Left atrial maze procedure using diathermy and high-frequency ultrasound as an adjunct to mitral valve replacement in mitral valve disease with atrial fibrillation: a comparative study

Santosh Kumar Pandey^{1,2} · Kakali Ghosh³ · Gautam Sengupta¹ · Gautham Shetty¹

Received: 31 March 2019 / Revised: 3 August 2019 / Accepted: 8 August 2019 / Published online: 30 August 2019
© Indian Association of Cardiovascular-Thoracic Surgeons 2019

Abstract

Purpose Mitral valve disease is often complicated with atrial fibrillation (AF). Conventional treatment for AF has now been replaced by various energy sources. Our purpose was to evaluate a cost-effective and efficient energy source for performing the Maze procedure. We evaluated and compared diathermy and high-frequency ultrasound as energy source to create maze lines, in terms of outcome.

Methods Forty patients with mitral valve disease requiring mitral valve replacement and in atrial fibrillation were included in the study. Twenty patients underwent the Maze procedure using diathermy and 20 using high-frequency ultrasound (Harmonic scalpel probe). All Maze lines were made endocardially from within the cavum of the left atrium isolating the pulmonary veins. All patients were assessed by standard 12 lead electrocardiogram (ECG) in the postoperative period as well as in each follow up visit. Left atrial appendage was ligated in those having left atrium (LA) clot.

Results Sinus rhythm was restored in 95% of patients in the immediate postop period in diathermy group as compared to 90% in the high-frequency ultrasound group. At 3 months, 90% were in sinus rhythm in the diathermy group and 85% in the high frequency ultrasound (HFU) group. Statistically significant differences between groups were observed in the following variables: cardiopulmonary bypass (CPB) time ($p = 0.011$), cross clamp time ($p = 0.019$), maze time ($p = 0.00$), and in hospital stay ($p = 0.05$).

Conclusion Both energy sources were safe, time sparing, effective, and simple; however, the diathermy took less time to perform maze than the HUF and the total CPB time and cross clamp time was less in the diathermy group.

Keywords Atrial fibrillation · Diathermy · High-frequency ultrasound

Introduction

AF is a frequent complication in patients with mitral valve disease causing systemic embolization, cardiac chamber dilatation, and decreased cardiac output [1]. Adequate treatment of mitral

valve disease often does not relieve the cardiac rhythm disorder and AF persists or recurs [2].

However, it is an established fact that the atrial contraction during the late diastolic filling phase with the heart in sinus rhythm contributes around 20 to 30% increase in the ejection fraction as atrial kick. This is more so in compromised hearts. So, treating AF during mitral valve replacement or repair with the goal to attain a sinus rhythm not only helps in early postop recovery but also has a potential to allow the patient to have better quality of life without the attendant risk of thromboembolism.

Maze procedure was proposed by James Cox as an effective surgical treatment for patients with atrial fibrillation [3]. This method can be combined with surgery for organic heart disease like mitral valve disease. However, from the surgical

✉ Santosh Kumar Pandey
drsantoshpandey@gmail.com

¹ Department of Cardiothoracic and Vascular Surgery, IPGME&R and SSKM Hospital, Kolkata, West Bengal, India

² IPGME&R and SSKM Hospital, Harish Mukharjee road, Bhowanipur, Kolkata, West Bengal 700020, India

³ Department of Cardiac anaesthesia, IPGME&R and SSKM Hospital, Kolkata, West Bengal, India

point of view, it is a complex and demanding procedure that prolongs significantly the aortic cross clamp time and cardio pulmonary bypass time which in turn increase peri- and post-operative morbidity. For this reason, this procedure has not gained wide spread clinical application.

The demonstration by Haissaguerre and associates [4] that majority of AF originates within the pulmonary veins orifices. This trigger zone has recently emerged for the design of several ablation devices capable of isolating these trigger zones. Advances in the understanding of the pathogenesis of AF and development of new ablation technologies enable surgeons to perform pulmonary vein ablation and create strategically placed linear left atrial lesions rapidly and safely [5].

The Maze procedure has evolved over time. The Maze IV procedure is a simpler modification of the cut and sew technique where it has been replaced by various energy sources such as radiofrequency, high-frequency ultrasound, laser, and microwave [5]. In isolated paroxysmal or persistent AF, radio-frequency ablation of the region of the pulmonary vein near the junction with the atria is practiced with variable results [6].

It was our contention that if a left atrial Maze is done during mitral valve replacement, the result might be even better due to the fact that the primary lesion in mitral valve disease secondarily affects the left atrium and the focus for ectopic fibrillatory impulses are more likely to be generated in the left atrium itself.

The utilization of diathermy as an energy source in the treatment of AF has generated positive early clinical results. Although this technology is easily available, simple to use, and affordable, even then, it has not been well studied for this indication [7–10].

High-intensity focused ultrasound has become an attractive option for treatment of AF and other arrhythmias. It can create rapid tissue modification in confined tissue volumes and capable of inducing intramural lesions at various depths [11–13]. The high-frequency ultrasound energy delivered via Harmonic Scalpel which primarily used a cutting and coagulating device has not been so far used for creating ablation lines in LA Maze.

We planned to use diathermy and high-frequency ultrasound (Harmonic scalpel) as the energy source for creating Maze lines. In our study, we evaluated the outcome and results for LA Maze in patients with mitral valve disease complicated by AF and also compared the efficiency of both energy sources.

Material and methods

Between November 2013 and June 2015, 40 patients were enrolled, 20 in each group. All patients had mitral valve disease with atrial fibrillation of varied duration. All underwent mitral valve replacement along with the Maze procedure using

either diathermy or high-frequency ultrasound (Harmonic Scalpel probe) and any other additional procedure such as aortic valve replacement, tricuspid annuloplasty, and coronary artery bypass grafting (CABG) was done whenever required. Diathermy was used in odd number-assigned patients and high-frequency ultrasound (Harmonic scalpel) was used in even number-assigned patients. Ethical committee clearance was taken before starting this study and each patient gave informed and written consent to undergo the maze procedure.

Inclusion criteria

All patients (both male and female) with organic mitral valve disease having AF requiring mitral valve replacement were included in our study.

Exclusion criteria

The following subjects were excluded from the study group:

1. Patient with only AF without indication for mitral valve replacement (MVR)
2. Paroxysmal AF
3. Evidence of active infection (acute valvular endocarditis)
4. Calcification of the left atrium
5. Left ventricle (LV) function < 25%
6. Extensive and diffuse coronary artery disease
7. Patients unwilling to undergo procedure
8. Absolute contraindication for anticoagulant therapy
9. Previous catheter ablation for AF
10. Women who are pregnant

Record of study parameters

Data sheet entry of different variable parameters was done based on ECG and echocardiographic findings. Study was mainly focused on the outcome of the procedure in terms of restoration to a regular or sinus rhythm, need of antiarrhythmic drugs (digoxin, amiodarone), need of inotropic support, need of temporary or permanent pacing, aortic cross clamp time, maze procedure time, and total CPB time.

Patients were observed immediately after the completion of surgery, on the first postop day, second postop day, just before discharge or seventh postop day, after 15 days, after 1 month, and 3 months for return of sinus rhythm. All patients were followed-up by 12 lead ECG and echocardiography, and adjustment of medication like antiarrhythmic and anticoagulant was done accordingly.

Study tools

We used a diathermy machine, high-frequency ultrasound (Harmonic scalpel), CPB machine, echocardiography machine, and ECG machine.

Surgical technique

All patients were put on cardiopulmonary bypass, conventional bicaval cannulation done, aorta cross clamped, and mitral valve was replaced through the LA approach along with other valve replacement when required. Left atrial Maze procedure was done using diathermy in odd number-assigned patients and high-frequency ultrasound in even number-assigned patients. Diathermy was set at 40 in coagulation spray mode with contact time of 1 to 2 s to create atrial lesion. The theoretical energy delivery was approximately 40 J for every second of cauterization. Lesions were created by slow progression of the cautery pencil such that the tissue blanched when the cautery arc was moved against the tissue. The Harmonic scalpel was used to deliver high-frequency ultrasound. It was set at 3 so that the probe vibrates at 55,000 Hz. It produces coaptive coagulation with denaturation of protein with less lateral damage at this energy level.

Standard right-sided left atriotomy was made parallel to the interatrial groove. Mitral valve was replaced, LA clot was removed when present, and LA appendage was closed by purse string when indicated, followed by LA Maze. All ablation lines were made endocardially from within the cavum of the left atrium. The first ablation line was made encircling both left pulmonary veins. The second was from mid-point of the posterior mitral annulus to the first encircling line. The third created was encircling the base of the LA appendage (closed by purse string). The fourth line joined the first and third encircled lines. The fifth line was created encircling both right pulmonary veins and then extending it in a U-shaped manner, such that the arms of the U ended at the left atriotomy edge. The final line joined the left and right pulmonary vein isolation encircling lines, as shown in Fig. 1. LA size reduction (tailoring procedure) was done where LA size was > 6 cm.

Postop antiarrhythmic protocol

No antiarrhythmic drugs were given to patients who returned to sinus rhythm and remained in sinus rhythm till the time of discharge. Amiodarone (100 mg twice or thrice daily) was started in those who again went into AF and continued during the whole follow-up period. All control groups were given digoxin (0.25 mg).

Fig. 1 Left atrial maze lines created by the two energy sources

Postop anticoagulant protocol

Anticoagulation (warfarin plus ecosprin 75 mg) were given to all patients irrespective of conversion to sinus rhythm. The dose of warfarin was titrated according to international normalized ratio (INR) values. In patients with double valve replacement, we have given 150 mg of ecosprin. In those patients with bioprosthetic valve, we continued warfarin and ecosprin for 3 months as the standard recommended protocol.

Statistical analysis

All relevant data were collected on Microsoft Excel sheet and statistical analysis was done using the standard statistical software SPSS version 21. All normal distributed numerical variables were compared between groups by the independent sample –Student's “*t* test”. Mann-Whitney *U* test was used for variables which were not normally distributed (by Kolmogorov-Smirnov goodness-of-fit test). Categorical variables were compared between groups by Fisher's exact text. All analysis was two tailed and the *P* value < 0.05 was considered as statistically significant.

Results

In both diathermy and HFU groups, 8 patients were male and 12 were female. The mean age, height, weight, and body surface area of the patients in both groups were comparable with *P* value 0.655, 0.871, 0.766, and 0.860, respectively, as depicted in Table 1. All patients were in atrial fibrillation for a mean duration of 8.75 ± 3.12 and 7.25 ± 3.16 months,

Table 1 Demographic data

Demographic data	Diathermy group Mean $\pm$ SD	HFU group Mean $\pm$ SD	<i>P</i> value
Age (years)	41.05 $\pm$ 14.13	39.75 $\pm$ 13.84	0.655
Height (cm)	158.40 $\pm$ 11.91	158.45 $\pm$ 12.11	0.871
Weight (Kg)	49.12 $\pm$ 11.38	49.07 $\pm$ 12.26	0.766
Body surface area	1.47 $\pm$ 0.20	1.45 $\pm$ 0.22	0.860

respectively, in the diathermy and HFU groups. The mean preop LA size was 6.05 $\pm$ 0.86 cm and 6.28 $\pm$ 1.14 (*P* value) respectively in the diathermy and HFU groups which was comparable as depicted in Table 2. Out of 20 patients in the diathermy group, 2 were in the New York heart association (NYHA) functional class II, 10 patients in NYHA III, and 8 were in NYHA IV. In the HFU group, 2 patients were in NYHHA class II, 12 in class III, and 6 in NYHA IV, *P* value 0.792.

All patients in both groups had mitral valve disease with atrial fibrillation with or without involvement of other valves and in each patient mitral valve replacement was done with or without replacement of other valves (Table 3). Aortic valve replacement was done in three patients of the diathermy group and six patients in the HFU group and tricuspid ring annuloplasty was done in four and two, respectively.

All varieties of prosthesis valve were used (St. Jude—21, TTK Chitra—4, Star Edward—12, Bio prosthetic—2, Sorin—2). Tricuspid ring was used in six patients.

Significant difference was observed in the groups regarding CPB time, cross clamp time, and the time required to perform the Maze procedure as depicted in Table 4.* - *P* value is significant

Sinus rhythm was restored in 19/20 (95%) patients and 18/20 (90%) patients, immediately after the procedure in the diathermy and HFU groups, respectively. Three patients in the diathermy group and two patients in the HFU group were in sinus bradycardia for the first 2 days, for which temporary pacing was given. The rhythm profile in both groups at different points of time is depicted in Table 5. At the end of 3 months, 90% of patient in were sinus rhythm in the diathermy group and 85% of patients were in sinus rhythm under HFU.

Table 2 Preop cardiac parameters

Preop parameter	Diathermy group Mean $\pm$ SD	HFU group Mean $\pm$ SD	<i>P</i> value
Duration of AF	8.75 $\pm$ 3.12	7.25 $\pm$ 3.16	0.181
Preop LA size	6.05 $\pm$ 0.86	6.28 $\pm$ 1.14	0.432
Ejection fraction (%)	52.85 $\pm$ 7.45	53.72 $\pm$ 7.80	0.704

Table 3 Preop disease profile

Diagnosis	Diathermy Group	HFU group
MS	3 (15%)	5 (25%)
MS + TR	3 (15%)	2 (10%)
MS, MR	5 (25%)	5 (25%)
MS + AS	1 (5%)	0
MR + TR	1 (5%)	0
MR	2 (10%)	1 (5%)
Post CMC MS	3 (15%)	1 (5%)
MS + AS, AR	1 (5%)	1 (5%)
MS,MR + AS, AR	1 (5%)	5 (25%)

MS mitral stenosis, MR mitral regurgitation, TR tricuspid regurgitation, AR aortic regurgitation, AS aortic stenosis, CMC closed mitral commissurotomy

Temporary pacing was required in 3 of the patients in the diathermy group in the first 48 h of the postoperative period due to sinus bradycardia (< 60/min). Two of the patients in the HFU group required temporary pacing. None of the patients required permanent pacing.

Mean ICU stay in the diathermy group was 2.5 $\pm$ 0.60 and 2.75 $\pm$ 0.71 in the HFU group, (*P* value 0.241). There was significant difference in hospital stay in both groups, 7.35 $\pm$ 1.49 and 8.50 $\pm$ 2.03 (*P* value 0.05), respectively, in the diathermy and HFU groups.

No major complication occurred during the study except congestive cardiac failure, reexploration for bleeding, and sternal wound infection as depicted in Table 6.

LA size reduction was done in all patients having LA size more than 60 mm. LA reduction was done in 8 patients in the diathermy group and in 10 patients of the HFU group. LA appendage was excluded in all patients having LA clots. LA appendage exclusion was done in 9 patients of the diathermy group and in 10 patients of the HFU group.

Discussion

Atrial fibrillation (AF) is present in approximately 50% of all patients undergoing surgery for mitral valve disease [1]. AF is also a significant cause of cardiovascular morbidity and mortality; the most feared complication is systemic

Table 4 Intra op Cardiac Parameters

Intra op parameters	Diathermy group Mean $\pm$ SD	HFU group Mean $\pm$ SD	<i>P</i> value
CPB time	98.95 $\pm$ 35.43	124.80 $\pm$ 31.29	0.011*
Cross clamp time	67.80 $\pm$ 27.56	88.05 $\pm$ 32.24	0.019*
Maze procedure time	4.65 $\pm$ 0.93	8.55 $\pm$ 1.23	0.000*

*denotes that the *P* value is significant

Table 5 Sinus rhythm status at different point of time

Time	Diathermy group	HFU group	P value
Immediate post op	19 (95%)	18 (90%)	1.000
1st Day	18 (90%)	16 (80%)	0.661
3rd Day	14 (70%)	16 (80%)	0.716
7th Day	16 (80%)	17 (85%)	1.001
15 Days	16 (80%)	16 (80%)	1.000
1 Month	17 (85%)	17 (85%)	1.000
3 Months	18 (90%)	17 (85%)	0.487

thromboembolism. Adequate treatment of mitral valve disease often does not relieve the cardiac rhythm disorder and AF persists or recurs [2]. Although most symptoms of atrial fibrillation are controlled with medications, a small percentage of patients have drug intolerance or severe side effects [14].

The surgical attempts to cure atrial fibrillation can be justified from the previous studies with regard to stroke risk, decreased life expectancy, and avoidance of toxic antiarrhythmic drugs [14]. Surgical treatment is the most effective means of curing AF in the olden days. Surgical correction of atrial fibrillation (AF) was first performed clinically in 1987 by Dr. James Cox [3]. The cut-and-sew Maze procedure consists of a series of predetermined incisions and in the left and right atria and is thought to cure AF in 85 to 95% of patients. The surgical Maze procedure addresses symptoms by establishing sinus rhythm, improving cardiac performance by restoring atrioventricular synchrony, and reducing the risk of thromboembolism [15]. Although the surgical maze procedure is highly effective, the complexity of the original procedure and the long operative time prevented its wide spread application by surgeons.

The demonstration by Haissaguerre and associates [4] that majority of AF originates within the pulmonary veins orifices. This trigger zone has recently emerged for the design of several ablation devices capable of isolating these trigger zones. Advances in the understanding of the pathogenesis of AF and development of new ablation technologies enable surgeons to perform pulmonary vein ablation and create strategically placed linear left atrial lesions rapidly and safely [5].

Hsu et al. have found that the left superior vena cava (LSVC), the embryological precursor of the ligament of Marshall, has been implicated in the initiation and maintenance of AF. The LSVC can be the arrhythmogenic source of AF with connections to the coronary sinus (CS)

and LA. Ablation of these connections resulted in electrical isolation. In our study, we had not considered ablating these connections as AF associated in mitral valve disease is primarily due to dilatation and stretching of the left atrium especially in and around pulmonary vein orifices [16]. A variety of energy sources such as radio frequency, microwave, ultrasound, laser, and electrocautery used to create lines of conduction block and replace surgical incisions of the maze procedure. Benefits of adding some form of maze procedure in patients with mitral valve disease have been proven in a number of studies [6, 8, 11]. Recently, the reported utilization of diathermy in the creation of atrial ablation lesions raised the possibility of an affordable, fast, easy to use, and readily available energy source for the surgical treatment of AF. We used electrocautery and high-frequency ultrasound to create Maze lines within the cavum of LA.

Lam et al. [7] demonstrated, at a histological level, the effect of the electrocauterization. Necrosis and extensive rupture of the endocardium were evidenced, besides the underlying myocardial destruction. Despite the good clinical outcomes, there are severe morphological damages in the atrial tissue. In the same study, it was evident that the power setting and the tissue contact time exert a direct effect on in the depth of atrial lesions. At a power setting lower than 25 W, the destruction is low, making it impossible to create atrial lesions. At a power setting higher than 45 W, there is a predisposition to atrial perforation; over 35 W also increases the proportion of having coagulated tissue. Thus, the best outcomes with high necrosis of tissue coagulation and lower perforation risk would be using a power setting between 30 and 35 W and tissue contact time ranging from 1 to 3 s/cm. In our study, diathermy was set at 40 W in coagulation spray mode with contact time of 1 to 2 s. The theoretical energy delivery was approximately 40 J for every second of cauterization. So at this energy level and contact time, we do not come across any morphological damage to the LA wall or its perforation or any collateral damage to the circumflex artery or coronary sinus.

Sueda et al. [17] addressed only the left atrium for AF treatment and successfully reached 100% of regular rhythm after surgery and 78% at 6 months. Kalil et al. [18] published a study in which they performed only the isolation of pulmonary vein ostia, reaching 86% of sinus rhythm after a 1-month follow-up. These results were similar to those achieved in our study, in which only the left atrium was addressed, with 95% of AF reversion after surgery and 90% at 3 months. This may show the importance of the left atrium approach, because it appears to be the most common site for generation of fibrillatory wave.

Many Indian studies have also used electrocautery for performing maze lines. Dhaliwal et al. found that sinus rhythm was restored in 80.76% of patients immediately after the procedure [9]. Rhythm profile in the follow-up period showed sinus rhythm in 42/52, 36/52, 30/52, and 41/52 patients at 10 days, 1 month, 3 months, and 6 months respectively.

Table 6 Complications

Complication	Diathermy group	HFU group
Sternal wound Infection	3 (15%)	2 (10%)
Reexploration for bleeding	2 (10%)	1 (05%)
Congestive cardiac failure	3 (15%)	2 (10%)

Simha P et al. presented their initial experience with 25 patients undergoing the maze procedure by electrocautery [8]. They show that lesions similar to those of the Cox-Maze procedure can be reproduced using the diathermy tip set to a power output of 40 W on spray mode at a nonspecific contact time. They reported 96% conversion rate to sinus rhythm. Inamdar et al. [10] studied electrocautery maze in 25 patients with chronic AF. They observed 92% freedom from AF at 6 months follow-up.

We also used high frequency ultrasound to perform the maze procedure. The Harmonic scalpel was used to deliver high-frequency ultrasound. It was set at 3 so that the probe vibrates at 55,000 Hz. It produces coaptive coagulation with denaturation of protein with less lateral damage at this energy level. Banerjee et al. [12] used high-frequency ultrasound with a ball-tipped Harmonic scalpel probe for intraoperative endocardial ablation of chronic AF along with mitral valve surgery in 24 patients. All the patients converted to sinus rhythm on the table and at the end of 12 weeks, 79.2% of patients had sinus rhythm and a regular atrial rhythm was present in the rest of the patients.

A multicenter trial concluded that epicardial, off-pump, beating-heart ablation with acoustic energy is safe and cures 80% of patients with permanent atrial fibrillation associated with long-standing structural heart disease. They used high-intensity focused ultrasound for surgical ablation in the maze procedure [11].

Other energy sources have also been studied extensively. Radio frequency is the most widely used energy source. Patwardhan et al. [19] studied the effectiveness of the radio frequency (RF)-modified Maze in early and late restorations of sinus rhythm in patients with rheumatic heart disease (RHD). They found that in the Maze group, sinus rhythm was restored in 60/70 of patients (85.71%) immediately and sustained in 55/70 of patients (78.57%) over the follow-up as against an immediate conversion rate of 5.3% (5/53 patients, in the non-maze group). The additional cardiopulmonary (CP) bypass time ($P=0.13$) and cross clamp time ($P=0.511$) needed for maze is not statistically significant. In our study, we used two energy sources, diathermy and high-frequency ultrasound (using harmonic scalpel probe). We compared both of these energy sources in terms of conversion to sinus rhythm and time taken to perform the procedure. We also compared different outcomes.

The main idea of using diathermy and HFU was its availability in our operation theater (OT) and its simplicity to use for the procedure; also, diathermy was cost effective. We used an ordinary, unipolar surgical diathermy and harmonic scalpel probe for creating maze lines. Alternate energy sources have been studied extensively. Radio frequency is the most widely used energy source. Our conversion rate in diathermy group was 90% and in HFU was 85% at the end of 3 months, thus comparable to other alternate energy sources.

There were no major complications other than sternal wound infection, few postop bleeding and congestive cardiac

failure. Three of the patients required temporary pacing and there was no mortality in any group.

The extensive pathogenesis variation, symptomatology, and patients' profile are factors hampering the development of global recommendations for a standard treatment of AF, but surgical ablation seems to play an increasing role for several reasons: high success rate, surgeons' direct view making the ablation safer and faster, the removal of left atrial appendage reduces the risks for thromboembolism, and the simplicity of the technique, which does not prolong surgery times, make it possible to be performed by every surgeon.

Limitations

Our study had several limitations. Our small sample size was very small. The duration of follow-up was very short. The relation of left atrium size and chronic atrial fibrillation is well documented but we have not considered the LA size. We will compare the LA size and return to sinus rhythm while performing LA Maze in a further study. We have not established that the ablation was full thickness or superficial with the protocol followed. Also, there are many other sites for generation of fibrillatory stimulus but we had considered only the LA cavity for ablation of reentrant circuit.

Conclusion

Both energy sources (diathermy and high-frequency ultrasound) used in the study for creation of the maze lines were safe, time sparing, effective, and simple; however, the diathermy took less time to perform maze than HUF and the total CPB time and cross clamp times were less in the diathermy group; however, both of these energy sources restored sinus rhythm in majority of the cases.

Funding This work was supported by IPGME&R and SSKM hospital, Kolkata, West Bengal, and received no specific grant from any funding agency, commercial, or not-for-profit sectors.

Compliance with ethical standards

Ethical committee clearance was taken before starting this study and each patient gave informed and written consent to undergo the maze procedure.

Conflict of interest The authors declare that they have no conflict of interests.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional ethics committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent Informed and written consent for the surgery was obtained from the parents or guardians in case the patient was a minor and from individual participant in case patient was a major. The study was a prospective study.

References

1. Chugh SS, JI B, Shen WK, Hammill SC, Gersh BJ. Epidemiology and natural history of atrial fibrillation: clinical implications. *J Am Coll Cardiol.* 2001;37:371–8.
2. Yuda S, Nakatani S, Kosakai Y, Yamagishi M, Miyatake K. Long-term follow up of atrial contraction after the maze procedure in patients with mitral valve disease. *J Am Coll Cardiol.* 2001;37:1622–7.
3. Cox JL, Schuessler RB, D’Agostino HJ Jr, et al. The surgical treatment of atrial fibrillation. III. Development of a definitive surgical procedure. *J Thorac Cardiovasc Surg.* 1991;101:569–83.
4. Haissaguerre M, Jais P, Shah DC, et al. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. *N Engl J Med.* 1998;339:659–66.
5. Gillinov AM, McCarthy PM. Advances in the surgical treatment of atrial fibrillation. *Cardiol Clin.* 2004;22:147–57.
6. Ruchat P, Schlaepfer J, Delabays A, Hurni M, Milne J. Von Segesser LK. left atrial radiofrequency compartmentalization for chronic atrial fibrillation during heart surgery. *Thorac Cardiovasc Surg.* 2002;50:155–9.
7. Lam BK, Boodhwani M, Veinot JP, Hendry PJ, Mesana TG. Surgical treatment of atrial fibrillation with diathermy: an in vitro study. *Eur J Cardiothorac Surg.* 2005;27:456–61.
8. Simha P, Bhat PS, Prabhudeva N. The electrocautery Maze – How I do it. *Heart Surg Forum.* 2001;4:340–4.
9. Dhaliwal RS, Das D, Luthra S, Goel S, Singh J, Kumar RM. Electrocautery Maze in patients with Atrial Fibrillation with Mitral Valve Disease. *Indian J Cardiol.* 2005;8:13–6.
10. Inamdar A, Reddy P, Inamdar S, Gaikwad V. Eletrocautery maze in chronic atrial fibrillation: an early experience. *Indian J Thorac Cardiovasc Surg.* 2005;21:9–14.
11. Ninet J, Roques X, Seitelberger R, et al. Surgical ablation of atrial fibrillation with off-pump, epicardial, high – intensity frequency focused ultra sound: results of multicentre trial. *J Thorac Cardiovasc Surg.* 2005;130:803–9.
12. Banerjee A, Singh S, Tempe DK. Intraoperative endocardial ablation of chronic atrial fibrillation along with mitral valve surgery using high frequency ultrasound with a ball-tipped harmonic scalpel probe. *Indian Heart J.* 2004;56:178–80.
13. He DS, Zimmer JE, Hynynen K, et al. Application of ultrasound energy for intracardiac ablation of arrhythmias. *Eur Heart J.* 1995;16:961–6.
14. Horowitz LN, Spielman SR, Greenspan AM, et al. Use of amiodarone in the treatment of persistent and paroxysmal atrial fibrillation resistant to quinidine therapy. *J Am Coll Cardiol.* 1985;6:1402–7.
15. Cox JL, Canavan TE, Schuessler RB, et al. The surgical treatment of atrial fibrillation. II. Intraoperative electrophysiologic mapping and description of the electrophysiologic basis of atrial flutter and atrial fibrillation. *J Thorac Cardiovasc Surg.* 1991;101:406–26.
16. Hsu LF, Jais P, Keane D, et al. Atrial fibrillation originating from persistent left superior vena cava. *Circulation.* 2004;109:828–32.
17. Sueda T, Nagata H, Orihashi K, et al. Efficacy of a simple left atrial procedure for chronic atrial fibrillation in mitral valve operations. *Ann Thorac Surg.* 1997;63:1070–5.
18. Kalil RAK, Lima GG, Abrahão R, et al. Simplified surgical technique may be effective in treating chronic atrial fibrillation econdary to injury mitral valve? *Rev Bras Cir Cardiovasc.* 2000;15:129–35.
19. Patwardhan AM, Lad VS, Kumar N, et al. Radiofrequency modified maze procedure for chronic atrial fibrillation. *Indian J Thorac Cardiovasc Surg.* 2003;19:136–40.

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.