

Radiofrequency and Microwave Energy Sources in Surgical Ablation of Atrial Fibrillation: A Comparative Analysis

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ABSTRACT

Background. Due to its complexity and risk of bleeding, the Maze III procedure has been largely replaced by surgical ablation for atrial fibrillation (AF) using alternative energy sources. Radiofrequency (RF) and microwave (MW) are the most commonly used energy forms. In this study, we sought to compare these energy modalities in terms of clinical outcomes.

Methods. Two hundred five patients underwent surgical ablation of AF from October 1999 to May 2004 at our institution via an endocardial approach. Patients were categorized into 2 groups: RF and MW. Baseline characteristics, operative details, and clinical outcomes were compared between the 2 groups. Rhythm success was defined as freedom from AF and atrial flutter as determined by postoperative electrocardiograms.

Results. One hundred twenty patients (58.5%) were ablated using RF, whereas 85 (41.5%) were ablated with MW. Most of the patients had persistent AF in both the RF and MW groups (85.7% versus 80.0%, respectively; $P = .363$). Intraoperative left atrial size was 6.4 ± 1.7 cm for the RF group and 6.4 ± 1.7 cm for the MW group ($P = .820$). Postoperative rhythm success at 6 and 12 months was 72.4% versus 71.4% ($P = .611$) and 75.0% versus 66.7% ($P = .909$) for the RF and MW groups, respectively. Hospital length of stay was comparable for both groups (15.4 ± 14.0 versus 13.3 ± 13.9 days; $P = .307$). Postoperative survival at 6 months, 1 year, and 3 years was 90.4%, 89.5%, and 86.1% for RF patients compared to 87.9%, 86.5%, and 84.4% for MW patients, respectively (log rank $P = .490$).

Conclusions. RF and MW energy forms yield comparable postoperative rhythm success, hospital length of stay, and

postoperative survival. Both sources are rapid, safe, and effective alternatives to "cut and sew" techniques for surgical treatment of AF.

INTRODUCTION

The Maze procedure was first introduced in 1989 by Dr. James Cox as a novel surgical treatment for chronic atrial fibrillation (AF) [Cox 1991]. This procedure was designed to prevent macro-reentrant circuits by creating a series of incisions within both the left and right atria. The development of left atrial dysfunction as well as the inability for patients to generate sinus tachycardia in response to exercise prompted the Maze procedure to be modified twice [Cox 1995]. These efforts resulted in the Cox-Maze III procedure, which maintained high success rates and became the gold standard for surgical treatment of AF. Despite its efficacy in treating AF, the Cox-Maze III procedure is associated with high morbidity due to technical complexity, increased operative times, and bleeding from incision sites [Melo 1997]. More recently, there has been a growing interest in simplifying this procedure using alternative energy sources. Radiofrequency (RF) and microwave (MW) are the two most commonly used energy sources in surgical ablation of AF. However, few studies with adequate sample sizes have compared these sources with regard to their clinical outcomes. In this review, we present our institution's experience with RF and MW energy sources.

MATERIAL AND METHODS

Patient Population

Patients who had AF for at least 6 months or patients who had AF for more than 3 months with failed cardioversion attempts undergoing concomitant procedures were selected for surgical ablation for AF (Table 1). The energy source used depended on the operating surgeon's preference. Data were prospectively collected at a single institution from October 1999 to May 2004 for 205 patients who underwent surgical ablation for AF via an endocardial approach. Patients were categorized into 2 groups: RF and MW. The groups were then compared with regards to baseline characteristics, operative details, postoperative rhythm success, incidence of stroke, and

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Table 1. Concomitant Procedures*

Procedure	n	Percent
Mitral valve procedure only	81	39.5
Aortic valve procedure only	7	3.4
CABG only	8	3.9
CABG + valve procedure	37	18.0
Double-valve procedure	37	18.0
Triple-valve procedure	8	3.9
Congenital procedure	10	4.9
Lone AF	2	1.0
Other procedures	15	7.3

*CABG indicates coronary artery bypass grafting; AF, atrial fibrillation.

postoperative survival. Postoperative rhythm success was defined as freedom from AF and atrial flutter at the time of evaluations made at 3 months, 6 months, 1 year, and 2 years from the date of operation.

Ablation Systems

RF ablation was performed using a unipolar probe (Cobra; Boston Scientific-EP Technologies, San Jose, CA, USA) and surgical RF generator (Cobra ESU; Boston Scientific-EP Technologies). The surgical probe consists of 7 flexible electrodes that can be selectively activated for the desired lesion length. MW ablation was performed using the MW ablation system (Guidant, Santa Clara, CA, USA), which consists of a surgical ablation probe (FLEX 4) connected by a coaxial cable to a MW generator.

Statistical Methods

Data are represented as frequency distributions and percentages. Values of continuous variables were expressed as a mean $\pm$ standard deviation. Continuous variables were compared using Student *t* test, whereas categorical variables were compared by means of χ^2 test. For all analyses, a *P* value of less than .05 was considered statistically significant. Kaplan-Meier analysis was used to calculate actuarial survival at 1, 3, and 5 years postoperatively, along with a log rank *P* value when comparing different groups. All data were analyzed utilizing SPSS 11.5 (SPSS, Chicago, IL, USA).

RESULTS

Preoperative Characteristics

Preoperative characteristics of patients are represented in Table 2. Baseline characteristics of patients in the RF and MW groups were similar, with the exception of mean age, which was significantly lower in the RF group as compared to the MW group (62.3 ± 15.7 versus 67.1 ± 11.8 respectively; *P* = .019). The majority of patients in both RF and MW groups were in persistent AF at the time of surgery (85.7% versus 80.0% ; *P* = .363). Comorbidities including presence of diabetes, hypertension, congestive heart failure, and history of reoperation were also comparable between groups.

Table 2. Baseline Characteristics*

	Radiofrequency	Microwave	<i>P</i>
Age, years	62.3 ± 15.7	67.1 ± 11.8	.019
Sex	Female	50.4%	43.5%
Race			
White	64.2%	78.8%	.024
Black	7.5%	3.5%	.233
Other	28.3%	17.6%	.077
Paroxysmal AF	14.3%	20.0%	.363
Persistent AF	85.7%	80.0%	.363
Diabetes mellitus	12.0%	13.4%	.761
Hypertension	44.4%	36.6%	.268
Renal failure	8.5%	8.5%	.998
Congestive heart failure	32.5%	31.7%	.909
Reoperation	21.2%	26.8%	.355
Previous MI	10.3%	13.4%	.493

*AF indicates atrial fibrillation; MI, myocardial infarction.

Operative Details

The percentage of RF ablation use compared to MW ablation use was significantly lower in cases performed via a minimally invasive approach. Mitral valve annulus lesion formation was comparable between groups (64.2% versus 68.2% ; *P* = .545) whereas the formation of the flutter lesion (30.0% versus 15.3% ; *P* = .015) and left atrial appendage lesion (65.8% versus 32.9% ; *P* < .001) were significantly higher in the RF group (Table 3). There was no difference in mean left atrial diameter between RF and MW patients, as determined by intraoperative transesophageal echocardiography, (6.4 ± 1.7 cm versus 6.4 ± 1.7 cm; *P* = .820).

Early Postoperative Outcomes

There was no difference in postoperative 30-day mortality (3.4% versus 3.5% ; *P* = .966). Incidence of postoperative stroke was 3.6% versus 4.0% for RF and MW groups, respectively. Mean hospital length of stay was 15.4 ± 14.0 days for RF patients as compared to 13.3 ± 13.9 days for MW (*P* = .307) patients.

Postoperative Rhythm Success

Postoperative freedom from AF and atrial flutter are represented in Figure 1. At all time points, rhythm successes were

Table 3. Operative Details

	Radiofrequency	Microwave	<i>P</i>
Surgical Approach			
Sternotomy	95.0%	78.8%	<.001
Minimally invasive	5.0%	21.2%	<.001
Lesion sets			
Pulmonary vein lesion	94.2%	98.8%	.090
Mitral annulus lesion	64.2%	68.2%	.545
Left atrial ablation lesion	65.8%	32.9%	<.001
Flutter lesion	30.0%	15.3%	.015

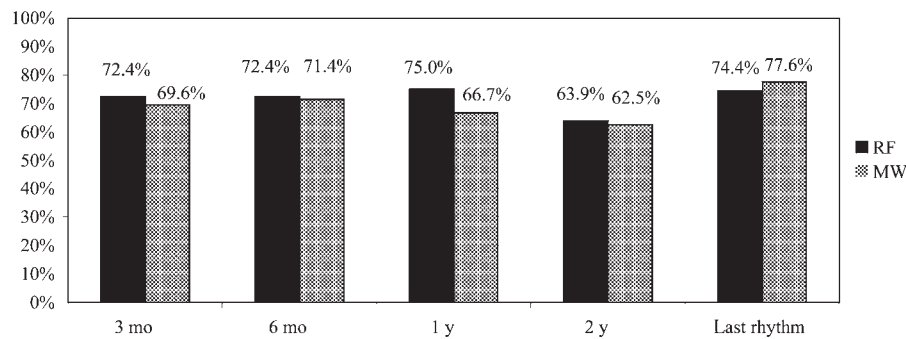


Figure 1. Freedom from atrial fibrillation and atrial flutter.

similar between RF and MW groups. Mean rhythm follow-up of patients was significantly higher in the RF group as compared to the MW group (1.4 ± 1.0 years versus 0.8 ± 0.6 years; $P < .001$), indicating the earlier availability of the RF source. Changing trends in surgical ablation for AF are shown in Figure 2.

Postoperative Survival

As depicted in Figure 3, postoperative survival determined by Kaplan-Meier analysis at 6 months, 1 year, and 3 years was also similar for RF and MW patients (90.4%, 89.5%, and 86.1% versus 87.9%, 86.5%, and 84.4%, respectively; log rank $P = .490$).

DISCUSSION

AF is a rapidly growing epidemiological problem that affects 6% of Americans over the age of 65 [Feinberg 1995]. Recent advancements in medical therapies for long-standing AF have provided options that include pharmacological cardioversion, catheter ablation, and surgical ablation. Pharmacological cardioversion is associated with side effects and offers only limited efficacy [Van Gelder 1996; Boriani 2004]. Although it remains a successful treatment for atrial flutter, catheter ablation for AF has been associated with procedure-related complications, and reduced long-term success rates, as well as a necessity for multiple interventions [Natale 2000].

Alternatively, the Cox-Maze procedure emerged as the gold standard surgical treatment for long-standing AF with more than a 90% cure rate [Cox 2000]. Despite its success, the Cox-

Maze procedure is not widely applied due to technical difficulties, increased operative times, and bleeding from incision sites. More recently, there has been an effort to simplify this procedure using alternative energy sources that include RF, MW, cryoablation, laser, and ultrasound in lieu of the "cut and sew" technique [Williams 2004]. Although these sources have different mechanisms of action, the goal is to create an electrically isolating lesion that will interrupt the multiple wavelets that cause aberrant electrical activity within the atria.

RF is an unmodulated alternative current at 500 to 1000 KHz. In unipolar RF ablation, current flows to the tip of the probe from the generator and passes through the tissue. The circuit is completed by the grounding pad. Current passing through the tissue generates heat by resistance, which mainly occurs in the first 1 millimeter of the tissue. This flow leads to a safe but relatively inefficient ablation. MW energy causes oscillation of water dipoles in tissue and this kinetic energy generates heat in turn. The current ablation device operates at a frequency of 2450 MHz. MW has the ability to propagate through blood, desiccated tissue, and scars, making it suitable for atrial ablation. These properties also permit MW to create deeper lesions than RF. With regards to safety of energy sources, esophageal injury is the most feared complication related to the left atrial ablation. Doll and coworkers recently reported an esophageal perforation incidence of 1% in a series with 387 patients undergoing left atrial ablation using RF [Doll 2003]. Gillinov also described a fatal esophageal injury during RF ablation [Gillinov 2001]. On the other hand, esophageal injury using MW ablation has not been reported.

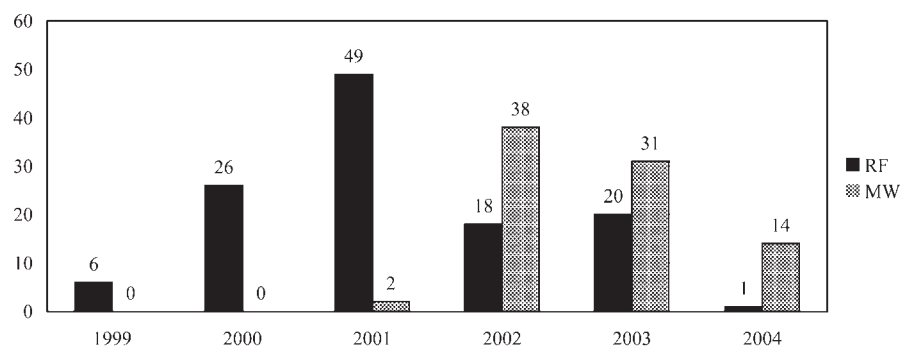


Figure 2. Number of patients undergoing endocardial Maze procedure from October 1999 to April 2004.

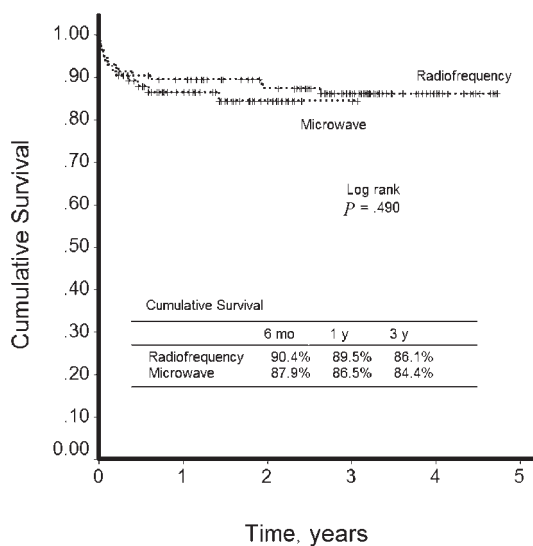


Figure 3. Postoperative survival: Kaplan-Meier analysis.

At our institution, we have not so far experienced esophageal injury during left atrial ablation using either energy source. We believe that many factors, including handling of the device, lesion pattern, temperature of the probe, and application time, play a role in esophageal injury. To minimize this risk, we encourage removing the transesophageal echocardiography probe during the ablation procedure.

This study shows significant differences in operative approach and the use of lesion sets between RF and MW patients. Patients undergoing RF ablation had additional lesion sets, including left atrial appendage and flutter lesions. Use of pulmonary vein and mitral annulus lesions were similar in both groups. Moreover, minimally invasive approaches were much more common in MW groups. These differences are not attributed to the energy sources. As depicted in Figure 2, MW is a newer energy source than RF and was available for use in the market later than RF. During this period, the surgical approach to AF has changed as the understanding and experience with the surgical treatment of AF increased. Therefore, differences in baseline characteristics and operative preferences between RF and MW groups actually reflect evolving approaches and changing trends in the surgical treatment of AF. We have witnessed an increase in the use of minimally invasive techniques, including minithoracotomy incisions as well as thoracoscopy, over traditional incisions in the treatment of AF. Our surgeons less commonly perform additional lesion sets, especially in paroxysmal cases. We have left out extra lesion sets due to the theory that 94% of paroxysmal AF is triggered around pulmonary veins, as described by Haissaguerre and colleagues. [Haissaguerre 1998].

RF and MW patients had similar 30-day mortality and incidence of stroke following the procedure, both of which were less than 4%. This finding is not surprising because 99% of our cases are concomitant procedures that involve coronary artery bypass grafts, valve replacements, both, or others. Another important finding in this study was the postoperative rhythm success rates, which were similar for both RF and

MW groups at each time point. We report 72.4% and 71.4% 6-month rhythm success rates for RF and MW patients, respectively ($P = .909$). This finding is in parallel with previous RF and MW studies that reported between 70% to 80% postoperative rhythm successes [Khargi 2005]. As depicted in the Kaplan-Meier curve, both RF and MW groups have greater than 84.0% cumulative postoperative survival rates at 3 years. Most of the deaths occur within 1 year following the surgery in which patients might also suffer from complications related to the primary cardiac pathology and concomitant operations.

In conclusion, surgical ablation of AF is a safe and effective procedure in restoring sinus rhythm. Both RF and MW systems are equivalent with regards to efficacy and safety in treating AF with promising clinical outcomes. It is our hope that further advancements in the field might eventually provide an endoscopic beating heart approach using alternative sources with higher rhythm success.

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