

High power short duration ablation of atrial fibrillation: A contemporary review

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Abstract

Catheter ablation using radiofrequency (RF) energy has been widely used to treat patients with atrial fibrillation (AF). The optimal levels of power and duration to increase the success rate while minimizing complications have not been fully established. Different centers continue to use various power protocols for catheter ablation of AF. Herein, we present a comprehensive review of the impact of power output on efficacy and safety of RF ablation for AF. High power short duration (HPSD) ablation can be performed safely with similar procedural efficacy as low power long duration (LPLD) ablation strategy. HPSD ablation has the potential to shorten procedural and RF times and create more durable and localized lesions.

Introduction

Radiofrequency (RF) ablation is a well-adopted rhythm control strategy in the management of atrial fibrillation (AF). Since the pioneering work of Haïssaguerre et al,^{1, 2} pulmonary vein (PV) isolation has been a standard strategy for catheter ablation of AF. RF remains the most common energy source for point-by-point ablation for wide antral PV isolation despite the availability of alternative energy sources like cryotherapy,³ laser energy⁴ and microwave. The success of PV isolation depends on achieving durable, transmural and contiguous lesions. However, despite the advent of irrigated and contact-force (CF) sensing catheters, PV reconnection occurs in 22% of PVs acutely and 15% of PVs three months after PV isolation.^{5, 6} The overall 1-year success rate for paroxysmal AF ablation is estimated at 59-89%.⁷ PV reconnection with recurrence of atrial arrhythmia is predominantly due to inability to achieve lesion transmurality or contiguity.⁸⁻¹⁰

The goal of successful catheter ablation is to cause irreversible tissue injury to the target cardiac tissue while avoiding unnecessary damage to surrounding tissue and collateral structures including the esophagus, coronary arteries, and the phrenic nerve. This requires a strategy to maximize the resistive heating phase and minimizing conductive heating to achieve immediate full thickness heating and minimize collateral damage. Lesion size can be increased by modulating power, CF and duration of ablation. Unfortunately, RF lesion formation is not always predictable in the clinical setting due to the variability in efficiency of energy coupling from the catheter electrode to cardiac tissue.¹¹ Evolution of irrigated-tip catheters and CF sensing catheters have mitigated this variability and enabled delivery of higher power without excessive endocardial heating.^{5, 6, 12-14} Development of CF sensing represents a significant milestone in optimizing efficiency and safety of RF ablation. CF catheters have demonstrated better long term outcomes compared to non-CF catheters as seen in both SMART AF and TOCCASTAR when CF applied appropriately.^{8, 15-18} CF stability has been shown to be an important predictor of reduced arrhythmia recurrence.^{8, 17-19} There has been further evolution in catheter irrigation technology to provide uniform cooling with less fluid delivery (SMART SF).²⁰

Many centers currently perform PV isolation and creation of additional extra-PV lesion sets using irrigated

catheters to deliver power of 20-40 W for durations of 20–40 seconds at each site with a CF range of 10 to 20 g.²¹ The resultant long procedure times and significant rates of PV reconnection have sparked an interest in the use of high power short duration (HPSD) ablation. The definition of high power short duration ablation is arbitrary and ranges from 40 W to 90 W with variable durations generally less than 15 seconds per lesion.²¹⁻²³ The biophysical ablation characteristics of HPSD ablation have been studied to determine the efficacy and safety profile of this novel technique.

Biophysics of HPSD ablation

RF ablation lesion formation is a result of thermal injury occurring in the resistive and conductive phases.²¹ The superficial tissue (~ 1 to 2 mm) is heated at the catheter-tissue interface directly by resistive (ohmic) heating.²¹ The superficial heated tissue extends the heat passively to deeper tissue layers in a time dependent manner during the conductive phase.²⁴ The standard RF lesion using low to moderate power and relatively long duration is created predominantly by conductive heating [Figure 1A]. In contrast to standard ablation, HPSD ablation creates a larger zone of direct resistive heating of tissue with a shorter temperature decay time. This increases the ratio of resistive to conductive tissue heating with irreversible injury of the resistive endocardial zone and less endocardial sparing [Figure 1B]. The lesion geometry in HPSD ablation is altered due to the change in balance between resistive and conductive heating. The maximal width of a standard ablation lesion is in the subendocardium resulting in a tear-drop shaped lesion (endocardial sparing due to smaller resistive zone). On the other hand, the HPSD ablation lesion width is maximum in the endocardium as well as the subendocardium.²¹ Lesions with HPSD ablation have lesser depth and bigger diameter with similar lesion volumes as standard ablation.²⁵ Shallower lesions with HPSD ablation may be favorable for thin tissues like the atria. HPSD ablation can potentially reduce collateral damage to neighboring structures like the esophagus due to reduction in the conductive heating phase.

Animal studies on HPSD

Several animal studies have studied the efficacy and safety of HPSD ablation for PV isolation. Researchers have studied several combinations of high power settings ranging from 50 W to 80 W for 5 s with a temperature cut-off of 60° C with a CF sensing catheter in an in vitro model and a sheep model. The HPSD ablation settings resulted in 100% transmural lesions and reduced collateral damage compared with ablation at 40 W for 30 s in the right atrium. Steam pops were noted at power > 70 W or longer duration ablation (8% incidence for 40 W/30 s and 11% for 80 W/5 s).²⁶ In an ex-vivo and in-vivo animal study, predictably increased lesion size was noted with greater power delivery or longer RF time. However, the same proportional increase in power will produce a significantly larger lesion volume compared with a proportional change in RF duration. Lesion volume proportionally increases with increase in power and only half as much for ablation duration provided the CF remains constant.²⁷ In yet another porcine study, the time needed to create a 4-mm deep lesion decreased from just over 20 s for 20 W to 6–7 s for 50 W with a CF of 20 g. This suggests that high power and short duration lesions might help to reduce collateral injury.²⁸

In a recent animal study by Leshem et al, HPSD ablation with 90 W/4 s resulted in higher power, average and maximal temperature, and larger impedance drop as compared to standard ablation using 25 W/20 s for PV isolation in a swine model. The catheter tissue temperature was noted to increase to an average of 63.2 ° C ± 75° C due to resistive heating. This was sufficient to cause a full wall thickness lesion in thin tissue like the atrium.²¹ Power was modulated automatically with a sensitive thermocouple system which enabled real-time temperature recording to prevent tissue boiling and steam pops. The 90 W/4 s ablation lesions were observed to be full thickness while the 25 W/20 s lesions resulted in some partial thickness lesions with many gaps between them. It was hypothesized that catheter irrigation led to an "endocardial preservation" effect at lower power longer duration ablation due to irrigation-induced endocardial cooling before resistive heating caused irreversible tissue injury.

HPSD ablation: Power Settings

The impact of power output during RF ablation on efficacy and safety has been studied in human subjects. There is significant variability in the power settings (ranging from 40 W to 90 W), types of ablation catheters

and irrigation flow used in these studies as summarized in Tables 1 and 2. Table 1 lists studies comparing high power to low power ablation strategies.²⁹⁻³⁹ Table 2 lists studies which only included high power ablation strategies.^{23, 40-42} Conventional irrigated CF-sensing catheters have been safely used to deliver high power (60-70 W) for 5-7 seconds in the left atrium.^{29, 43} Reddy et al²³ studied the concept of very high power short duration (vHPSD) ablation for PV isolation in a multicenter study. The novel CF catheter (QDot Micro catheter, Biosense Webster, Inc., Irvine, CA) used to deliver 90 W/ 4 s lesions allows for real-time temperature monitoring using microelectrodes and 6 thermocouples. The vHPSD algorithm rapidly modulates power based on the hottest surface thermocouple (cutoff at 65deg to 70degC) thereby reducing excessive tissue heating leading to steam pops.

HPSD ablation: Procedure Efficiency

Multiple studies have shown that HPSD ablation technique is associated with shorter RF times and ablation times compared to LPLD technique (Table 1).^{29, 30, 32, 35, 37, 39} Figure 2 shows RF times in the two ablation techniques across different studies. Majority of the studies show significantly lower RF times with HPSD compared to LPLD ablation. Figure 3 shows fluoroscopy times in HPSD compared to LPLD ablation across six studies. Three out of the six studies show significantly lower fluoroscopy time with HPSD versus LPLD ablation.³⁴⁻³⁶ Thus, HPSD ablation potentially results in lower radiation use and shorter overall procedure duration compared to LPLD ablation. The reduction in procedure time is important because longer ablation times have been associated with worsening heart failure in patients with left ventricular dysfunction as a result of fluid overload from catheter irrigation and increased post-procedure cognitive dysfunction.^{44, 45}

HPSD ablation: Procedure Outcomes

A randomized pilot study compared AF outcomes at different power outputs titrated to echogenic microbubble formation for PV isolation using a 3.5 mm open-irrigation tip catheter as well as an 8-mm tip catheter.³⁴ In patients undergoing ablation at 50 W (3.5 mm open-irrigation tip catheter), the freedom from AF was 82% at 6 months, compared to 78% in those undergoing ablation at 70 W (8-mm tip catheter group) and only 66% in those undergoing ablation at 35 W (3.5 mm open-irrigation tip catheter). In another study, operators reported the use of 50 W for short periods (2-5 seconds at each location) using a "dragging" technique of moving the catheter through a small area to minimize time dependent deep tissue heat transfer.⁴⁶ The reported freedom from AF was 85% after 1 or 2 ablations with a mean follow-up of 338 days.⁴⁶ Winkle et al have also reported this technique of "perpetual motion" using open irrigated catheters at 50 W with short durations for each site. Delivery of short 50 W ablations had better long-term freedom from AF and shorter procedural, left atrial and fluoroscopy times as compared with lower power longer duration ablation lesions.⁴¹

The concern with the "dragging" technique is the possibility of catheter instability and insufficient contact force at each location which can lead to tissue edema. Even with HPSD RF application, insufficient tissue contact with <5 g of contact force cannot be compensated by just increasing RF power and will lead to suboptimal lesions.²⁵ Commonly used real time surrogates for durable lesion formation are force-time integral (FTI), lesion index (LSI) and now a novel lesion quality marker, ablation index (AI) are used to increase lesion quality.⁴⁷ Catheter instability can be circumvented to some extent using steerable sheaths, atrial pacing and use of high frequency, jet ventilation.⁴⁸ The absolute time required for catheter stability is shorter with HPSD ablation which results in higher proportion of RF applications producing irreversible injury as compared to LPLD ablation.

In a recent prospective study by Yavin et al³⁹ comparing 112 patients undergoing HPSD ablation with 112 historical controls undergoing standard ablation, the authors found higher acute success with HPSD ablation (90.2% vs. 83%, $p = 0.006$), shorter RF time (17.2 +/- 3.4 min vs. 31.1 +/- 5.6 min, $p < 0.001$) as well as lower incidence of chronic pulmonary vein (PV) reconnections (16.6% patients vs. 52.2% patients, $p = 0.03$). The authors also observed that in a higher proportion of HPSD applications, catheter motion was less than 1 mm during 50% or more of the application duration, thereby allowing energy delivery with greater stability.³⁹ HPSD ablation (70 W/ 5-7 s) has also demonstrated significantly greater freedom from AF during

1-year follow-up (83.1% vs 65.1% $P < 0.013$) compared to conventional power controlled protocol (30-40 W/ 20-40 s) using a standard non-CF sensing irrigated ablation catheter.²⁹ In the Q-DOT FAST trial, using 90 W/ 4 s and thermocouple temperature cut-off at 65-70degC, PV isolation was achieved in all 52 patients acutely with success rate of 94.2% at 3 months.²³ These findings underline the importance of power as an important weighted parameter in lesion quality and durability.

HPSD ablation: Complications

There has been concern regarding using HPSD ablation with CF sensing catheters especially over the thin posterior wall of the LA due to potential complications like atrioesophageal fistula and steam pops leading to cardiac tamponade. Most previous clinical studies utilized high power and longer ablation duration to perform segmental PV isolation using non-CF catheters that resulted in an increased incidence of cardiac tamponade and PV stenosis.^{38, 49, 50} Therefore, it was thought that shortening the duration of the high power ablation might mitigate these complications. Subsequent studies shortened the ablation duration to less than 15 seconds depending on the power used and demonstrated a comparable safety profile to conventional ablation.^{23, 29, 39}

A) Esophageal Complications

The proximity of the esophagus to the posterior wall of the left atrium (LA) limits power delivery and hence the quality of lesion. There is no consensus on the best RF setting to create effective transmural lesions on the posterior wall while minimizing risk of esophageal thermal injury. Conventionally, the preferred ablation strategy over the posterior wall is a low power setting (ranging from 20-30 W). However, several studies have shown safety of HPSD technique with regards to esophageal complications. In a study utilizing late gadolinium enhancement magnetic resonance imaging (LGE MRI) to assess extent and persistence of esophageal thermal injury post AF ablation, moderate to severe esophageal enhancement was seen in 14.3% patients undergoing AF ablation with both HPSD (50 W/ 5 s) and LPLD (<35 W for 10 to 30 s) ablation strategies on same day LGE MRI.³² There were no atrioesophageal fistulas noted even with use of CF catheters in the HPSD group underlining the importance of appropriate titration of ablation parameters on the posterior wall (i.e., short duration of 5 s or less, and reduced CF on the posterior wall to 10 to 15 g).³² Posterior wall applications using 45-50 W for 2-10 s have been noted to be safe in a multicenter study by Winkle et al.³¹ In a study including 10,284 patients from 4 experienced centers, 1 atrioesophageal fistula (0.0087%) occurred in 11,436 HPSD ablations performed using 45-50 W for 2-10 s on the posterior wall, while 3 atrioesophageal fistulas (0.12%) occurred in 2,538 LPLD ablations using 35 W on the posterior wall for 20 s ($p = 0.021$). Notably, the researchers reported that 2 of the 3 atrioesophageal fistulas in the 35 W group did not undergo esophageal temperature monitoring. In another retrospective study including 76 AF patients, there was a trend towards less esophageal heating with HPSD technique (45 W for 6 s on the posterior wall with CF 8-15 g & 50 W for 6 s on the anterior wall with CF 10-20 g) compared to LPLD technique (30 W for 30 s with CF 10-30 g) with the incidence of esophageal heating being 51.2% in the HPSD group and 74.3% in the LPLD group ($p = 0.0578$).³⁰

B) Other Complications

The concern of HPSD ablation using standard ablation catheters is the potential for tissue and electrode overheating leading to char formation and steam pops. In studies using 50 W and titrating power to echogenic microbubble formation, the rate of pericardial effusion was as high as 20%.³⁴ The researchers speculated that shortening the ablation duration while using high power could have reduced the rate of complications. Real time tissue temperature monitoring may help circumvent this issue. A study using a novel temperature-sensing, diamond-tip open-irrigated catheter showed significantly reduced procedure and RF ablation times.⁵¹ However, this catheter is not contact-force sensing, with power limited to 50 W and average duration of 18.8 +/- 1.9 seconds per lesion, thus is unable to deliver very high power lesions.⁵¹ Interestingly, Kottmaier et al²⁹ compared a power-controlled ablation protocol with 70 W/ 7 s at the anterior left atrium (LA) and 70 W/ 5 s at the posterior LA to a conventional protocol with 30-40 W/ 20-40 s using a standard non-CF sensing irrigated ablation catheter (FlexAbility SE catheter; Abbott, Minneapolis, MN, USA). There were no

complications noted in any of the 197 patients studied, although esophageal temperature monitoring was not used. vHPSD ablation in a temperature-controlled mode (90 W/4 s) using the QDot Micro catheter (Biosense Webster, Inc., Irvine, CA) has been shown to be safe with no incident deaths, stroke, atriophageal fistula or PV stenosis.²³ The vHPSD ablation strategy enables modulation of power based on temperature leading to reduced risk of char formation due to less tissue overheating.^{19, 23}

Conclusions

AF ablation can be performed safely using HPSD strategy with very low complication rates, including low rates of esophageal complications. HPSD ablation has the potential to shorten procedural and total RF times and create more localized and durable lesions. The optimal power and duration of energy delivery has yet to be determined. Large clinical trials are needed to study long term efficacy and safety of novel ablation catheters for very short duration HPSD ablation and to delineate optimal power settings.

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Figure Legends

Figure 1: Schematic showing lesion geometry with standard (low power long duration) versus high power short duration (HPSD) ablation.

In homogenous tissue, radiofrequency ablation at conventional setting using low to moderate power and relatively long duration results in a smaller zone (yellow arrows) of resistive heating (red circle). The deeper tissue is largely heated because of conductive heating (curved black arrows).

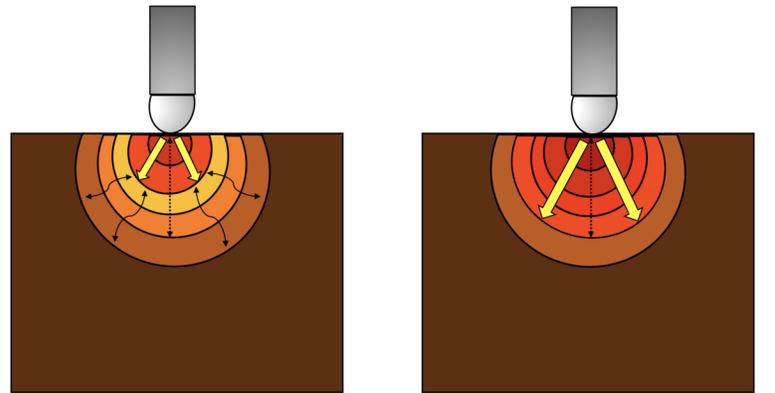
High power and short duration ablation results in a larger zone (yellow arrows) of direct resistive heating (red circles). Due to shorter duration of ablation, there is a shorter temperature decay resulting in less conductive heating. The bidirectional dotted arrows represent irreversible tissue damage (modified from an illustration by Leshem et al. *J Am Coll Cardiol EP* 2018;4:467–79).

Figure 2: Average radiofrequency (RF) times in high power short duration (HPSD) ablation compared to low power long duration (LPLD) ablation across different studies.

*Values reported as mean +/- standard deviation, except Yavin et al (reported as median with interquartile range).

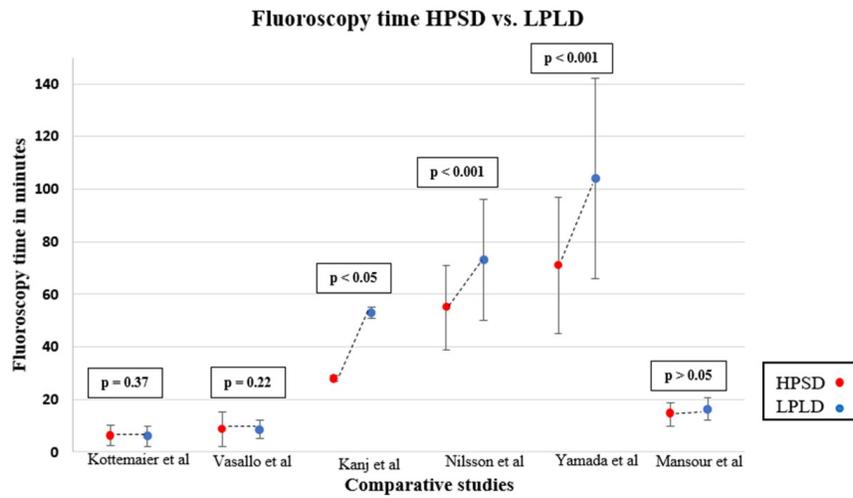
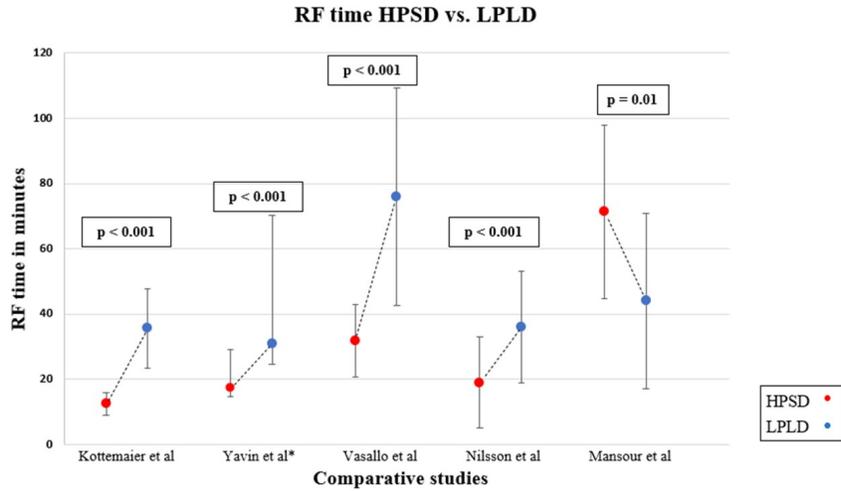
Figure 3: Average fluoroscopy times in high power short duration (HPSD) ablation compared to low power long duration (LPLD) ablation across different studies.

Values reported as mean +/- standard deviation.



A. Low power long duration (LPLD) ablation

B. High power short duration (HPSD) ablation



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