alert when the pacing lead tip reaches the target depth range.

8. A cardiac intervention guidance system comprising:

   – one or more data interfaces configured to acquire multimodal cardiac data including imaging of cardiac anatomy and real-time electrophysiological signals;

   – a processing unit comprising at least one processor and memory, the memory storing program instructions and an artificial intelligence inference engine which, when executed by the processor, causes the system to analyze the acquired data and generate guidance outputs comprising an ablation lesion plan and/or a pacing lead implantation recommendation; and

   – a user interface module configured to present the guidance outputs to a clinical user during a procedure, wherein the guidance outputs are updated in real time as new data is received, thereby providing dynamic decision support.

9. The system of claim 8, wherein the data interfaces include: an imaging interface to import cardiac MRI or CT data for substrate mapping, a catheter interface to receive electroanatomic mapping coordinates and electrograms, and a pacing interface to receive pacing lead metrics including lead tip impedance and detected left bundle branch potential signals.

10. The system of claim 8, wherein the artificial intelligence inference engine comprises: a first model trained to output recommended ablation lesion locations given input features of scar distribution, voltage map, and arrhythmia type; and a second model trained to output an estimated optimal lead depth or turns count for LBBAP given input features of septal thickness, real-time lead electrical parameters, and observed QRS morphology

changes .

11. The system of claim 8, wherein the processing unit is configured to operate in a cloud-computing environment remote from the procedure site, and further comprising a secure communication module to transmit patient data to the cloud and return AI guidance results with latency compatible with real-time use.

12. The system of claim 8, wherein the processing unit is an on-site computing device integrated with an electrophysiology mapping system, such that the system operates as an edge device without requiring internet connectivity.

13. The system of claim 8, wherein the user interface module includes an overlay component that integrates with a three-dimensional mapping system display to show suggested lesion sites, and an alert component that provides auditory or visual alerts when certain conditions are met (selected from: completion of all suggested lesions, pacing lead reaching target depth, or deviation from plan requiring user attention).

14. The system of claim 8, further comprising a data logging and feedback module that records the guidance provided and the actual clinician actions and outcomes, the recorded data being usable to retrain or improve the artificial intelligence inference engine for future procedures (continuous learning under supervision).

15. A non-transitory computer-readable medium storing instructions which, when executed by one or more processors of a medical system, cause the system to perform the steps of the method of any of claims 1–7, thereby enabling the system to provide AI-driven ablation planning and pacing lead guidance.

16. A method of training an artificial intelligence model for a cardiac guidance system, the method comprising:

– collecting a training dataset comprising, for a plurality of historical cardiac procedures, multimodal input data (including imaging, mapping signals, and procedure logs) and corresponding outputs (including lesion sets applied and clinical outcomes, or lead depth achieved and pacing outcomes);

– configuring a model architecture that includes at least a first output branch for lesion planning and a second output branch for lead depth recommendation;

– training the model on the dataset using a machine learning algorithm to minimize a loss function that penalizes differences between the model's outputs and the actual successful lesion sets or lead placements in the training cases; and

– validating the trained model on a separate set of cases to ensure accuracy and generalization, including confirming that the model's suggested lesion plans align with

expert strategies in those cases and that predicted lead depths correlate with successful pacing capture thresholds.

17. The training method of claim 16, wherein the training process uses a combination of supervised learning (with labeled optimal solutions from experts) and reinforcement learning (where the model receives higher reward for outputs that would result in termination of arrhythmia or successful pacing), thereby capturing both expert knowledge and data-driven patterns.

18. The training method of claim 16, further comprising augmenting the dataset with simulated scenarios or "virtual patient" data to ensure the model is exposed to rare but critical conditions (such as atypical arrhythmia circuits or extremely thick septum for pacing), improving robustness of the model's guidance.

19. A clinical workflow method for using the system of claim 8 in a cardiac procedure, the method comprising:

– pre-procedurally importing patient-specific cardiac imaging into the system and identifying key anatomical features on the images;

– during the procedure, connecting the system to real-time mapping catheters and/or pacing leads to stream live data;

– allowing the system to generate and display AI guidance in the form of suggested ablation targets or lead placement cues;

– executing the cardiac procedure steps by the clinician while referring to the displayed guidance, including delivering ablation lesions along suggested lines and advancing the pacing lead according to depth cues; and

– updating the procedure plan based on system feedback, wherein if the system indicates incomplete lesion effect or suboptimal lead position, the clinician evaluates and performs additional adjustments, thereby iteratively achieving the desired procedural outcome with assistance from the AI system.

20. The clinical workflow method of claim 19, wherein during an atrial fibrillation ablation, the system's suggested lesion plan is used as a reference, and upon isolation of pulmonary veins and other target areas as confirmed by the mapping system, the system confirms achievement of goals (e.g., no gap detected in lesion lines) before the procedure is concluded.

21. The clinical workflow method of claim 19, wherein during a pacemaker implant, the system provides depth guidance and automatically measures the paced QRS duration and morphology after each incremental lead advancement, alerting the clinician to stop

advancing when a predetermined QRS narrowing or morphology criterion indicative of left bundle branch capture is met, thereby standardizing the endpoint of lead placement .

22. The system of claim 8, wherein the guidance system is configured as a software module classified as a Class II medical device, providing advisory information that does not directly control delivery of therapy but is intended to be verified by a human operator, and wherein fail-safes are built in such that any AI output that conflicts with predefined safety rules (including minimum distance from critical anatomical structures or maximum allowed ablation energy in one spot) is automatically flagged or suppressed.

23. The system of claim 8, wherein the guidance system further comprises an expert override feature that allows an operator to modify or input custom lesion locations or depth targets, wherein the system then evaluates the operator-input plan against the multimodal data to provide feedback on the likelihood of success or potential issues, thus facilitating an interactive planning process between the AI and the clinician.

24. The method of claim 1, wherein the multimodal data further includes real-time feedback on lesion formation, and the analyzing step for aspect (i) includes predicting lesion efficacy by assessing parameters such as impedance drop or tissue elasticity change at each lesion site, and updating the suggested ablation plan on-the-fly to fill in any gaps or retreat areas that appear inadequately ablated.

25. The method of claim 1, wherein aspect (ii) further comprises, in response to detecting an anomalous condition during lead insertion (selected from: septal perforation, loss of lead fixation, or engagement of an unwanted structure), automatically recommending a corrective action including repositioning the lead or adjusting the implantation site, wherein the recommendation is generated based on learned scenarios in the AI model's knowledge base.