Chapter

High-Power, Short-Duration Ablation in the Treatment of Atrial Fibrillation Patients

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Abstract

Catheter ablation is the cornerstone of the rhythm control treatment of atrial fibrillation (AF). During this procedure, creating a contiguous and durable lesion set is essential to achieve good long-term results. Radiofrequency lesions are created in two phases: resistive and conductive heating. The ablation catheters and the generators have undergone impressive technical developments to enable homogenous and good-quality lesion creation. Despite recent years' achievements, the durable isolation of the pulmonary veins remains a challenge. These days, intensive research aims to evaluate the role of high-power radiofrequency applications in the treatment of patients with cardiac arrhythmias. The use of high-power, short-duration applications might result in a uniform, transmural lesion set. It is associated with shorter procedure time, shorter left atrial, and fluoroscopy time than low-power ablation. This technique was also associated with a better clinical outcome, possibly due to the better durability of lesions. Multiple clinical studies have proven the safety and efficacy of high-power, short-duration PVI.

Keywords: catheter ablation, high power, short duration, lesion formation, atrial fibrillation

1. Introduction

Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia. AF is associated with a higher risk of mortality, and it is one of the major causes of stroke, heart failure, sudden death, and cardiovascular morbidity worldwide [1, 2]. Thus, appropriate management of this arrhythmia and underlying diseases is essential.

Catheter ablation is the cornerstone of the rhythm control treatment of AF by isolating the pulmonary veins from the left atrium (pulmonary vein isolation; PVI). During this procedure, creating a contiguous and durable lesion set is essential to achieve good long-term results [3, 4]. When applying radiofrequency (RF) ablations, the lesions are created in two phases: resistive and conductive heating of the myocardial tissue [5]. Both the ablation catheters and the generators have undergone impressive technical developments to reach homogenous and good-quality lesion creation. Despite recent years' technological developments, the durable isolation of the pulmonary veins remains a challenge. Moreover, procedural complications also remained a significant issue [6–8].

Nowadays, the use of high-power (HP) radiofrequency applications is in the center of scientific research. High-power, short-duration (HPSD) ablation might result in a more uniform, transmural lesion set [9]. Thus, it can reduce procedure time and seems to be non-inferior compared to low-power (LP) ablation. This technique was associated with a better clinical outcome, possibly due to the better durability of PVI [10]. Multiple clinical studies have proven the safety and efficacy of high-power, short-duration PVI for AF ablation.

In this chapter, we will introduce the theoretical background of HPSD ablation, and we also aim to discuss the main differences with low-power ablations, also mentioning some relevant clinical trials.

2. Theoretical background of radiofrequency lesion formation

Radiofrequency catheter ablation is the first-line treatment choice for most symptomatic arrhythmias. The tissue injury caused by this energy source is thermally mediated, resulting in discrete and homogeneous lesions.

2.1 Radiofrequency energy delivery and tissue heating

The standard RF generator used for catheter ablation produces a sine wave alternating current at 350–500 kHz. The RF energy delivery is usually unipolar between the ablation catheter's tip electrode and a large surface indifferent electrode applied to the patient's skin. During RF energy delivery, the alternating electrical current traverses from the ablation catheter's tip electrode through the intervening tissue to the indifferent electrode. The passage of the electric current through the tissue results in electromagnetic heating, termed resistive heating. Resistive heating is proportional to the square of the current density; current density is inversely proportional to the square of the distance from the ablation electrode. Therefore, power dissipation per unit volume decreases dramatically with the distance, and resistive heating decreases with the distance from the ablation electrode to the fourth power. Since the region of the highest current density is at the tissue below the ablation electrode, resistive heating of the tissue only occurs in a thin layer within a very close vicinity to the ablation electrode. Deeper tissue heating occurs as a result of passive heat conduction from this narrow resistive heating zone, termed conductive heating (**Figure 1**). Temperatures above 50°C are required for irreversible myocardial injury. Of note, a non-negligible part of the delivered energy will be lost as a consequence of convective heat loss to the blood pool surrounding the ablation electrode [5].

2.2 Factors influencing radiofrequency lesion creation

Lesion formation is dependent on optimal electrode-tissue contact force (CF), RF power, size of ablation catheter tip electrode, and the duration of RF delivery.

The role of the ablation catheter tip size will not be discussed in this chapter, as the vast majority of the electrophysiology laboratories only use 3.5–4-mm tip electrodes in everyday practice, and large-tip electrodes are utilized less commonly.

Lesion size is directly proportional to the electrode-tissue contact temperature. Therefore, those factors that increase the temperature at the electrode-tissue interface (e.g., RF power and contact force) will also increase the lesion size.

It is known that the lesion size is proportional to RF power, as a higher RF power results in a larger current density at the ablation electrode leading to greater tissue heating. However, the deliverable power (and time) might be limited by an impedance rise that occurs when the temperature at the electrode-tissue interface reaches 100°C. This impedance rise can be prevented by maintaining the electrode-tissue

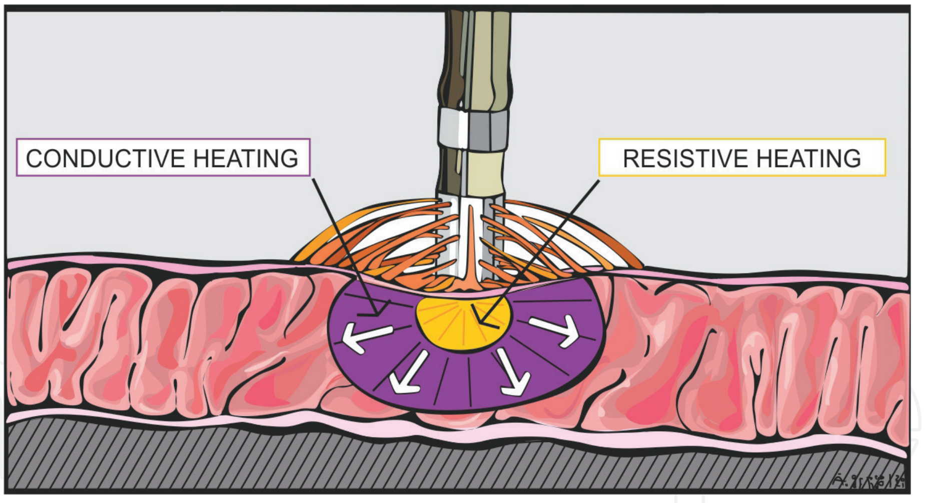

Figure 1.
Phases of lesion formation during radiofrequency ablation. The first phase is the resistive heating occurring in a thin layer of the tissue contacting the ablation electrode. The second phase is the heat conduction from the resistively heated zone to the more distant tissue layers (conductive heating).

interface temperature below 100°C by cooling the tip of the ablation catheter. A landmark *in vivo* study was presented by Nakagawa et al. [11]. They evaluated the role of presence or absence of catheter tip irrigation in eleven anesthetized dogs' tight muscles. They executed temperature measurements on the catheter-tissue surface and tissue temperatures in 3.5 mm and 7 mm depth. The main findings were that in the case of applications with irrigation of the catheter tip, electrode and electrode-tissue interface temperatures were consistently lower than the tissue temperature at 3.5 mm depth. Moreover, lesion sizes were larger in the case of irrigated ablations, most likely because they could deliver higher-power applications in this group [11, 12].

Later, studies concluded that irrigation minimally affects lesion size by cooling the tissue surface (when the applied power is the same). Larger lesions may only be created with the use of irrigation by making the delivery of higher-power levels possible. This is especially important in case of low blood flow areas where high temperatures are reached at relatively low-power levels, resulting in insufficient lesion formation. In such areas, irrigation decreases temperature during ablation and therefore makes the delivery of a higher power possible [13].

When tissue contact is poor, a larger surface area of the ablation electrode is exposed to the circulating blood pool, which results in less-efficient tissue heating. Conversely, good tissue contact results in a larger area where catheter touches the tissue and less amount of current will be lost to the blood pool. In case of low CF, a higher power might be necessary to reach an optimal degree of tissue heating. On the other hand, similarly, good lesion formation can be produced even with smaller CF in case of high-power applications [5]. A few years ago, contact force-sensing ablation catheters were introduced and nowadays, their use is a part of everyday practice. They allow to reach better durability of lesions and thus facilitate the procedure in terms of achieving better safety and efficacy [3, 14–16].

Finally, an essential determinant of lesion size is the duration of RF application. The rate of tissue heating at the electrode-tissue contact point is rapid, and steady-state temperatures are reached within a few seconds in the resistive heating zone. Conversely, deeper tissue sites have a much slower rate of temperature rise due to the time required for conductive heating. Thus, the lesion growth is rapid in the first few seconds but much slower thereafter. Studies have demonstrated that the half-time of lesion growth is approximately 7–10 s, and maximum lesion size is achieved after 30–40 s of RF energy delivery [5].

3. Experimental studies on HPSD ablation

In case of conventional, low-power RF applications, most of the thermal injury is a result of heat conduction from the resistively heated thin surface layer. On the other hand, lesion size could be increased by producing direct resistive heating deeper in the tissue by applying higher RF power. The use of a high-power level is allowed by irrigation of the ablation electrode with saline. Saline irrigation maintains a low electrode-tissue interface temperature during radiofrequency application at high power, which prevents a rapid temperature and impedance rise.

Nakagawa et al. found that by applying higher power with an irrigated catheter, a higher temperature can be measured at 3.5 mm tissue depth than at the electrode-tissue interface, which indicates that direct resistive heating occurred deeper in the tissue (rather than by conduction of heat from the surface) [11]. Other early studies also found that high-power ablations are effective; however, there was a concern regarding the safety of the procedures based on the animal study results [17]. This seems justified since high-power ablations necessitate reliable real-time feedback on lesion formation to avoid serious complications. Lesion-predicting parameters were not available before the contact force era; therefore, research interest regarding high-power RF ablation decreased transiently. However, after introducing CF-sensing catheters and lesion-predicting parameters, the topic became interesting again. If high power is applied for a long duration, it leads to a big resistive heating zone to which a large conductive heating zone is added, resulting in the creation of extensive lesions. Therefore, high-power ablations should only be applied for a short time to avoid the injury of extracardiac structures.

Nowadays, intensive research is going on examining high-power, short-duration RF ablation technology. Bourier et al. [9] showed that HPSD ablation results in a different lesion geometry (e.g., larger diameters but smaller depth) compared to conventional lower-power ablation. Still, the depth of the high-power applications seems sufficient to reach transmural lesions in the atria (**Figure 2**). Moreover, the larger diameters might improve the chance of creating a contiguous lesion set [9].

Two other preclinical studies evaluated the efficacy and safety of very high-power, short-duration RF ablation (90-W power applied for 4 s) compared to low-power, long-duration ablation in swine models. Both studies showed that HPSD ablation results in improved lesion continuity, lesion transmurality, and shorter ablation time, while the safety profile is comparable to conventional low-power ablation [10, 18].

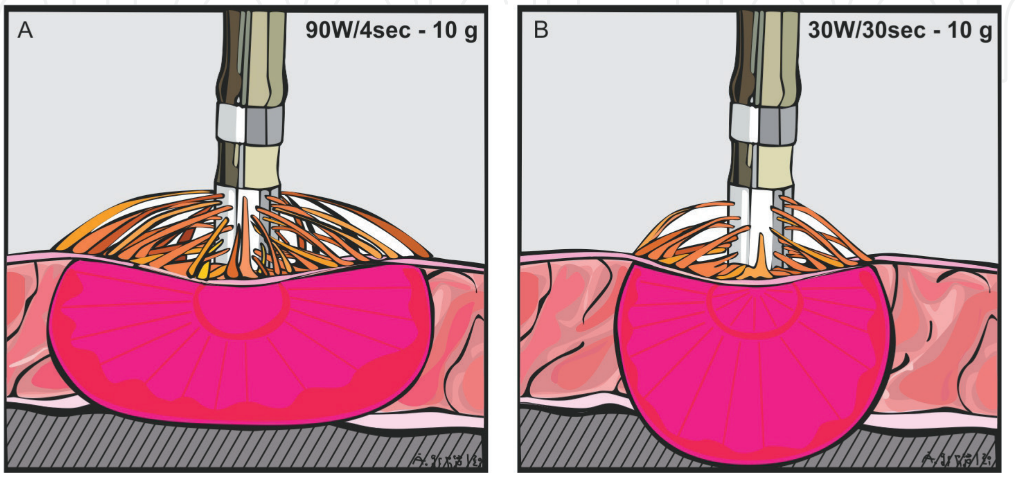

Figure 2.
Properties of lesions created by high-power, short-duration and low-power, long-duration radiofrequency ablation. The high-power, short-duration ablation (panel A) results in a different lesion geometry (e.g., larger diameters but smaller depth) compared to conventional lower-power ablation (panel B). Still, the depth of the high-power application's lesion seems sufficient to reach transmurality in the atria.

4. Clinical trials evaluating HPSD PVI

4.1 Ablation index-guided PVI with HPSD applications

According to previous studies, ablation index (AI) is a valuable marker of lesion creation during PVI procedure, minimizing the risk of AF recurrence after ablation [14, 19]. AI is calculated by a weighted formula including CF, RF time, and power so that a higher-power application can reach target AI with a shorter duration and even with high energy, RF applications' lesion creation can be monitored in real time properly. Of note, the AI is validated up to 45 W; thus, lesion creation can be reliably monitored with AI at a maximal power of 45 W. The decrease of RF time per application theoretically makes the maintenance of a stable catheter position at the given site easier, resulting in a better lesion quality. It is well known that HPSD ablation results in a different lesion geometry (e.g., larger diameters but smaller depth) compared to conventional lower-power ablation. Still, the depth of the HP applications is sufficient to reach transmural lesions in the atria. The power used for ablation can be varied based on the operating physician's decision. As we will show in this subchapter, 45–50 W was used in the majority of trials.

The use of high-power (HP) RF applications can reduce procedural time and seemed to be non-inferior to low-power (LP) ablation in a multicenter study [20]. Vassallo et al. investigated patients who underwent AF ablation with HP (50 W on the anterior wall and 45 W elsewhere in the left atrium) or LP (30 W) RF ablation power settings. HPSD was safe and efficient compared with LP ablation and was associated with a reduced procedural time and total RF time. They also concluded that HPSD might reduce the chance of esophageal injury and it may also reduce the recurrence of atrial tachyarrythmias [21]. The PVI procedure time was also decreased significantly with HP (50 W) ablation compared to conventional LP (30 W) ablation settings in a study published by Bunch et al. [22].

We would like to highlight a prospective randomized trial conducted by Wielandts et al. [23]. They randomized 96 AF patients to HPSD (45 W) or LPLD (35 W), CLOSE protocol-guided PVI and found that fluoroscopy dose and RF time are lower in case of HPSD ablation. There was no difference in terms of six-month AF-free survival between the two groups. On the other hand, postprocedural endoscopic evaluation of esophageal lesions drew attention to a narrower safety margin at the posterior wall using high power, especially when applying higher CF and reaching higher AI values [23].

Finally, we would like to mention a recent meta-analysis of 15 studies evaluating PVI with HPSD *versus* LP ablation technique. Overall, data of 3718 patients were included in the analysis. The main result is that freedom from atrial arrhythmias was higher in case of HPSD RF ablation when compared with conventional LP RF ablation. Acute PV reconnection was lower and first-pass isolation was higher with HPSD. There was no statistically significant difference in total complications between the two groups. Total procedure duration, fluoroscopy duration, and RF ablation time were all significantly lower in HPSD ablation [24].

4.2 HPSD safety endpoints: esophageal lesions

Esophageal lesions are not rare after RF point-by-point PVI, even with the use of CF sensing catheters [25, 26]. A rare but potentially lethal complication of pulmonary vein isolation is atrio-esophageal fistula [6]. Thus, besides improving efficacy, reducing the possibility of causing esophageal lesions should be the main goal of technological developments. High-power RF applications have a larger resistive heating zone, but conductive heating does not significantly affect the lesion creation if the application is kept short. On the other hand, one has to keep in mind that applying high power for a longer duration can cause extensive tissue injury damaging peri-cardiac structures such as the lung or the esophagus.

A study involving 85 patients who underwent PVI with 35-W power using CF-sensing catheters and AI guidance showed that the occurrence of esophageal injury after PVI is markedly low (1.2%), even in those cases where an intraesophageal temperature rise was detected during the procedure. They concluded that their strategy of delivering contiguous, relatively high-power, and short-duration radiofrequency applications is safe even at the posterior wall [27]. Two other larger trials involving 355 and 271 patients who underwent AI-guided PVI with 45–50-W power also concluded that HPSD technique is relatively safe. Esophageal lesions had a similar incidence in HPSD group as in the low-power group, and there was a low incidence of esophageal temperature elevation in the HPSD group [28]. They concluded that HPSD might even have a protective effect avoiding incidental esophageal injury due to the smaller lesion depth [29]. Of note, this is only true if high-power applications are kept very short on the posterior wall, but longer-duration ablations might lead to severe complications.

5. Very high-power, short-duration ablation of AF

The impressive safety and efficacy profile of high-power, short-duration PVI procedures performed with 45–50 W formed a claim to even higher-power ablations with the potential promise of making procedures even shorter while maintaining safety and efficacy. For sure, ablations with very high power should be carried out with caution to avoid the use of high CF values. Appropriate irrigation is also essential to use this technology, which is solved at the recent version of the CoolFlow (Biosense Webster) pump used for 90-W ablations with the QDOT Micro (Biosense Webster) catheter. Because of the very short time of the applications, lesion-predicting parameters such as AI do not work for this type of ablation. Visual tags of the ablated area are located at the spot where the application was started (**Figure 3**).

Long-term results of such clinical trials are likely to be published in the near future. Here, we would like to mention two studies dealing with very high-power, short-duration PVI.

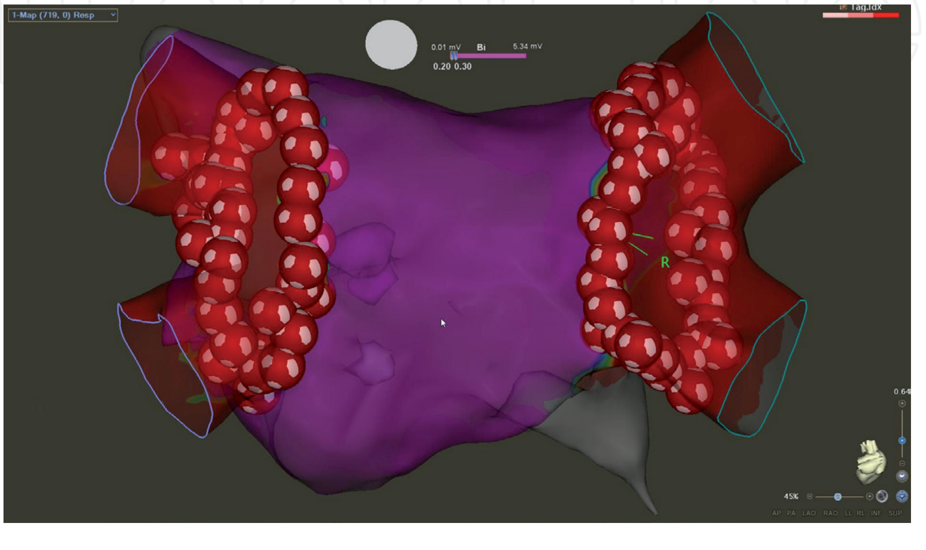

Figure 3.
Electroanatomical map of a successful pulmonary vein isolation performed with very high-power, short-duration ablation technique. All ablation tags represent single applications with 90-W power for 4 s.

Kottmaier et al. [30] compared PVI procedures performed with 70 W *versus* 30–40 W. Very high-power applications were terminated at 5 and 7 s on the posterior and anterior walls, respectively. HPSD ablation demonstrated a comparable safety profile to conventional ablation. Moreover, HPSD ablation led to significantly fewer arrhythmia recurrences after the one-year, follow-up period. Of course, RF time and procedural time were also significantly shortened by the use of HPSD [30].

A prospective, multicenter, single-arm study was published by Reddy et al. [31], aiming to evaluate the safety and efficacy of very HPSD pulmonary vein isolation with 90 W. All applications were terminated after 4 s. They demonstrated the clinical feasibility and safety of very high-power, short-duration ablation, with very low procedure and fluoroscopy times [31].

6. Conclusions

Pulmonary vein isolation is the cornerstone of rhythm-control therapy for atrial fibrillation. A few years ago, new technologies such as contact force-sensing ablation catheters were introduced and became a part of everyday practice. The routine use of CF-sensing ablation catheters improved the arrhythmia-free survival after PVI. However, the recurrence rate of atrial tachyarrhythmias remained a substantial issue. The durability of PVI depends on the accurate lesion creation and contiguity of lesions. The use of high-power, short-duration radiofrequency applications might enable the operators to create a more uniform, more contiguous lesion set; therefore, a more durable PVI can be achieved. This high rate of durable PV isolation is expected to be associated with improved clinical outcomes for atrial fibrillation ablation. Clinical studies uniformly showed that PVI with high-power, short-duration technique is safe and effective and is associated with shorter procedure and ablation times when compared with conventional low-power RF ablation. The long-term efficacy of very HPSD ablation is not available at the moment and needs to be confirmed by further trials.

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Conflict of interest

The authors declare no conflict of interest.

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