IN VIVO AND IN VITRO STUDY OF RADIO-FREQUENCY APPLICATION WITH A NEW LONG LINEAR PROBE: IMPLICATION FOR THE MAZE OPERATION

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Background: The maze operation for atrial fibrillation is effective but highly invasive. We tested, both in vitro and in vivo, a new technique for creating long linear atrial lesions with a custom-made, 25-mm long, stainless-steel, linear probe and a corresponding 500-kHz generator for assistance in the maze operation.

Methods: In the in vitro study with the isolated canine atria, the power of the delivered radio-frequency energy and the saline irrigating flow rate were changed independently, and the sizes of the lesions were measured. In the in vivo study radio-frequency energy was delivered to 4 portions (ie, the smooth and trabeculated portions of the right and left atria). The sizes of the lesions were measured, and the histologic features of the lesions were examined. Electrical isolation of the right atrial appendage from the remaining right atrium was attempted by using this linear probe.

Results: In the in vitro study the size of the lesion became larger as the delivered power was increased, although the lesion was limited when the flow rate was high. In the in vivo study the size of the lesion was equal at the 4 different sites. Histologic examinations demonstrated linear and transmural lesions, and electrophysiologic examinations revealed conduction block between the right atrial appendage and the remaining right atrium.

Conclusions: The new original long linear probe was effective for creating transmural linear atrial lesions with the irrigation method, presenting the possibility of an intraoperative technique that mimics the maze procedure. (J Thorac Cardiovasc Surg 2000;120:164-72)

Atrial fibrillation (AF) is the most frequently encountered arrhythmia within the general population. There has been a consensus that one of the available curative treatments for AF is surgical.¹⁻⁴ The maze surgical procedure described initially by Cox and colleagues¹ offers a curative treatment for AF because it is highly successful in the restoration of sinus rhythm and in the preservation of atrial booster pump function in

patients with lone AF, as well as AF based on organic heart diseases.^{4,5} However, the maze procedure entails extensive atrial incision and suturing in addition to excessive blood loss and extended cardiopulmonary bypass and aortic crossclamp times.⁵

Radio frequency (RF) catheter ablation has gained widespread acceptance as a safe and effective approach with its ability to cure many types of cardiac arrhythmias. There have recently been some reports concerning the catheter-maze procedure for AF.⁶⁻⁹ Overall, the percutaneous approach of RF catheter ablation for AF remains an investigational technique.

With this trend in mind, we attempted in the present in vitro and in vivo studies to create a long linear lesion by using a new long linear probe together with an RF energy generator, as we reported recently.¹⁰ These devices may offer potential therapeutic benefit for AF because the atrial linear lesions created by RF energy may obviate the necessity for extensive atrial incision and suturing as required with the original maze surgical

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Received for publication Nov 22, 1999; revisions requested Jan 24, 2000; revisions received Feb 29, 2000; accepted for publication Feb 29, 2000.

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0022-5223/2000 \$12.00 + 0 12/1/106985

doi:10.1067/mtc.2000.106985

Fig 1. The stainless-steel linear ablation probe. The tissue-contact part of the probe is approximately 25 mm in length.

Table I. Length of the created lesion in the *in vitro* study

	Length (mm)					
	10 W*	20 W*	30 W*	40 W*	50 W*†	60 W*
Flow rate						
10 mL/min§	26.4 ± 0.6	27.3 ± 0.6	27.8 ± 0.6	28.4 ± 0.7	28.7 ± 0.6	28.9 ± 0.6
30 mL/min	25.6 ± 0.5	25.9 ± 0.5	26.5 ± 0.6	26.9 ± 0.6	27.1 ± 0.6	27.2 ± 0.6

Values are means ± SD.

* $P < .01$ compared with each other, with the exception of comparison between 40 and 50 W and between 50 and 60 W.

† $P < .05$ compared with 40 W.

§ $P < .01$ compared with 30 mL/min.

procedure, thereby minimizing the duration of heart operations.

Material and methods

Humane animal care. All adult mongrel dogs received humane care in compliance with the “Principles of Laboratory Animal Care” formulated by the National Society for Medical Research and the “Guide for the Care and Use of Laboratory Animals” prepared by the Institute of Laboratory Animal Resources and published by the National Institutes of Health (National Institutes of Health publication No. 86-23, revised 1985). This experiment was reviewed by the Committee of the Ethics on Animal Experiment of the Faculty of Medicine, Kyushu University, and carried out under the control of the Guidelines for Animal Experiments of the Faculty of Medicine, Kyushu University, and The Law (No. 105) and Notification (No. 6) of the Government of Japan.

In vitro study. Thirty adult mongrel dogs weighing 9 to 26 kg (14.1 ± 3.4 kg) were used in this study. Anesthesia was induced with a dose of intravenous thiamylal sodium (25

mg/kg). After endotracheal intubation, mechanical ventilation with a mixture of room air and 100% oxygen with an artificial respirator was performed, and 10 µg/kg fentanyl was slowly injected intravenously. Anesthesia was maintained with a continuous infusion of fentanyl ($10 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$), midazolam ($0.5 \text{ mg} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$), and vecuronium bromide ($0.2 \text{ mg} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$). A median sternotomy was performed. Fresh isolated canine heart and lung preparations were obtained, and a tissue block of the smooth portion of the right atrium (RA) or left atrium (LA) was prepared within 15 minutes after isolation of the beating whole heart. The thickness of the specimen was 2 to 3 mm. A custom-made, linear, stainless-steel probe 25 mm in length was used for RF energy application (Fig 1). This probe was connected to a 500-kHz generator that was designed to deliver power-controlled RF energy. The probe was positioned parallel to the fiber orientation of the specimens, and pressure was exerted perpendicular to the specimens at a constant weight of 10 g with a custom balance. The probe was in good contact with atrial surface along the most distal linear portion, which was perpendicular to the grip portion. Initially, an excessive delivery

Fig 2. Schematic illustration of the in vitro experimental study. RF energy was delivered between the probe tip and an adhesive electrode patch attached to the back of the specimen.

Table II. Width of the created lesion in the in vitro study

	Width (mm)					
	10 W*	20 W*	30 W*	40 W*	50 W*	60 W*
Flow rate						
10 mL/min†	3.5 ± 0.4	4.1 ± 0.4	5.3 ± 0.4	6.0 ± 0.5	6.3 ± 0.3	6.9 ± 0.5
30 mL/min	3.3 ± 0.4	3.5 ± 0.4	3.8 ± 0.4	4.2 ± 0.4	4.5 ± 0.4	4.9 ± 0.4

Values are means ± SD.

* $P < .01$ compared with each other.

† $P < .01$ compared with 30 mL/min.

of RF power without irrigation often caused charring or popping in our in vitro and in vivo studies. Therefore, we used a manual irrigation technique, flushing the catheter tip and the surrounding atrial tissue with small amounts of saline solution during RF delivery, to prevent excessive heat formation.

To investigate factors that can influence the size of the lesion and complications associated with RF application, we delivered RF energy between the probe and a large (6 × 12 cm) patch electrode attached to the back of the specimen while varying the RF energy and irrigating flow rate (Fig 2). RF energy was applied to the smooth portion of the RA or LA on the epicardial side. The lesion size was examined by changing the delivered power to 10, 20, 30, 40, 50, and 60 W and the flush flow rate to 10 and 30 mL/min. The RF application time was a constant duration of 30 seconds. The temperature of the irrigation fluid was 20°C. The length and width of the lesions were measured on the epicardial side of the surface. The lesion continuity was judged according to the discoloration of the preparations.

In vivo study. Nine adult mongrel dogs weighing 12 to 33 kg (20.2 ± 6.7 kg) were used in this study. First, 7 dogs were used to measure the lesion size created by the linear probe, whereas the other 2 dogs were used for electrophysiologic

isolation of the RA appendage. Induction and maintenance of anesthesia were the same as in the in vitro study. Ventilation was maintained as described in the in vitro study. The arterial blood gases and blood pH were maintained within physiologic ranges by adjusting the respiratory rate and tidal volume and also by administering sodium bicarbonate. The arterial blood pH, PCO₂, and PO₂ were kept within the range of 7.35 to 7.45, 35 to 45 mm Hg, and 90 to 150 mm Hg, respectively. Thereafter, the dog was placed on a heated pad, and catheters were inserted into the descending aorta and inferior vena cava through the left femoral artery and vein for blood pressure monitoring, blood sampling, and drug administration. Blood pressure and surface electrocardiograms were monitored continuously on a multichannel oscillograph (Polygraph 360 system; NEC San-ei Kogyo, Tokyo, Japan). The activated clotting time was maintained at greater than 300 seconds with intravenous heparin.

A median sternotomy was performed. The linear probe was positioned perpendicular to the atrial epicardium while RF energy was delivered. The contact pressure of the linear probe on the atrial epicardium was manually controlled to be almost equal at every delivery. Saline solution at a temperature of 20°C was flushed over the probe and the surrounding

Fig 3. A, Representative photograph of the epicardial surface of the created lesions. This lesion was created at the trabeculated RA with 30 W of delivered energy, 30 mL/min of flush flow, and an RF energy delivery duration of 30 seconds. The lesion was well demarcated from the surrounding tissue, and the edges of the lesion were well ablated compared with the central portion of the probe. Vaporized craters and ruptures of the myocardial surface were not observed. **B,** Endocardial surface photograph of the above lesion. The lesion was well demarcated from the surrounding tissue. *Arrowheads* indicate the margin of the created lesion.

atrial tissue at a flow rate of 30 mL/min. The delivered energy was 30 W, and the delivery duration was 30 seconds in every RF application.

We delivered RF energy to 4 different sites of the atrium: the site posterior to the crista terminalis of the RA (smooth portion of the RA); the site anterior to the crista terminalis, including the RA appendage (trabeculated portion of the RA); the site just below the lower pulmonary veins (smooth portion of the LA); and the site just anterior to the ligament of Marshall, including the LA appendage (trabeculated portion of the LA) in the first 7 dogs. We selected the RF application sites to avoid the visible coronary artery branches running on the epicardial atrial surface. After we had confirmed that good contact between the probe and the target

site was obtained as in the *in vitro* study, RF current was delivered between the probe and an adhesive electrosurgical dispersive patch applied to the shaved skin of the abdominal wall. In 2 dogs RF energy was delivered around the RA appendage, and isolation of the RA appendage from other parts of the atrium was attempted. After ablation around the RA appendage, pacing at the RA appendage with bipolar electrodes was performed at a pacing rate of 150 beats/min. Bipolar recording electrodes were placed on the upper and middle RAs.

The maximal length and width of the lesions were measured on the epicardium. After completion of the RF energy delivery, the dogs were killed, their hearts were removed, and the cardiac cavities were then washed with saline solu-

Table III. Length and width of the created lesion in the *in vivo* study

	RAS	RAT	LAS	LAT
Length (mm)	27.6 ± 0.7	27.5 ± 0.5	27.3 ± 0.3	27.5 ± 0.6
Width (mm)	4.1 ± 0.8	4.4 ± 0.4	4.2 ± 0.4	4.5 ± 0.3

Values are means ± SD. No statistically significant difference was found among the 4 portions with regard to length or width. RAS, Smooth portion of the right atrium; RAT, trabeculated portion of the right atrium; LAS, smooth portion of the left atrium; LAT, trabeculated portion of the left atrium.

tion. The endocardial surface of each atrium was inspected grossly, and the transmural of the lesions was investigated. A complete transmural lesion was defined as one with continuous epicardial and endocardial imprints of the ablated surface. After the excised hearts had been fixed in neutralized formalin, each of the lesions was blocked in paraffin and sectioned parallel to the short axis of the lesion in a plane perpendicular to the endocardial surface. Sections were stained with Azan and hematoxylin-eosin for microscopic examination.

Statistical analysis. Data are presented as the mean value ± SD. In the *in vitro* study we used 2-way factorial analysis of variance (ANOVA) for comparison among the multiple groups. Thereafter, the Fisher protected least significant difference methods were used to compare the size of the lesions created under the two different conditions, when the ANOVA result was statistically significant. In the *in vivo* study, 1-way factorial ANOVA was used to compare the size of the lesion. A *P* value of less than .05 was determined to be statistically significant.

Results

In vitro study. A total of 240 lesions were created in the smooth portion of the canine epicardial atrial specimens. There was no charring or popping. The number of RF deliveries was 20 times in every category. The lesion progression from both edges to the center was noted in all the specimens. All the atrial lesions were continuous and transmural. Both the epicardial and endocardial surfaces of the lesions were discolored and well demarcated from the surrounding tissue.

The sizes of the lesions are listed in Tables I and II. Lesion length and width increased as the RF power was increased (*P* < .0001 in both dimensions). The length increased only up to 50 W (differences below 40 W, *P* < .01; between 40 and 50 W, *P* < .05; between 50 and 60 W, *P* = .26). The width increased up to 60 W (*P* < .01). The lesion length and width were decreased as the flush flow rate of the saline solution was increased (*P* < .0001). The increasing size of the lesion as the delivered energy was increased was affected by the flush flow rate of the saline solution. The size change was less as the flush flow rate varied from 10 to 30 mL/min (*P* < .05 in length and *P* < .0001 in width).

In vivo study. On the basis of the *in vitro* study, RF power was fixed at 30 W, and the duration of the RF

application was 30 seconds. A total of 56 lesions were created in every dog (*n* = 7). Fourteen lesions were created in each portion (ie, the smooth and trabeculated portions of the RA and LA). No arrhythmia occurred during any of the ablation procedures. The ablation procedure had no effect on systemic blood pressure and heart rate. There was no popping or perforation of the specimens during any of the RF deliveries. The lesion was created earlier at both edges than in the central part and became linear in a few seconds. The epicardial surface of the lesions was well demarcated from the surrounding tissue. Both edges of the lesion were well ablated. The created lesion was continuous and dumb-bell-shaped (Fig 3, A). The endocardial surface of each lesion was also well demarcated from the surrounding tissue (Fig 3, B). The length and width of the lesions were not significantly different among the smooth and trabeculated portions of the LA and RA (Table III). The thickness of the smooth portion of the RA and LA was 2 to 3 mm, and that of the trabeculated portion of the RA and LA was 3 to 6 mm.

Histologically, all the atrial lesions were transmural, including the central portion. A line of demarcation between the ablated and intact area was evident (Fig 4, A). A higher magnification of the lesion showed coagulation of the cytoplasm, waviness of the myocardial fiber, and interstitial hemorrhage and edema (Fig 4, B and C). These microscopic findings were confirmed in all the specimens examined histologically.

In the other 2 dogs, 4 applications of RF energy were applied around the RA appendage. Thereafter, bipolar pacing from the RA appendage with a pulse width of 1 ms and a pulse amplitude of 5 mA at a rate of 150 beats/min was performed during sinus rhythm. The RA appendage was captured by the pacing, independent of the sinus rhythm of the heart (Fig 5), thus suggesting that the RA appendage was isolated functionally from other parts of the atrium.

Discussion

The present *in vitro* and *in vivo* experiments indicate that a new device composed of a long linear probe and a custom-made generator produces well-demarcated, transmural, and linear atrial lesions, which would be

Fig 4. Histologic examination of the trabeculated portion of the RA in the in vivo canine experiment of linear probe ablation. **A**, The short axis histologic section at the central portion of the lesion shows a line of demarcation between the damaged area and the intact area (arrowheads; Azan stain). **B**, Higher magnification of the lesion shows coagulation and pycnosis of the myocardial cells (hematoxylin and eosin stain). **C**, This photomicrograph shows interstitial edema and interstitial hemorrhage (hematoxylin and eosin stain). *Epi*, Epicardium of the RA; *End*, endocardium of the RA.

suitable for intraoperative assistance in mimicking the maze procedure carried out for the termination of AF.

Our recent in vitro study with porcine atria immersed in isotonic saline-dextrose solution showed that this new custom-made probe-generator system was effective in creating a well-demarcated, transmural, and linear lesion by a one-time epicardial RF application. The lesions were well visualized as pale and continuous. The lesion size increased as the delivered power, tissue-probe contact pressure, and duration of RF delivery were increased independently.¹⁰ In our in vitro experiment in the present study, we used an irrigation method during RF application. In the case of epicardial RF energy delivery with a conventional catheter, excessive heating could be prevented by irrigation with saline solution during RF application in the canine AF

model.¹¹ By use of this method, the incidence of complications, such as popping or charring, could be avoided even without a thermosensor. In our in vitro study, the length and width of the created lesions increased as the power of the delivered energy was increased up to 50 and 60 W, respectively. Continuity and the transmural nature of the created lesions were maintained despite changing the flow rate of the irrigating solution. The length of the lesion was more than 25 mm, which was similar to the lesion created in our recent in vitro study with the porcine atrium. The lesion created in this study was one of the longest linear lesions created by one-site RF application in the literature.¹² This has the potential advantage of the segment-by-segment linear ablation creating long block lines between anatomic obstacles (vascular orifices and atrioventricular ring) in

Fig 5. Electrophysiologic study conducted after circumferential ablation around the right atrial appendage (RAA). Paced electrical activity in the right atrial appendage was dissociated from spontaneous activity in the rest of the atrium, indicating the electrophysiologic isolation of the right atrial appendage (simultaneous recordings from surface lead II, right atrial appendage, high right atrium [HRA], and middle right atrium [MRA] electrograms).

both atria. Because block lines should be 20 mm (isthmus) to 75 mm (pulmonary vein to mitral ring), these lines could theoretically be created by one to three contiguous sequential applications of this device.¹³

The original maze procedure first introduced by Cox and coworkers¹ was an extensive surgical procedure with the placement of multiple suture lines, allowing relatively normal atrial activation from sinus to atrioventricular node while blocking the propagation of re-entrant impulses with a maze of conduction alleys and lines of blockage. However, such surgical procedures entail extensive atrial incision and suturing, excessive blood loss, as well as prolonged cardiac arrest for the patients.⁵ There have been some reports with respect to intraoperative endocardial RF or cryoablation mimicking the surgical maze procedure to resolve some of these problems.¹⁴⁻¹⁹ The results of these studies showed that using RF power was a timesaving and less-invasive procedure. However, some patients had new atrial tachycardias or atrial flutter after intraoperative ablation.^{16,18,19} It is essential to make a continuous and transmural lesion because a skipped or discontinuous lesion gives rise to proarrhythmic effects, resulting in the induction of new atrial flutters.²⁰⁻²² Therefore, it is ideal to investigate the lesion's continuity and transmural nature macroscopically and microscopically, as well as by means of electrophysiologic examination.

Other recent experimental RF ablation studies have focused on the feasibility of an epicardial approach mimicking the maze procedure for the treatment of AF.^{11,23} Chevalier and colleagues²³ reported that epicardial atrial RF catheter ablation under the video-

assisted endoscopic monitoring was effective in stopping vagally mediated canine AF. Epicardial RF ablation is also expected to reduce the thromboembolic risk. However, the accessibility of the ablation catheter by means of the video-guided technique was limited (ie, most but not all atria sites were accessible), which might have influenced the antifibrillatory effects of this procedure. Moreover, good electrode-tissue contact was not guaranteed, even under visual guidance. Elvan and colleagues¹¹ reported the effectiveness of epicardial RF application to the beating heart of the open-chest canine AF model. They mentioned that their attempt was preparatory to the closed-chest approach and confirmed the satisfactory accessibility of the entire atria, firm tissue-electrode contact, and partial vagal denervation, which has potential advantages concerning vagally induced AF. This RF ablation technique used the conventional electrode catheter. Our in vivo study also demonstrated the effectiveness of the epicardial approach to make a transmural linear atrial lesion, even in the trabeculated regions in the beating canine heart without the need of a cardiopulmonary bypass. We confirmed the electrophysiologic isolation of the RA appendage in 2 dogs by using the circumferential RF application. In the maze operation, isolation of the right and left atrial appendages is essential.¹⁻³ The epicardial approach with this linear probe can lead to a minimally invasive approach for AF.

Study limitation. The first limitation of this study is that the effects of the atrial linear lesions on atrial contractile function were not studied. In an animal model the epicardial modified catheter maze did not

affect atrial contraction.¹¹ Moreover, there have been several clinical reports that describe how the modified maze procedure with RF energy with a concomitant valvular operation was successful in restoring atrial contractile function.¹⁵ Accordingly, we do not believe this to be a problem. The second limitation is the lack of antiarrhythmic evidence of this original device. To confirm the functional isolation of the RA appendage, we delivered RF energy during sinus rhythm. However, it would be ideal to apply the RF energy during AF and to confirm the termination of AF, which is inducible in the in vivo canine model.¹¹ The third limitation is the lack of long-term consequences of RF lesions. The possibility exists that complications, such as atrial wall rupture, atrial aneurysm formation, or pulmonary vein stenosis, could occur. Actually, 2 cases of pulmonary vein stenosis caused by RF application have recently been reported.²⁴ However, to the best of our knowledge, there have been no reports concerning atrial rupture or aneurysm formation as late complications of RF application. Furthermore, histologic examination of the linear lesion reported in the literature²⁵ led us to speculate that conduction blockage would have been maintained rather than attenuated. The last limitation is that although we selected RF application sites to avoid the visible coronary artery branches running on the epicardial atrial surface in an in vivo study, the possibility exists that RF energy could disturb the microcirculation.

Conclusion

In the present in vitro and in vivo canine study, a new original long linear probe equipped with a custom-made RF generator was able to produce continuous, long, linear, and transmural atrial lesions independently of the atrial wall smoothness or trabeculation. The lesions were produced by using this probe-generator system without any popping or perforation, by using the irrigation method, at a wide range of RF power. This newly developed probe-generator system presents the possibility of a great contribution to and improvement of the maze surgical procedure.

We thank Dr Toshihide Nakano, Dr Ichiro Nagano, Dr Shigeki Morita, Dr Hisataka Yasui, Mr Yamaoka, and Mr Shibata for their technical assistance.

REFERENCES

1. Cox JL, Schuessler RB, D'Agostino HJ, Stone CM, Chang BC, Cain ME, et al. The surgical treatment of atrial fibrillation: III. Development of a definitive surgical procedure. *J Thorac Cardiovasc Surg* 1991;101:569-83.
2. Cox JL, Boineau JP, Schuessler RB, Kater KM, Lappas DG. Five-year experience with the maze procedure for atrial fibrillation. *Ann Thorac Surg* 1993;56:814-24.
3. Kosakai Y, Kawaguchi AT, Isobe F, Sasako Y, Nakano K, Eishi K, et al. Modified maze procedure for patients with atrial fibrillation undergoing simultaneous open heart surgery. *Circulation* 1995;92(Suppl):II-359-64.
4. Sandoval N, Velasco VM, Orjuela H, Caicedo V, Santos H, Rosas F, et al. Concomitant mitral valve or atrial septal defect surgery and the modified Cox-maze procedure. *Am J Cardiol* 1996;77:591-6.
5. Kawaguchi AT, Kosakai Y, Sasako Y, Eishi K, Nakano K, Kawashima Y. Risks and benefits of combined maze procedure for atrial fibrillation associated with organic heart disease. *J Am Coll Cardiol* 1996;28:985-90.
6. Swartz JF, Pellersels G, Silvers J, Patten L, Cervantez D. A catheter-based curative approach to atrial fibrillation in humans. *Circulation* 1994;90(Suppl):I-335.
7. Haïssaguerre M, Gencel L, Fischer B, Métayer PL, Poquet F, Marcus FI, et al. Successful catheter ablation of atrial fibrillation. *J Cardiovasc Electrophysiol* 1994;5:1045-52.
8. Gaita F, Riccardi R, Calò L, Scaglione M, Garberoglio L, Antolini R, et al. Atrial mapping and radiofrequency catheter ablation in patients with idiopathic atrial fibrillation: electrophysiological findings and ablation results. *Circulation* 1998;97:2136-45.
9. Haïssaguerre M, Jaïs P, Shah DC, Takahashi A, Hocini M, Quiniou G, et al. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. *N Engl J Med* 1998;339:659-66.
10. Shimoike E, Ueda N, Maruyama T, Kaji Y, Kanaya S, Fujino T, et al. Experimental ablation study using a new long linear probe in isolated porcine hearts. *Jpn Heart J* 1999;40:189-97.
11. Elvan A, Pride HP, Eble JN, Zipes DP. Radiofrequency catheter ablation of the atria reduces inducibility and duration of atrial fibrillation in dogs. *Circulation* 1995;91:2235-44.
12. Laverne T, Jaïs P, Bruszewski W, Shah DC, Bruneval P, Takahashi A, et al. Segment by segment linear ablation with an articulated bilimb catheter: initial experimental results. *PACE* 1998;21:2539-46.
13. Jaïs P, Coste P, Shah DC, Gencel L, Laverne T, Chouairi S, et al. Batrial dimensions relevant to catheter ablation [abstract]. *Eur J Cardiac Pacing Electrophysiol* 1996;6(Suppl):V87.
14. Melo J, Adragão P, Aguiar C, Neves J, Ferreira M, Teles R, et al. Bilateral pulmonary veins isolation by intraoperative radiofrequency ablation for atrial fibrillation surgery [abstract]. *PACE* 1999;22:893.
15. Patwardhan A, Kumar N, Dave H, Pandit S, Golam K, Dalvi B, et al. Efficacy of radiofrequency coagulation to replace Cox's maze incisions in restoring sinus rhythm in patients with rheumatic valvular disease and atrial fibrillation [abstract]. *PACE* 1999;22:847.
16. Chen MC, Guo GBF, Chang JP, Yeh KH, Fu M. Radiofrequency and cryoablation of atrial fibrillation in patients undergoing valvular operations. *Ann Thorac Surg* 1998;65:1666-72.
17. Kottkamp H, Hindricks G, Hammel D, Autschbach R, Mergenthaler J, Borggrefe M, et al. Intraoperative radiofrequency ablation of chronic atrial fibrillation: a left atrial curative approach by elimination of anatomic "anchor" reentrant circuits. *J Cardiovasc Electrophysiol* 1999;10:772-80.
18. Thomas SP, Nunn GR, Nicholson I, Rees AE, Daly MPJ, Uther JB. An endocardial radiofrequency ablative technique for cure of

- atrial fibrillation during cardiac surgery [abstract]. *Circulation* 1997;70(Suppl):I-450.
19. Beukema WP, Sie HT, Misier ARR, Smeets JL, Ennema JJ, Jacobs CC, et al. Radiofrequency modified MAZE in patients undergoing valve surgery [abstract]. *PACE* 1998;21:869.
20. Avitall B, Helms RW, Chiang W, Periman BA. Nonlinear atrial radiofrequency lesions are arrhythmogenic: a study of skipped lesions in the normal atria [abstract]. *Circulation* 1995;92(Suppl):I-265.
21. Avitall B, Kotov A, Helms RW, Gupta GN, Bharati S. Transcatheter ablation of chronic atrial fibrillation in the canine rapid atrial pacing model: Is the cure worse than the disease? [abstract]. *J Am Coll Cardiol* 1997;29(Suppl):32A.
22. Avitall B, Gupta GN, Bharati S, Helms R, Kotov A. Are transmural contiguous lesions essential? Post atrial fibrillation ablation: lesion morphology vs. outcome [abstract]. *J Am Coll Cardiol* 1998;31(Suppl):367A.
23. Chevalier P, Obadia JF, Timour Q, Bui-Xuan B, Fatemi M, Kirkorian G, et al. Thoracoscopic epicardial radiofrequency ablation for vagal atrial fibrillation in dogs. *PACE* 1999;22:880-6.
24. Robbins IM, Colvin EV, Doyle TP, Kemp WE, Loyd JE, McMahon WS, et al. Pulmonary vein stenosis after catheter ablation of atrial fibrillation. *Circulation* 1998;98:1769-75.
25. Schwartzman D, Fischer DD, Spencer EP, Anderson KP. Linear radiofrequency atrial lesions deployed using an irrigated electrode: electrical and histologic evolution [abstract]. *Circulation* 1998;98(Suppl):I-567.