

IRRIGATED RF ABLATION: POWER TITRATION AND FLUID MANAGEMENT FOR OPTIMAL SAFETY AND EFFICACY

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INTRODUCTION

Radiofrequency (RF) catheter ablation damages cardiac tissue by heating. High frequency electrical current is passed through the myocardial tissue between the catheter electrode and a dispersive electrode on the body surface. Although the tip electrode has a low resistance, the tissue through which current must flow has a substantially greater resistance. Current flowing through this resistance generates heat, like the heating element in a toaster. This heat is conducted to the surrounding tissue. Thus there is a very hot area beneath the electrode due to resistive heating; this heat is then conducted to the surrounding tissue, where the temperature is slightly lower. Irreversible damage to myocytes occurs when tissue temperatures exceed 48° to 50°C.^{1,2} The hotter the region of maximum temperature, the larger the "kill zone" in which the temperature exceeds this critical limit. If a larger lesion is desired, one can try to increase current flow into the tissue to increase heating. This is done by increasing the driving force for current, which is the voltage. With most RF generators the parameter that is adjusted to increase heating is the power, which is measured in watts (W). Watts = voltage x current. Thus as power is increased, both current (milliamperes, or mA) and voltage are increased.

It is important to recognize that the electrode on the ablation catheter is not heated directly by the current. The temperature of the electrode increases only because it is in contact with the tissue that is being heated. Heat conducts from the tissue to the electrode. Thus, there is a difference between the tissue temperature and electrode temperature. For example, tissue temperature might reach 100°C when the temperature of the electrode is only 70°C. This difference between electrode temperature and tissue temperature increases if the electrode is cooled by irrigation or by the brisk flow of surrounding blood. In fact, the hottest region in the tissue may be just below the surface of the tissue, because the surface is cooled by flowing blood.

There is a limit to which current can be increased to increase tissue temperature and thereby enlarge the size of the ablation lesion. When any part of the

electrode reaches a temperature exceeding 75°C and certainly by 100°C, blood proteins coagulate on the electrode.³ Heating these proteins forms a layer of coagulum or char, which is a high-resistance barrier to further current flow. Formation of this coagulum produces an increase in impedance.⁴ Typically the impedance reported by the RF generator reflects the resistance to current flow through the entire circuit of catheter, connecting cable, patient, cutaneous electrode and its connecting cable. In most patients this will be somewhere between 90 and 120 ohms. A sudden increase in impedance of more than 20 ohms is almost always an indication of coagulum formation. If current delivery continues, impedance rapidly increases, reaching the limit at which the RF generator will automatically shut off. (Please refer to the Stockert User Manual for default setting for impedance.) With most RF generators, the level at which an automatic shut-off occurs is much greater than that at which the coagulum begins to form. Monitoring impedance is often useful during ablation, particularly during irrigated ablation. When the catheter is in tissue contact and tissue heating begins, the measured impedance begins decreasing. A fall at the beginning of RF application of approximately 10%, followed by a slow decrease for another 3 – 5%, is an indication of lesion creation caused by tissue heating. Small fluctuations in impedance (increases or decreases of 5 to 10 ohms) are usually caused by catheter movement; slight increases in impedance may be due to coagulum. Coagulum typically begins forming around the collar of the electrode where it meets the shaft. If only a small amount forms, it may have no effect on measured impedance. There is concern that this coagulum could be a risk for embolization, a risk that has not been proven but is of concern.

With standard RF ablation, power is typically adjusted to achieve a target temperature that is lower than that which allows coagulum to form. Temperature during RF ablation is monitored from temperature sensors (either a thermocouple or thermister) embedded in the tip electrode. This provides a useful but incomplete indication of electrode temperature.^{1,5,6} When the electrode is in flowing blood, a temperature gradient exists across its surface;

the temperature is not uniform, but can be > 15°C higher at the region that is in contact with the tissue compared to the portion that is in the bloodstream. Electrode temperature is cooler on the side that is facing the flow of blood than on the side opposite the direction of flow. Thus a portion of the electrode can reach temperatures exceeding 75°C, causing coagulum formation at a time when the temperature reported by the sensor(s) is lower. Extensive clinical experience has shown that with solid 4 or 5 mm electrodes, limiting the electrode temperature to 60°C is usually effective in preventing coagulum formation. With 8 mm electrodes, we frequently observe coagulum formation at this temperature during long ablation applications because there is a greater range of temperature across the larger electrode.

THE THERMOCOOL® IRRIGATED ABLATION CATHETER

The THERMOCOOL® Catheter allows saline to flow through a lumen in the catheter, emerging from six small holes in the tip electrode. The saline is at room temperature (e.g., 23°C) and acts to cool the electrode. Cooling the electrode in this manner allows more power to be applied, with more current flowing through the tissue, before the temperature at the surface of the tissue exceeds 75°C and coagulum begins to form. It has also been suggested that irrigation washes away blood proteins before coagulum can form on the electrode. Thus, the lesions that can be created are larger than those achieved with similar sized, nonirrigated electrodes.

Appropriate use of the THERMOCOOL® Catheter requires recognition of the important difference that irrigation causes in the temperature measured from the electrode. During mapping, irrigation is performed with a continuous infusion of 2 ml/min to maintain patency of the small pores in the electrode. During ablation, the flow rate is increased to either 17 ml/min or 30 ml/min. With the increase in flow, electrode temperature falls below 35°C. As RF current is applied, the temperature of the electrode increases, but with active electrode cooling, the electrode remains substantially cooler than the underlying tissue. Typically, the temperature increases from 35°C to 38 – 45°C. Substantial lesions may be created even though measured electrode temperature remains below 40°C. During irrigation at 17 ml/min with up to 30 W or 30 ml/min with up to 50 W, the electrode temperature generally remains below 50°C. Reaching 50°C can indicate that the irrigation pump has been shut off or is disconnected from the catheter. This can also be an

indication of inadequate cooling or coagulum formation blocking the irrigation ducts; immediate assessment is warranted. With tissue heating, impedance does fall, similar to that observed with nonirrigated RF ablation. Failure of impedance to decrease with initiation of RF energy suggests that the electrode catheter is not in good contact.

Because electrode temperature is a poor indicator of tissue heating, it is recommended that irrigated RF ablation be performed in a power-control mode, rather than a temperature-control mode. In the temperature control that is often used with nonirrigated ablation, the RF generator is set to a target temperature and maximum power, and the generator automatically increases power to reach the target temperature. In the power-control mode, recommended for the THERMOCOOL® Catheter, the operator specifies the power setting and gradually increases or decreases power as desired. An upper temperature limit is set for safety, so that the generator will automatically shut down or reduce power if the upper temperature limit is exceeded. Operating in the power-control mode allows the operator to exert more control over energy delivery. Thus, if low power (15 to 20 W) produces the desired effect of reduction of the recorded electrogram or emergence of double potentials indicative of conduction block with a temperature that reaches only 40°C, the power can be kept low to avoid excessive energy delivery and reduce the risk of steam pops. Pops occur when temperature reaches 100°C either in the tissue or at the electrode tip-tissue interface. Sudden formation of steam can result in an explosion, sometimes audible as a “pop,”⁵ that can cause cardiac perforation.^{1,5,6} It is likely that the chance of a steam pop increases with greater RF energy. If low power is ineffective, power is increased by the operator. If greater than 30 W is required, the irrigation flow rate is increased to 30 ml/min.

FLUID ADMINISTRATION DURING CATHETER ABLATION WITH THE THERMOCOOL® CATHETER

Saline irrigation from the THERMOCOOL® Catheter goes directly into the patient’s bloodstream. Awareness and management of this volume load is important. In susceptible patients, administration of this volume load can cause acute pulmonary edema. The amount administered depends on the flow rate, number of RF lesions, and duration of each lesion. The flow rate recommended for use with the THERMOCOOL® Catheter is shown in Table 1, and the number of lesions that would result in administration of one liter of saline for different

lesion durations and flow rates is shown in Table 2. It is recommended that the irrigation rate be increased to the ablation rate for 5 seconds before ablation and continued for 5 seconds after ablation. As shown in Table 2, one liter of saline is infused into the patient with every 29 RF lesions if the duration of application is 1 minute with a flow rate of 30 ml/min. If 2-minute RF applications with an irrigation flow of 30 ml are used, the patient will receive one liter of saline with every 15 RF applications. To appreciate the potential impact on the patient's volume status, consider that one liter of normal saline contains 9 grams of sodium chloride, which includes 3.6 grams of sodium. Patients with heart failure or hypertension are typically advised to reduce the sodium in their diet to 2.4 grams daily.

In addition to the volume load, each liter of saline irrigation contains 1,000 Units of heparin. Thus, there is the potential for greater anticoagulation than would be achieved without irrigation. Monitoring activated coagulation times (ACT) is prudent during long procedures.

TABLE 1. RECOMMENDED IRRIGATION RATES

	RF Power (watts)	Irrigation Rate (ml/min)
Between lesion applications during mapping	0	2 ml/min
5 sec before to 5 sec after RF	< 30 W	17 ml/min
5 sec before to 5 sec after RF	30 - 50 W	30 ml/min

TABLE 2. NUMBER OF RF APPLICATIONS TO INFUSE 1000 ML OF SALINE FOR DIFFERENT INFUSION RATES AND RF DURATIONS

Flow (ml/min)	Duration of each RF application (sec)	Number of RF lesions/liter of saline*	Total minutes of RF for 1 liter of saline
17	60	50	50
17	90	35	53
17	120	27	54
30	60	29	29
30	90	20	30
30	120	15	31

*includes 5 seconds of flow before and after each lesion

CONSEQUENCES OF SALINE ADMINISTRATION DURING IRRIGATION

Approximately 60% of total body weight in women and 50% in men is water. The majority -- 55% to 75% -- of total body water is located within cells. The remainder (25% to 45%) is extracellular.

Approximately a quarter of the extracellular water is located in the vascular system, with the remainder in the interstitial space. Total blood volume is approximately 7% of body weight. The total solute concentration is tightly regulated to an osmolality of 285 – 295 mosm largely through renal mechanisms and diffusion of water between the vasculature, interstitial and intracellular spaces. There is a continuous flow of saline from the intravascular space across capillary walls into the interstitial space from which lymphatics return it back to the vascular space. Flow of water from the intravascular space into the interstitial space is determined by the balance between hydrostatic and osmotic pressure within the capillaries and that in the interstitium.

Administration of a volume load, such as saline irrigation, produces an increase in venous pressure, which increases capillary pressure. The amount of fluid leaving the vasculature increases. If lymphatic drainage is able to keep up with the increase in fluid, no symptoms occur. The increase in saline load also results in an increase in renal excretion of saline to restore homeostasis. If, however, the capacity of the lymphatics is exceeded, fluid accumulates in the interstitial spaces, causing edema. In the lungs, this edema increases the work of breathing and, when severe, can impair the exchange of oxygen from alveoli to blood. As the severity increases, fluid accumulates within the alveoli themselves, which may lead to increased respiratory rate, agitation, dyspnea, evidence of sympathetic activation with diaphoresis and tachycardia. Symptoms are worse in the supine position, as on the catheterization table. Patients who are minimally sedated may become agitated. Symptoms are absent in those who are heavily sedated or under general anesthesia. Peripheral oxygen saturation, however, will eventually begin to fall. Elevated filling pressures may be recorded from a pulmonary artery catheter (PCWP, pulmonary capillary wedge pressure) or left atrial transeptal sheath if these are present. Obvious edema in the extremities or dependent areas (over the lower back in a supine patient) is a relatively late manifestation of volume administration.

Treatment is to ensure adequate peripheral oxygenation with administration of oxygen and to initiate diuresis with intravenous administration of potent diuretics. In patients with poor cardiac function, administration of an inotropic agent, such as dopamine, may be required to attempt to improve renal perfusion and to acutely lower cardiac filling pressures by increasing cardiac output. In severe

cases, endotracheal intubation and assisted ventilation may be required to achieve adequate peripheral oxygenation until diuresis is achieved.

PREVENTION OF COMPLICATIONS FROM VOLUME ADMINISTRATION

Before the procedure – identify the patient at risk for volume overload

Most patients will respond to the volume infused through the irrigation catheter by excreting it through the kidneys, increasing urine output. However, many patients who undergo ablation have factors that reduce their ability to handle this volume load, making them susceptible to developing pulmonary edema or heart failure during or after the procedure (Table 3). Patients with congestive heart failure or renal insufficiency and the elderly are particularly susceptible.

TABLE 3. FACTORS THAT PREDISPOSE TO PULMONARY EDEMA

1. History of heart failure
2. Heart disease (even with no prior history of heart failure)
 - a. Aortic valve disease
 - b. Mitral valve disease
 - c. Depressed LV ejection fraction (e.g., < 35%)
 - d. Cardiomyopathy
 - e. Previous myocardial infarction
 - f. Incessant tachycardia
3. Renal insufficiency (e.g., serum creatinine > 1.5 mg/dl)
4. Diabetes mellitus
5. Advanced age
6. Multi-system disease (e.g., autoimmune disease) or aggressive therapy (chemotherapy or radiotherapy)

Prior to ablation, it is prudent to consider these factors and to plan to manage the fluid administered, with administration of diuretics if needed. Patients with heart failure should ideally have their volume status optimized so that they are not volume overloaded prior to starting the procedure. Ablation with the THERMOCOOL® Catheter should not be attempted in patients who cannot tolerate administration of additional saline, particularly if they have renal insufficiency such that they may not respond well to diuretics. Patients who have heart failure with dyspnea at rest or minimal exertion (NYHA class III or IV), cardiogenic shock, acute myocardial infarction, or severe renal insufficiency (serum creatinine > 2.5 mg/dl) should usually not be considered candidates for ablation with this technology. Even in patients without these factors, it is prudent to assess blood electrolytes, markers of renal or liver failure, and left ventricular ejection fraction, as severe abnormalities indicate impaired ability to excrete the volume that may be administered during ablation.

During the procedure

Continuously monitor intake and output. If a long procedure is anticipated, placement of a urinary catheter may be considered. If fluid balance becomes markedly positive (e.g., > 1 – 1.5 liters), administration of an intravenous diuretic agent such as furosemide may be reasonable. Be aware that the development of agitation, increase in respiratory rate, or falling oxygen saturation may be manifestations of volume overload, warranting diuresis. Blood electrolytes, especially potassium, should be monitored in cases of frequent administration of diuretics.

After the procedure

Review the patient's fluid balance. In some cases, symptoms of volume overload may not become apparent until after the procedure. Consider instituting diuresis if the intake/output is markedly positive. A large diuresis can also deplete serum potassium and magnesium. If administration and diuresis of large volumes has occurred, consider checking electrolytes and administering appropriate supplementation if warranted.

REFERENCES

1. Stevenson WG, Cooper J, Sapp J. Optimizing RF output for cooled RF ablation. *J Cardiovasc Electrophysiol.* 2004;15:S24-7.
2. Nakagawa H, Wittkampf FH, Yamanashi WS, Pitha JV, Imai S, Campbell B, Arruda M, Lazzara R, Jackman WM. Inverse relationship between electrode size and lesion size during radiofrequency ablation with active electrode cooling. *Circulation.* 1998;98:458-65.
3. Matsudaira K, Nakagawa H, Wittkampf Fred HM, Yamanashi W, Imai S, Pitha J V, Lazzara R, Jackman WM. High incidence of thrombus formation without impedance rise during radiofrequency ablation using electrode temperature control. *PACE.* May 2003; 26:1227-37.
4. Haines D. Biophysics of ablation: application to technology. *J Cardiovasc Electrophysiol.* 2004;15:S2-S11.
5. Scavee C, Jais P, Hsu LF, Sanders P, Hocini M, Weerasooriya R, Macle L, Raybaud F, Clementy J, Haissaguerre M. Prospective randomised comparison of irrigated-tip and large-tip catheter ablation of cavotricuspid isthmus-dependent atrial flutter. *Eur Heart J.* 2004;25:963-9.
6. Jais P, Haissaguerre M, Shah DC, Takahashi A, Hocini M, Lavergne T, Lafitte S, Le Mouroux A, Fischer B, Clementy J. Successful irrigated-tip catheter ablation of atrial flutter resistant to conventional radiofrequency ablation. *Circulation.* 1998;98:835-8.



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