Clinical research

Atrial structural remodelling and restoration of atrial contraction after linear ablation for atrial fibrillation

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Aims We determined late atrial function following a surgical linear endocardial radiofrequency (RF) ablation procedure that aimed to restore and maintain sinus rhythm (SR) in atrial fibrillation (AF). We tested the hypothesis that successful restoration of SR is accompanied by measurable mechanical atrial function that is at normal or near normal levels.

Methods Forty-seven patients who underwent the surgical RF procedure at least 6 months previously (median 2.86 years; range: 0.6–4.2 years) were studied using an array of echocardiographic variables. Two patient groups (SR restored [RF-SR], persistent AF [RF-AF]) and an age matched control group were studied. Among the echocardiographic variables measured were left atrial (LA) size and volume, LA active fractional emptying and mitral annular displacement corresponding to atrial contraction (A' velocity) by Doppler tissue imaging.

Results At long term follow up 29/47 of patients who underwent the RF procedure were in SR with atrial contraction present echocardiographically. Of the patients initially restored to SR, the proportion remaining in SR at 3 years was 79% (SE 9%). The atrial-emptying fraction was reduced in comparison to that seen in normal controls (27±14% vs 46±10%). The A’ velocity was decreased in the surgical RF cohort vs controls (4.4±1.3 vs 9.7±1.7 cm/s; P=0.0001). Despite LA size preoperatively being similar in both surgical groups, atrial size decreased in those in whom SR was restored (48.6±7.6 vs 44.8±4.7 mm; P=0.0001) but increased in those in whom AF persisted (48.2±8.1 mm vs 52.3±7.8 mm; P=0.0001).

Conclusion The radial pattern of linear radiofrequency ablation used in the present study resulted in restoration of SR and atrial function. Procedural success was independent of preoperative atrial size. Restoration of SR results in ‘reverse’ atrial remodelling and improved atrial function. However atrial function remains modestly impaired, either due to the ablation lesions or pre-existing atrial disease.

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Introduction

Atrial fibrillation (AF) occurs in 0.4% of the general population, increasing to 5% in those over 65 years of age.1 AF results in loss of effective atrial contraction with chamber dilatation thereby decreasing cardiac function and increasing the risk of thromboembolism. The Cox-maze surgical procedure2,3 usually restored sinus rhythm (SR) and atrial contraction in patients with chronic AF. Recently, linear radiofrequency ablation techniques, simpler and less time consuming than the incisional maze procedure4–10 have been developed. We have reported on such a procedure using a radial pattern of radiofrequency (RF) lesions, under direct vision, during open-heart surgery11 in an attempt to maintain normal cranio caudal atrial activation and minimize electrical isolation of areas of the atrial myocardium. This operation was termed ‘Star’ procedure because of the radial pattern of lesions (Fig. 1).

The aim of this cross sectional study was to examine echocardiographically atrial volume and function in patients who underwent the RF procedure and to compare them to an age matched normal cohort. We examined the effect of restoration of SR on atrial function in these patients.

We hypothesized that (1) atrial function would be restored at least partially following the RF procedure and (2) that persistent AF would cause further deterioration in atrial function. We evaluated atrial mechanical function extensively using traditional echocardiographic measures and in addition, the peak velocity of atrial contraction (A' velocity) using Doppler tissue imaging (DTI). This parameter may be less load dependent than traditional measures of atrial function.

Methods

From July 1995 to December 2001, 52 patients with chronic (71%) and paroxysmal (29%) AF for a mean duration of 54±41 months (range 4 months to 12 years), underwent the RF procedure. Of these, five with complex congenital heart disease had a modified RF procedure; these patients were excluded from analysis. Of the remaining 47 patients, 17 had only the RF procedure while 30 had other concomitant procedures (Table 1). There were two immediate deaths from pump failure (<48 h: one with hypertrophic cardiomyopathy and one with a mitral valve replacement) and two later deaths (>1 month: one who had an aortic valve replacement and bypass grafting from presumed ventricular tachycardia and one from prostatic carcinoma). All four deaths occurred in the group that had the RF with concomitant procedures. In the initial cohort who underwent the RF...
procedure routine electrophysiological studies were performed at 6 months and 22/42 had additional RF ablation primarily for inducible atrial flutter. Subgroup analysis of this group demonstrated no significant differences in atrial function (data not shown). Of the remaining 43 patients, 42 were reviewed by ECG and transthoracic echocardiography at ≥6 months after the RF procedure (median follow up time 2.86 years: range 0.6–4.2 years). Assessment of atrial function was difficult preoperatively because of the high proportion of patients (76%) in AF. Therefore, we compared the RF patients with 42 age matched normal controls with no history of ischaemic heart disease, significant valvular, peripheral vascular or cerebrovascular disease, hypertension or diabetes. None of the control subjects was on cardioactive medications. Among the 42 patients, 29 were in SR (two patients had back-up pacemakers) while 13 still had an arrhythmia (10 with persistent AF (two with pacemakers), one with paroxysmal AF and one with atrial flutter). Four of the 29 patients in whom SR was restored were on antiarrhythmic medications. Among the 42 patients, 29 were in SR (two patients had back-up pacemakers) while 13 still had an arrhythmia (10 with persistent AF (two with pacemakers), one with paroxysmal AF and one with atrial flutter). Four of the 29 patients in whom SR was restored were on antiarrhythmic agents as compared to 6/13 in the AF group. Study approval was obtained from the Human Research Ethics Committee at Westmead Hospital.

**Standard transthoracic echocardiogram**

Doppler, M mode and two-dimensional echocardiography were performed according to established clinical laboratory practice using commercially available instruments (General Electric/Vingmed System 5 and offline measuring station Echopac) using harmonic 3.5 MHz variable frequency phased array transducers. Left atrial (LA) anteroposterior size was estimated by M mode diameter in the parasternal long axis view. Left ventricular end diastolic and end systolic volumes were determined from the apical four- and two-chamber views using the biplane method of discs. Left ventricular stroke volume and ejection fraction were measured in all patients.

**Left atrial volumes and mechanical function**

Left atrial end systolic volume (LAESV) (the maximum LA volume in ventricular systole) and LA end diastolic volume (LAEDV) (the minimum LA volume in ventricular diastole) were calculated from apical four- and two-chamber zoomed views of the LA, using the biplane method of discs. LA stroke volume was estimated as the difference between LA ESV and LA EDV. Left atrial ejection fraction was measured in all patients as (LAESV-LAEDV/LAESV)×100. In patients who were in AF, LAESV was estimated as the largest left atrial volume during ventricular systole with the mitral valve closed. LAEDV was the smallest atrial volume during ventricular diastole.

**Traditional parameters of atrial function**

Mitral inflow velocity was obtained by pulsed wave Doppler examination at a sweep speed of 100 mm/s from the apical four-chamber view by placing the sample volume at the tips of the mitral leaflets or at the centre of the prosthetic valve in the four patients who had mitral valve replacement. Peak velocity of atrial contraction in diastole (A-wave velocity) was measured. The velocity time integral (VTI) of the A wave was measured and the atrial emptying fraction estimated as A VTI divided by the total VTI of mitral inflow.

**Pulsed wave Doppler tissue imaging**

Traditional measures of atrial function have been criticized because of their dependence on preload. Peak velocity of mitral annular motion in late diastole secondary to atrial contraction (A′) was measured in all patients using pulsed wave DTI at a sweep speed of 100 mm/s. The pulsed wave Doppler sample volume was placed on the atrial side of the mitral annulus at the basal interatrial septum in the apical four-chamber view (Fig. 2). Special attention was made to align the Doppler beam to the interatrial septum to optimize measurements. Doppler traces were obtained during end expiration to eliminate respiratory variation and an average of three beats was measured. Digital images were obtained and stored on magneto-optical discs and reviewed on a stand-alone offline measuring systems.

**Pulmonary vein flow**

Pulmonary vein flow velocities were recorded from the apical four-chamber view with the sample volume placed within the proximal 2 cm/s of the right upper pulmonary vein. Colour flow Doppler was helpful in aligning the Doppler cursor parallel to the pulmonary venous flow. Pulsed wave Doppler signals were obtained at a sweep speed of 100 mm/s. Peak velocities and VTIs were measured for systolic and diastolic forward flow and for atrial reversed flow. The systolic fraction of forward flow was estimated as systolic VTI divided by the total VTI of forward flow.

**Pre operative echocardiogram**

All 42 RF patients had a preoperative echocardiogram. As 32/42 (76%) were in AF, only limited transmitral flow data was available. LA diameter measured by M mode was used as a preoperative marker of LA size.

**Observer agreement**

In 10 randomly selected studies from each group (using the SPSS for Windows version 10, random number generator), two readers independently measured the peak A’ velocity. One observer re-measured the same 20 studies at a separate time to determine intraobserver agreement.

**Analysis**

All values are expressed as a mean±SD. Differences between groups were examined by means of a paired Students t-test. Two sided tests with a 5% significance level were used throughout. In this study an exploratory data analysis approach has been used to investigate the behaviour of many outcome variables and therefore no adjustment was made for multiple comparisons. Repeated measures analysis of variance was done to evaluate
changes in left atrial size within patients after the RF procedure. The degree of linear association between A’ velocity, atrial emptying fraction, LAEF, LAESV and LAEDV were quantified using Pearsons correlation coefficient. Kaplan–Meier survival analysis technique was used to estimate restoration of sinus rhythm. Bland–Altman analysis19 was performed to analyse intra and interobserver variability. Data were analysed using Statview (version 4.0) and SPSS (version 10.0).

Results

Forty-two patients out of forty-seven were studied and compared with age matched normal controls. The patients were categorised as having sinus rhythm restored based on electrocardiographic evidence of the presence of ‘P’ waves and a regular RR interval and with echocardiographic evidence of atrial contraction based on the presence of transmitral A wave secondary to atrial contraction. Ten of the 47 patients were not restored to SR after the procedure. Of the group restored to sinus rhythm initially, the Kaplan–Meier estimate of the proportion remaining in sinus rhythm at 3 years was 79% (SE 9%) and at 4 years was 68% (SE 13%).

The RF patients were divided into two groups on the basis of their underlying cardiac rhythm [RF-SR (n=29) and RF-AF (n=13)]. The demographic, clinical, Doppler and echocardiographic parameters in the RF and control cohorts are listed (Table 2A). An additional comparison was performed between patients with lone AF, who underwent an isolated RF procedure and were in SR at follow up, with their age matched normal controls (Table 2B).

Restoration of sinus rhythm

Twenty nine out of 47 (62%) patients were in SR at long-term follow-up with echocardiographic atrial contraction (peak A velocity >0.2 m/s). The restoration of SR was similar in patients undergoing the RF procedure in isolation (71%; 12/17) compared to the group where other concomitant surgical procedures were performed (68%; 17/25; P=ns). At late follow-up, two patients, both of whom had remained in AF had transient neurological deficits. No cerebrovascular events were reported in the group restored to sinus rhythm.

Atrial volumes

The mean LA diameter for all RF patients was 48.5±7.7 mm preoperatively, and 47±6.7 mm at follow-up. Both pre and postoperative measurements were significantly larger than age matched controls (post operative LA diameter in RF group vs controls: 47±7 vs 36.6±5 mm; P=0.0001). The LAESV (65.7±26 vs 38.7±10 ml; P=0.0001) and LAEDV (45.6±21 vs 18.7±4.9 ml; P=0.0001) were significantly larger in the post RF cohort than age matched controls. The LASV showed no significant difference between groups. Similar
results were obtained when a subgroup of lone AF patients who underwent the RF procedure were compared with age matched normals (Table 2B).

### Atrial function

Peak A wave velocity and VTI in the RF-SR group suggested partial recovery of atrial function when compared with age matched normals (Table 2A). The atrial emptying fraction (27±14 vs 46±10; P=0.0001) and LAEF (32±14 vs 51±7%; P=0.0001) were lower in the RF-SR group compared to controls.

### A' velocity as a measure of atrial function

A' velocity, similar to the atrial fraction and LAEF, was lower in the RF-SR group compared to normal controls (4.4±1.3 vs 9.7±1.7 cm/s; P=0.0001). A' velocity showed a modest but significant correlation to atrial emptying fraction (r=0.61; P=0.0001) and LAEF (r=0.64; P=0.0001) (Fig. 3). A' velocity demonstrated an inverse correlation to LAESV (r=−0.53; P=0.0001) and LAEDV (r=−0.61; P=0.0001), thus demonstrating that in this population, atrial enlargement is associated with a decrease in atrial contractile force.

### Left atrial size

Pre operative LA diameter using M mode showed no significant difference between the RF-SR and RF-AF groups (RF-SR vs RF-AF: 48.6±7.6 vs 48.2±8.1 mm; P=ns). A significant difference was noted in LA diameter between RF-SR and RF-AF at follow up (RF-SR vs RF-AF: 44.8±4.7 vs 52.3±7.8 mm; P=0.0001). Paired t test within

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### Table 2A

Demographic and echocardiographic variables of RF SR group and normal controls (mean±SD) with the mean difference between groups and the 95% confidence intervals

<table>
<thead>
<tr>
<th>RF-SR (n=29)</th>
<th>Normals (n=29)</th>
<th>Mean diff RFSR-normals</th>
<th>95% CI for RFSR-normals</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td>61.8±11</td>
<td>61.7±11</td>
<td>0.997</td>
<td></td>
</tr>
<tr>
<td><strong>LAD M mode (mm)</strong></td>
<td>47±7</td>
<td>37±5</td>
<td>10.4</td>
<td>8.7, 12.9</td>
</tr>
<tr>
<td><strong>LAESV (ml)</strong></td>
<td>66±26</td>
<td>39±10</td>
<td>27.1</td>
<td>18.5, 35.7</td>
</tr>
<tr>
<td><strong>LAEDV (ml)</strong></td>
<td>46±21</td>
<td>19±5</td>
<td>26.9</td>
<td>20.5, 33.3</td>
</tr>
<tr>
<td><strong>LASV (ml)</strong></td>
<td>20±9</td>
<td>20±7</td>
<td>0.16</td>
<td>-3.5, 3.8</td>
</tr>
<tr>
<td><strong>LAEF (%)</strong></td>
<td>32±11</td>
<td>51±7</td>
<td>-19.4</td>
<td>-23.8, -15.1</td>
</tr>
<tr>
<td><strong>A velocity (m/s)</strong></td>
<td>0.5±0.3</td>
<td>0.8±0.2</td>
<td>-0.24</td>
<td>-0.37, -0.12</td>
</tr>
<tr>
<td><strong>A VTI (cm)</strong></td>
<td>8.8±4.7</td>
<td>11.9±3.7</td>
<td>-3.1</td>
<td>-5.3, -0.86</td>
</tr>
<tr>
<td><strong>Atrial fraction (%)</strong></td>
<td>27±14</td>
<td>46±10</td>
<td>-19</td>
<td>-24.9, -12.7</td>
</tr>
<tr>
<td><strong>A’ velocity (cm/s)</strong></td>
<td>4.5±1.4</td>
<td>9.6±1.9</td>
<td>-5.1</td>
<td>-5.9, -4.3</td>
</tr>
<tr>
<td><strong>Peak systolic velocity (m/s)</strong></td>
<td>0.29±0.1</td>
<td>0.55±0.1</td>
<td>-0.267</td>
<td>-0.32, -0.22</td>
</tr>
<tr>
<td><strong>Systolic VTI (cm)</strong></td>
<td>6.8±2.2</td>
<td>14.6±4</td>
<td>-7.79</td>
<td>-9.2, -6.4</td>
</tr>
<tr>
<td><strong>Peak diastolic velocity (m/s)</strong></td>
<td>0.76±0.2</td>
<td>0.46±0.1</td>
<td>0.3</td>
<td>0.22, 0.4</td>
</tr>
<tr>
<td><strong>Diastolic VTI (cm)</strong></td>
<td>19.6±5.7</td>
<td>9.7±3.2</td>
<td>9.9</td>
<td>7.8, 12.04</td>
</tr>
<tr>
<td><strong>Peak AR vel (m/s)</strong></td>
<td>0.25±0.1</td>
<td>0.29±0.1</td>
<td>-0.04</td>
<td>-0.07, -0.12</td>
</tr>
<tr>
<td><strong>AR VTI (cm)</strong></td>
<td>5.1±1.4</td>
<td>3.9±1.1</td>
<td>1.16</td>
<td>0.51, 1.8</td>
</tr>
</tbody>
</table>

*Abbreviations: A velocity=peak mitral inflow atrial contraction velocity, A’=peak atrial contraction velocity using Doppler tissue imaging, AR=pulmonary vein flow atrial reversal, CI=confidence intervals, LAD=left atrial diameter, LAESV=left atrial end systolic volume, LAEDV=left atrial end diastolic volume, LASV=left atrial stroke volume, LAEF=left atrial ejection fraction, VTI=velocity time integral.

### Table 2B

Demographic and echocardiographic variables in the group with lone AF restored to SR after the RF procedure vs age matched normals who were successfully restored to SR (mean±SD)

<table>
<thead>
<tr>
<th>Lone AF (RF SR group) (n=12)</th>
<th>Age matched normals (n=12)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td>59.4±8</td>
<td>59.6±8</td>
</tr>
<tr>
<td><strong>LAD M mode (mm)</strong></td>
<td>44±4</td>
<td>39±4</td>
</tr>
<tr>
<td><strong>LAESV (ml)</strong></td>
<td>50.5±13</td>
<td>36.6±7</td>
</tr>
<tr>
<td><strong>LAEDV (ml)</strong></td>
<td>33.9±13</td>
<td>17.9±4</td>
</tr>
<tr>
<td><strong>LASV (ml)</strong></td>
<td>16.6±6</td>
<td>18.8±5</td>
</tr>
<tr>
<td><strong>LAEF (%)</strong></td>
<td>34±13</td>
<td>51±8</td>
</tr>
<tr>
<td><strong>A velocity (m/s)</strong></td>
<td>0.5±0.2</td>
<td>0.7±0.1</td>
</tr>
<tr>
<td><strong>A VTI (cm)</strong></td>
<td>7.5±2.6</td>
<td>12.9±3.8</td>
</tr>
<tr>
<td><strong>Atrial fraction (%)</strong></td>
<td>27±11</td>
<td>47±11</td>
</tr>
<tr>
<td><strong>A’ velocity (cm/s)</strong></td>
<td>4.9±1.3</td>
<td>9.5±1.9</td>
</tr>
</tbody>
</table>

*Abbreviations: A velocity=peak mitral inflow atrial contraction velocity, A’=peak atrial contraction velocity using Doppler tissue imaging, LAD=left atrial diameter, LAESV=left atrial end systolic volume, LAEDV=left atrial end diastolic volume, LASV=left atrial stroke volume, LAEF=left atrial ejection fraction, VTI=velocity time integral.
the RF-SR patients preoperatively and at follow up showed a significant decrease in LA diameter while in the RF-AF group, a significant increase in LA diameter was noted (Fig. 4). Repeated measures analysis of variance demonstrated a statistically significant interaction between the rhythm and within patient change in left atrial diameter ($P=0.03$). Comparison of biplane LAESV and LAEDV in RF-AF vs RF-SR demonstrated a significant difference between groups (Table 3).

**Pulmonary vein flow**

The peak velocity of systolic forward flow and VTI was lower in the RF patients than in the normal controls (RF vs controls: 0.29±0.9 vs 0.55±0.12 m/s; $P=0.0001$ and 14.1±3.7 vs 7±2.5 cm; $P=0.0001$ respectively). A relative increase in peak diastolic velocity and VTI was noted in the RF group (RF vs controls: 0.75±0.22 vs 0.46±0.13 m/s; $P=0.0001$ and 19.8±5.8 vs 9.8±3.3 cm; $P=0.0001$ respectively). No difference was noted in the systolic and diastolic peak velocity and VTI between the RF-SR and RF-AF group (Table 3).

**Comparisons of atrial size and function within the RF cohort**

As the RF cohort was a heterogeneous group, we further analysed atrial size and function in the paroxysmal and chronic AF groups (Table 4). No significant differences were noted in the parameters of atrial size and atrial function between groups. We also performed subgroup analysis between the patients who underwent an isolated RF procedure and those in whom the RF procedure was performed as an adjunct to surgical intervention for an associated cardiac lesion (Table 5). Interestingly, the only statistically significant difference noted was that the LAESV was larger in the group with underlying cardiac disease as compared to those with isolated AF.

**Observer variability**

10 studies in the RF and normal control cohorts were randomly selected to assess inter and intra-observer variability (see methods). Bland–Altman analysis for peak $A'$ velocity demonstrated an intraobserver mean difference of $-0.1$ cm/s (95% CI $-0.3$ to $-0.5$ cm/s). The inter-observer variability showed a mean difference of $0.1$ cm/s (95% CI $0.3$ to $0.5$ cm/s).

**Discussion**

This study comprehensively evaluates atrial mechanical function after restoration of SR following a linear RF procedure for treatment of AF. The main findings of this study were that the radial RF procedure resulted in effective atrial contraction in all patients in SR at late follow up. At follow up, a decrease in atrial size was noted in the group with restored SR. In contrast, persisting AF was associated with continued increase in LA size.

**The RF (Star) procedure**

The RF procedure design differs from the conventional maze procedure in two respects; (i) it uses RF ablation...
rather than surgical incision and (ii) uses the radial pattern of lesions that maintains craniocaudal activation with lines of ablation placed, where possible, parallel to the normal direction of wavefront propagation. The area of electrical isolation in the posterior LA is also minimized. The proportion of patients maintained in SR at late follow up is similar to published reports$^{20-24}$ with the incisional maze procedure (61–78%) performed either in isolation or in combination with other surgical procedures.

Ninety-three percent of patients were restored to SR in a recent study$^4$ where RF was performed for AF in the absence of associated cardiac disease. Several previous studies of curative surgery and RF procedures for AF demonstrated worse outcomes in patients with larger atria.$^8,10,20,24$ In our cohort, procedural success was independent of LA size, similar to the findings reported by William et al.$^5$ While the reason for this is unclear, the number, spacing and spatial arrangement of lesions in the RF procedure may contribute to its success, making it an effective therapeutic option even with LA enlargement.

### Atrial rhythm and structural remodelling

A decrease in atrial size was noted in patients successfully restored to SR. Post-operative decrease in LA diameter following the maze and RF procedures has been reported.$^4,9,21-24$ Benussi et al.$^6$ and Chen et al.$^24$ demonstrated a significant difference in LA size postoperatively based on rhythm. However, patients in both reports had mitral valve disease and a postoperative decrease in LA diameter was noted in both groups, irrespective of rhythm. This decrease in atrial size may be secondary to correction of the underlying valve disease, as no significant difference was noted between the SR and AF group$^{24}$ at long-term follow-up (>12 months).

The present data in contrast demonstrates a decrease in LA diameter in the RF-SR group with a corresponding increase in LA diameter in the RF- AF group compared
with preoperative values (Fig. 4). Thus although both groups had a similar intervention that in itself may cause a reduction in atrial size due to scarring resulting from linear ablation, achievement of SR was necessary to achieve a late reduction in LA size. These results are in agreement with previous reports that cardioversion is associated with a reduction in LA size\textsuperscript{25} while persistence of AF\textsuperscript{26} resulted in LA enlargement. Thus ‘reverse’ atrial remodelling consequent from restoration of SR appears to be an important determinant for postoperative reduction in LA size.

**Left atrial function**

While atrial function was restored in the RF cohort, it was reduced compared to age matched controls. This reduction in function could result from atrial scarring and loss of atrial myocardial mass from ablation to the atrium as previously demonstrated in a canine model.\textsuperscript{27} Another plausible explanation is permanent mechanical remodelling caused by preoperative AF or loss of contractile function due to underlying structural disease.

Studies evaluating the surgical maze procedure have demonstrated a decrease in post operative LA function\textsuperscript{20–22,28} with an atrial emptying fraction between 17–20%. In comparison, atrial function after the RF procedure showed a better atrial emptying fraction of 27%. This improved contractility may be the result of reduced LA damage from RF compared with surgical incisions. The posterior atrial wall represents 36% of the surface area of left atrial muscle.\textsuperscript{29} The RF procedure described does not isolate the posterior wall of the LA. This, combined with the radial pattern of lesions to improve craniocaudal activation is a significant change from previously described techniques and is consistent with data generated using the new incisional radial approach.\textsuperscript{30}

**The A’ velocity**

A novel echocardiographic measure of atrial function, the A’ velocity, using Doppler tissue imaging was also used to evaluate atrial function. While peak A velocity may be decreased in atrial dysfunction, transmitial flow is significantly influenced by LV relaxation and loading conditions.\textsuperscript{31} The A’ velocity which measures intrinsic atrial longitudinal contraction, may be a more robust marker of atrial function being preload independent. We measured septal A’ velocity since no significant difference was demonstrated previously between septal and lateral peak A’ velocity.\textsuperscript{32} The atrial volume demonstrated an inverse correlation to A’ velocity. Thus atrial remodelling with SR may decrease LA size with a resultant improvement in effective atrial contractile function.

**Left atrial compliance**

Blunted systolic forward pulmonary vein flow consequent to decreased atrial compliance has been demonstrated in AF.\textsuperscript{33} Decreased atrial compliance, similar to this study, was demonstrated following the incisional maze procedure.\textsuperscript{28} Atrial relaxation may be decreased by an atrial myopathic process secondary to AF. Scarring resulting from the radiofrequency ablation may result in splinting of the atria, further decreasing left atrial filling.

**Limitations**

The RF procedure was performed in a heterogeneous cohort; patients had paroxysmal and chronic AF and a significant percentage had underlying cardiac disease. While subgroup analysis demonstrated no significant differences between these groups in relation to atrial size or

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**Table 5** Demographic and echocardiographic variables in the isolated RF group vs RF with cardiac procedure group that were successfully restored to SR (mean±SD)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Isolated RF (n=12)</th>
<th>RF combined with procedure (n=17)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>59±8</td>
<td>65±12</td>
<td>0.27</td>
</tr>
<tr>
<td>LAD M mode (mm)</td>
<td>45±4</td>
<td>45±5</td>
<td>0.84</td>
</tr>
<tr>
<td>LAESV (ml)</td>
<td>50.5±13</td>
<td>66.4±23</td>
<td>0.04</td>
</tr>
<tr>
<td>LAEDV (ml)</td>
<td>33.8±13</td>
<td>46.2±20.5</td>
<td>0.076</td>
</tr>
<tr>
<td>LAVS (ml)</td>
<td>16.6±6</td>
<td>18.7±8</td>
<td>0.46</td>
</tr>
<tr>
<td>LAEF (%)</td>
<td>34±13</td>
<td>30±11</td>
<td>0.37</td>
</tr>
<tr>
<td>A velocity (m/s)\textsuperscript{a}</td>
<td>0.5±0.2</td>
<td>0.6±0.3</td>
<td>0.48</td>
</tr>
<tr>
<td>A VTI (cm)</td>
<td>7.5±2.6</td>
<td>9.8±6</td>
<td>0.21</td>
</tr>
<tr>
<td>Atrial fraction (%)</td>
<td>27±10</td>
<td>27±16</td>
<td>0.99</td>
</tr>
<tr>
<td>A’ velocity (cm/s)</td>
<td>4.9±1.3</td>
<td>4.1±1.4</td>
<td>0.18</td>
</tr>
<tr>
<td>Peak systolic velocity (m/s)</td>
<td>0.3±0.06</td>
<td>0.29±0.1</td>
<td>0.82</td>
</tr>
<tr>
<td>Systolic VTI (cm)</td>
<td>6.3±2.2</td>
<td>7.4±2.5</td>
<td>0.18</td>
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<tr>
<td>Peak diastolic velocity (m/s)</td>
<td>0.81±0.2</td>
<td>0.72±0.2</td>
<td>0.42</td>
</tr>
<tr>
<td>Diastolic VTI (cm)</td>
<td>21.1±5.8</td>
<td>19.2±5.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Peak AR vel (m/s)</td>
<td>0.26±0.04</td>
<td>0.24±0.06</td>
<td>0.41</td>
</tr>
<tr>
<td>AR VTI (cm)</td>
<td>5.6±1.1</td>
<td>4.7±1.5</td>
<td>0.09</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Abbreviations: A velocity=peak mitral inflow atrial contraction velocity, A’ peak atrial contraction velocity using Doppler tissue imaging, AR=pulmonary vein flow atrial reversal, LAD=left atrial diameter, LAESV=left atrial end systolic volume, LAEDV=left atrial end diastolic volume, LAVS=left atrial stroke volume, LAEF=left atrial ejection fraction, VTI=velocity time integral.
function (Table 4 and Table 5), the numbers in each subgroup are relatively small. This was a cross sectional study in that patients were recruited at varying times for their postoperative follow-up. However, previous reports have demonstrated that the most significant change in atrial size occurred within the first 6 months.\(^4,24\) As the aim of this study was to evaluate atrial function at late follow up (>6 months), we believe that the results presented possibly reflect a significant degree of the improvement in atrial function after a curative intervention for AF. Longer term follow up would be required to evaluate further changes in atrial function with restoration of SR.

In this study an exploratory data analysis approach has been used to investigate the behaviour of many outcome variables. Since no adjustment was made for multiple comparisons, it is possible that some spurious positive results may have been identified.

Age matched normals were used for comparison. Thus the effect of underlying cardiac disease as well as effects of cardiac surgery could be additive effects on atrial function. While the aim of the study was to evaluate restoration of atrial function in the RF group, we are unable to determine the extent to which correction of the underlying cardiac disease would have contributed to reduction in atrial size.

We did not evaluate right atrial function. Previous studies have demonstrated that right atrial function is not significantly altered after the maze procedure.\(^20,21,28\) Right atrial function may be restored even when left atrial function is absent,\(^21,28\) but the converse has never been observed. Further, left atrial contraction is more important since it relates to maintenance of cardiac output and prevention of systemic thromboembolism.

Four of the 29 patients in SR were on antiarrhythmic agents (sotalol, amiodarone, flecaïnine). These medications may affect the atrial function in these four patients, but as 86% in SR were not on antiarrhythmic therapy, its effect may not significantly alter the results of the group.

**Conclusions**

The RF procedure is an effective procedure for restoring SR in patients with predominantly chronic AF at late follow up. Atrial emptying fraction is improved and is higher than that reported with the traditional surgical maze procedure. This improvement may be due to the more physiological function obtained with the radial patterns of lesions. Restoration of sinus rhythm causes ‘reverse’ atrial remodelling with a resultant decrease in atrial size while persistent AF causes further atrial enlargement.

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**References**


