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BIOPHYSICS OF ABLATION REVISITED

High-Power and Short-Duration Ablation for Pulmonary Vein Isolation

Biophysical Characterization

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ABSTRACT

OBJECTIVES This study sought to examine the biophysical properties of high-power and short-duration (HP-SD) radiofrequency ablation for pulmonary vein isolation.

BACKGROUND Pulmonary vein isolation is the cornerstone of atrial fibrillation ablation. However, pulmonary vein reconnection is frequent and is often the result of catheter instability, tissue edema, and a reversible nontransmural injury. We postulated that HP-SD ablation increases lesion-to-lesion uniformity and transmurality.

METHODS This study included 20 swine and a novel open-irrigated ablation catheter with a thermocouple system able to record temperature at the catheter-tissue interface (QDOT Micro Catheter). Step 1 compared 3 HP-SD ablation settings: 90 W/4 s, 90 W/6 s, and 70 W/8 s in a thigh muscle preparation. Ablation at 90 W/4 s was identified as the best compromise between lesion size and safety parameters, with no steam-pop or char. In step 2, a total of 174 single ablation applications were performed in the beating heart and resulted in 3 (1.7%) steam-pops, all occurring at catheter-tissue interface temperature ≥85°C. Additional 233 applications at 90 W/4 s and temperature limit of 65°C were applied without steam-pop. Step 3 compared the presence of gaps and lesion transmurality in atrial lines and pulmonary vein isolation between HP-SD (90 W/4 s, T ≤65°C) and standard (25 W/20 s) ablation.

RESULTS HP-SD ablation resulted in 100% contiguous lines with all transmural lesions, whereas standard ablation had linear gaps in 25% and partial thickness lesions in 29%. Ablation with HP-SD produced wider lesions (6.02 ± 0.2 mm vs. 4.43 ± 1.0 mm; $p = 0.003$) at similar depth (3.58 ± 0.3 mm vs. 3.53 ± 0.6 mm; $p = 0.81$) and improved lesion-to-lesion uniformity with comparable safety end points.

CONCLUSIONS In a preclinical model, HP-SD ablation (90 W/4 s, T ≤65°C) produced an improved lesion-to-lesion uniformity, linear contiguity, and transmurality at a similar safety profile of conventional ablation. (J Am Coll Cardiol EP 2018;4:467–79) © 2018 by the American College of Cardiology Foundation.

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ABBREVIATIONS AND ACRONYMS

HP-SD = high power and short duration

PV = pulmonary vein

PVI = pulmonary vein isolation

RF = radiofrequency

SVC = superior vena cava

The objective of pulmonary vein isolation (PVI) is to create a transmural, continuous, and permanent cellular damage. The current practice of radiofrequency (RF) ablation with irrigated catheters involves the delivery of moderate power (20 to 40 W) for a relatively long duration (20 to 40 s) at a contract force range of 10 to 20 g. At these conventional parameters, the incidence of pulmonary vein (PV) reconnection remains significant, occurring acutely and 3 months after PVI at a frequency of 22% and 15%, respectively (1,2). Although the mechanisms underlying PV reconnection are not entirely understood, incomplete ablation with partial-thickness and/or reversible injury may be a major contributor (3–5).

Ablation in striated muscle tissue preparation, where parameter and catheter stability are optimized, results in lesions of similar or greater depth than the human left atrium (6–9). This indirectly suggests that reversible or nontransmural injury may be related to other factors, such as catheter instability in a beating heart and tissue edema without permanent cellular damage, limiting the long-term efficacy of ablation.

SEE PAGE 480

RF ablation lesions result from thermal injury that occurs in 2 consecutive phases: resistive and conductive. During the resistive phase, electrical current delivered at the catheter-tissue interface leads to immediate heating of the superficial tissue layer (approximately 1 to 2 mm). This resistive heating phase creates a heat source that then extends passively to deeper tissue layers during the conductive phase. Conductive heating is time dependent and the result of the current applied and heat produced in the resistive phase (10). Irreversible myocardial tissue injury with cellular death occurs at temperature ≥50°C, whereas reversible tissue injury often occurs at lower tissue temperatures (**Figure 1A**).

A potential method to achieve uniform, transmural lesions during PVI is to modify the relationship between the resistive and conductive heating phases, such that the resistive heating phase is increased to deliver immediate heating to the full thickness of the human PV circumference, whereas the conductive heating phase is reduced to limit collateral tissue damage (**Figure 1B**) (11). To achieve this, a larger current must be delivered for a shorter duration.

However, the biophysical ablation properties of high-power and short-duration (HP-SD) ablation are not known. Specifically: 1) increased electrical current may result in char and/or steam-pop (tissue boiling) formation, and appropriate power parameters have not yet been determined; 2) ablation duration (and power over time) may be different compared with standard ablation, such that the safety range of ablation duration at higher power setting may be smaller; and 3) it is unclear whether HP-SD ablation can create irreversible, transmural heating in atrial tissue.

In this study, we examined the biophysical characteristics of HP-SD RF ablation in a thigh muscle preparation model and the beating heart. In addition, we compared single lesion dimensions, linear ablation continuity, and safety parameters between HP-SD and conventional RF ablation.

METHODS

ANIMALS AND PROTOCOL. This prospective study included a total of 20 Yorkshire swine (55 to 70 kg). All experiments were performed under general anesthesia. The Beth Israel Deaconess Medical Center Institutional Animal Care and Use Committee approved the research protocol. Experiments were performed at 3 sites: 1) Beth Israel Deaconess Medical Center (Boston, Massachusetts); 2) Technion Institute of Technology (Haifa, Israel); and 3) CBSET, Inc. (Lexington, Massachusetts).

RF DELIVERY SYSTEM. To perform high-power ablation with adequate safety, it is imperative to record temperature at the catheter-tissue interface to avoid overheating that can result in char and/or steam-pop formation. We therefore used a novel ablation catheter that incorporates 6 thermocouples symmetrically embedded in the circumference of the tip electrode: 3 distal thermocouples positioned 75 μm from the tip and 3 proximal thermocouples positioned 3 mm proximally (**Figure 2**) (QDOT Micro Catheter, Biosense Webster, Irvine, California) (12). The symmetrical distribution of the proximal and distal thermocouples is optimized to record temperature at both perpendicular and parallel catheter orientations. Measurement of temperature at the catheter-tissue interface has been traditionally limited by the confounding effect of the cold irrigation fluid during ablation. To record accurate temperature at the catheter-tissue interface, an algorithm was developed, validated, and applied to scale the temperature recorded with these specific thermocouples and actual tissue temperature recorded using fluoroptic thermal probes embedded in tissue (data not shown). In addition, this catheter has an improved irrigation system that includes backward flow toward the proximal electrode, allowing increased irrigation during ablation in a parallel orientation. Ablation has been performed