Transcatheter ablation of atrioventricular junctional re-entrant tachycardia in children and adolescents in Hong Kong: comparison of cryothermal with radiofrequency energy

Robin HS Chen 陳羲舜
KT Wong 黃健德
KS Lun 倫建成
TC Yung 翁德璋

Objective To compare the outcome of cryothermal and radiofrequency energy transcatheter ablation of atrioventricular junctional re-entrant tachycardia in children and adolescents.

Design Case series with internal comparison.

Setting Two hospitals in Hong Kong.

Patients Consecutive transcatheter ablation procedures for atrioventricular junctional re-entrant tachycardia in children and adolescents in our unit from August 2000 to September 2008 were retrospectively reviewed. Radiofrequency ablation was performed from August 2000 to June 2005, and cryoablation from July 2005 to September 2008.

Main outcome measures Demographic data, outcome and procedural details.

Results Thirty-eight procedures were reviewed. The radiofrequency ablation group (n=20) and cryoablation group (n=18) had similar demographic characteristics, except that there were more patients with congenital heart disease in the latter group (P=0.03). Acute procedural success rate was 100% in both groups. One patient from the radiofrequency ablation group had recurrence of atrioventricular junctional re-entrant tachycardia. The frequency of post-ablation persistent heart block was higher in the radiofrequency ablation than cryoablation group (10% vs 0%, P=0.17), but this difference was not statistically significant. A shorter fluoroscopy time was noted in the cryoablation group (31 ± 13 vs 38 ± 18 minutes; P=0.03).

Conclusions Transcatheter cryoablation for atrioventricular junctional re-entrant tachycardia in children and adolescents is as effective as radiofrequency ablation over the medium term. It has an excellent safety profile in terms of avoiding heart block.

Key words Catheter ablation, radiofrequency; Cryosurgery; Tachycardia, atrioventricular nodal reentry

Hong Kong Med J 2012;18:207-13

Introduction

Supraventricular tachycardia (SVT) is one of the most common cardiac arrhythmias in children and young adults. Although considered benign, frequent symptomatic SVT imposes significant adversity on quality of life. Transcatheter radiofrequency (RF) ablation was introduced in late 1980s as a definitive treatment for SVTs in adult patients. With growing experience, RF ablation has also become the standard treatment for symptomatic SVT in children. Radiofrequency ablation has excellent efficacy, with acute success rates ranging from 95 to 100%. However, when RF energy is applied close to the atrioventricular node (AVN) to ablate atrioventricular junctional re-entrant tachycardia (AVRT) and septal pathways, the AVN may be inadvertently damaged. Published reports indicated a 1.2 to
2.6% risk of heart block. In order to reduce the risk of heart block, transcatheter ablation using a safer alternative energy was desirable. In this context, application of cryothermal energy can be titrated to a temperature that results in only reversible interruption of cellular function. With this technique, ablation at critical sites that result in inadvertent heart block can therefore be avoided.

In 2004, the first case series of successful transcatheter cryoablation of accessory pathways was reported in paediatric patients. Subsequent reports have also demonstrated satisfactory efficacy for the treatment of paediatric AVJRT. In our centre at Grantham Hospital, we have performed transcatheter RF ablation for paediatric SVT since 1994. Moreover, ours is the only centre in Hong Kong providing electrophysiological study (EPS) and transcatheter ablation for paediatric patients. The overall risk of transient and permanent AVN damage is 7.6%. Since August 2005, we started using cryothermal energy for transcatheter ablation of AVJRT. The purpose of this study therefore was to compare the outcomes of cryothermal and RF energy used for transcatheter ablation of AVJRT.
performed. Isoproterenol infusion was given if AVJRT was not induced during the extra-stimulus testing.

**Cryoablation system, cryomapping, and cryoablation**

A 7-French steerable cryoablation catheter (Freezor Xtra; CryoCath Technologies Inc., Kirkland, Canada) with a 6-mm tip electrode was used for cryomapping and cryoablation. The catheter consisted of four electrodes and two concentric lumens for delivery and removal of refrigerant fluid, nitrous oxide, which was supplied by a central console (CryoCath Technologies Inc., Kirkland, Canada). After confirmation of the diagnosis and determination of a reproducible protocol for AVJRT induction, the cryoablation catheter was inserted via the right or left femoral vein. Cryomapping was performed using an electrogram and an anatomic-guided approach, targeting the slow pathway of the AVJRT. The cryoablation catheter tip was initially positioned at the tricuspid-coronary sinus isthmus, just posterior or next to the ostium of the coronary sinus (Fig). Cryomapping was performed by lowering the catheter tip temperature to -30°C for a maximum of 55 seconds, during which the efficacy of cryoapplication was tested by programmed atrial stimulation to induce AVJRT, or elimination of the slow AVN pathway. During cryomapping, the AH interval was monitored to observe impairment of AVN conduction. If cryomapping was positive (ie AVJRT non-inducible), the mapping could proceed to cryoablation by lowering the catheter tip temperature to -75°C for 4 minutes. One to two ‘insurance’ lesions were created in close proximity to the successful cryolesion. During cryoablation, programmed atrial stimulation was continued to monitor the ablation effect and AVN conduction. If cryomapping was negative, it was stopped and the catheter tip was repositioned to a more anterior site for repeated cryomapping.

**Radiofrequency system and ablation**

For RF ablation of AVJRT, a 7-French steerable ablation catheter with 4-mm tip electrode (Marinr; Medtronic, Minneapolis, US) was inserted via the right or left femoral vein. The catheter was used to target the slow pathway using an electrogram and an anatomical approach similar to that for the cryoablation procedure. The RF energy was delivered at a power limited to a maximum of 30 W, and temperature limited to 60°C. If accelerated junctional rhythm indicative of a successful lesion was observed within 15 seconds, the ablation was continued for up to 60 seconds. If no effect was obtained in 15 seconds, RF ablation was terminated and the catheter was repositioned to a more anterior site and the ablation procedure was repeated. Similar to cryoablation, ‘insurance’ lesions were created in close proximity to successful RF ablation sites.

**Post-procedural monitoring and follow-up**

All patients were observed for 30 minutes after the last ablation. An EPS was performed at the end of the observation period to document the AVN conduction physiology. Induction of the AVJRT was undertaken both with and without isoproterenol infusion. The ablation was regarded as successful if AVJRT was non-inducible, or no more than a single atrial echo beat was noted during atrial stimulation in the presence of a slow pathway conduction.

An ECG was performed prior to discharge from the hospital to evaluate the PR interval. The patients were followed up in the out-patient unit at 1, 3, 6, and 12 months post-ablation, and yearly thereafter. During follow-up, patients were questioned on symptoms of recurrent SVT. An ECG was also performed to assess the PR interval. Recurrence of SVT was to be documented by a 12-lead ECG, event recorder, or 24-hour Holter-type monitoring.

**Data collection**

Demographic and clinical data including age at the time of cryoablation or RF ablation, gender, body weight, associated cardiac lesions, anti-arrhythmic agent use prior to the procedure, and indication for transcatheter ablation were recorded. The follow-up duration was also recorded.

The acute procedural success rate for AVJRT ablation, recurrence rate, and the time to first recurrence (defined as the interval from ablation to the episode of documented recurrence) were all recorded. Other outcome measures, including total procedural time, fluoroscopy time, and complications such as AVN conduction abnormality, were also recorded.

**Statistical analyses**

Descriptive data were presented in the form of mean ± standard deviation (SD). Student’s t test was used to compare means of different groups. Categorical variables were analysed by Chi squared or Fisher’s exact tests. A cut-off P value of 0.05 was taken as statistically significant. Statistical analyses were performed with the Statistical Package for the Social Sciences (Windows version 15.0; SPSS Inc, Chicago [IL], US).

**Results**

**Demographics**

During the study period, 37 patients underwent a total of 38 transcatheter ablation procedures for
AVJRT. The mean age of the patients was 14 (SD, 4) years. There were 13 males and 24 females, all of whom presented with palpitations. One patient also had dizziness during attacks of SVT. None had any syncope or any life-threatening event. Of the 38 procedures, 20 belonged to the RF ablation group and 18 belonged to the cryoablation group. One patient received two procedures. She developed recurrence of SVT 6 months after initial successful RF ablation, and 2.5 years later underwent successful cryoablation.

Both groups had similar demographic and baseline clinical characteristics (Table 1), except that all four of the patients with congenital heart disease were in the cryoablation group. Regarding the patients with congenital heart disease, two had perimembranous ventricular septal defects, one of whom had had prior surgery, and the other two had pulmonary atresia with intact ventricular septa, both of whom had had prior right ventricular outflow tract reconstructions. The RF ablation group, being a historical group, had been followed up for significantly longer time than the cryoablation group (P=0.04).

### Acute success rate and procedural characteristics

Relevant data about the RF ablation and cryoablation groups are shown in Table 2. All 38 procedures were successful, and there was no significant difference between them with respect to total procedural time. However, the fluoroscopy time was significantly shorter in the cryoablation group (31 ± 13 vs 38 ± 18 minutes; P=0.03).

### Complications

There were three procedural complications, all in the RF group and all entailed AVN conduction abnormalities. Two of these patients had persistent prolonged PR intervals (240 and 320 ms; upper normal reference limit, 200 ms). Both of these patients were asymptomatic at follow-up. One patient developed transient complete heart block during RF ablation, which resolved within 5 minutes of terminating RF energy delivery. Two patients in the cryoablation group developed transient second-degree heart block during cryomapping, which resolved soon after termination of cryomapping. These were not considered to be complications. There was no persistent AVN conduction abnormality after cryoablation. Although persistent AVN conduction abnormality was more common in the RF ablation, the difference was not statistically significant. No other complication was documented in either group.

### Medium-term result

None of the patients were lost to follow-up. The mean follow-up duration was 5.8 (SD, 1.4) years for the RF ablation group and 2.2 (SD, 1.0) years for the cryoablation group. Recurrence of arrhythmia occurred in one patient 6 months after initial successful RF ablation; 2.5 years later that patient underwent successful cryoablation.

### Discussion

Ablation for AVJRT by RF has been performed by modifying the relevant slow re-entry pathway. Although the efficacy of RF ablation was excellent, inadvertent heart block has been a particular concern. According to previous reports of RF ablation in children, the risk of heart block ranges from 1.2 to 2.6%.\(^3,4\) To reduce the risk of heart block, cryotherapy has been proposed as an alternative to RF energy. During cryoablation, transient application of a subzero temperature of around -30°C to myocardial cells results in reversible loss of electrical function. As soon as the energy application is terminated, the myocardial tissue rapidly rewarms by convective heat exchange with circulating blood and adjacent tissue vascular supply, which restores its electrical activity. This underlies the concept of cryomapping, which

### TABLE 1. Demographic data

<table>
<thead>
<tr>
<th>Demographics</th>
<th>No. (%) of patients or mean ± standard deviation</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cryoablation (n=18)</td>
<td>Radiofrequency ablation (n=20)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>16 ± 3</td>
<td>13 ± 3</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>48 ± 7</td>
<td>42 ± 18</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>9/9</td>
<td>4/16</td>
</tr>
<tr>
<td>Anti-arrhythmic drug</td>
<td>10 (56%)</td>
<td>11 (55%)</td>
</tr>
<tr>
<td>Congenital heart disease*</td>
<td>4 (22%)</td>
<td>0</td>
</tr>
<tr>
<td>Follow-up duration (years)</td>
<td>2.2 ± 1.0</td>
<td>5.8 ± 1.4</td>
</tr>
</tbody>
</table>

* Two had ventricular septal defects, and two had pulmonary atresia with intact ventricular septa; all, except one with a ventricular septal defect, had received corrective surgery

### TABLE 2. Comparison of outcomes and procedural details

<table>
<thead>
<tr>
<th>Outcome/procedural details</th>
<th>No. (%) of patients or mean ± standard deviation</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cryoablation (n=18)</td>
<td>Radiofrequency ablation (n=20)</td>
</tr>
<tr>
<td>Initial success</td>
<td>18 (100%)</td>
<td>20 (100%)</td>
</tr>
<tr>
<td>Recurrence</td>
<td>0</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>Complications</td>
<td>0</td>
<td>3 (15%)</td>
</tr>
<tr>
<td>Persistent impaired AVN* conduction</td>
<td>0</td>
<td>2 (10%)*</td>
</tr>
<tr>
<td>Procedural time (mins)</td>
<td>172 ± 48</td>
<td>187 ± 59</td>
</tr>
<tr>
<td>Fluoroscopy time (mins)</td>
<td>31 ± 13</td>
<td>38 ± 18</td>
</tr>
</tbody>
</table>

* AVN denotes atrioventricular node
* Two patients in the radiofrequency ablation group had persistent prolonged PR interval
allows determination of the efficacy of the cryothermal energy application and its potential undesirable effect on AVN conduction. By performing cryomapping, sites liable to be associated with impairment of AVN conduction can be identified, and definitive ablation of such targets can be avoided.5-7 Furthermore, during cryoablation, the catheter tip adheres to the endocardium and prevents accidental catheter tip movement towards the AVN.9 Lesions created by cryoablation are therefore also more discrete and smaller in size than those due to RF ablation,10,11 and as a result the risk of damaging AVN is reduced.

In our series, AVN conduction abnormalities were more frequent in the RF ablation group, although the difference was not statistically significant. By resorting to cryomapping, impaired atrioventricular conduction was detected in two patients and delivery of cryothermal energy was immediately stopped. Owing to the reversible nature of cryomapping lesions, the second-degree heart block in these patients resolved forthwith, none of whom had persistent conduction problems. In the RF ablation group, however, two of three patients with evidence of AVN conduction impairment during the procedure had persistent first-degree heart block. By contrast, the safety profile of cryoablation has been demonstrated since the earliest studies in adults and children.5,7,9,12 In each of these reports, despite occurrence of transient AVN conduction problems during the procedures, none of them reported persistent heart block. To date, out of a total of more than 500 cryoablation procedures (including our series) reported for AVJRT in young patients,2,5-7,12-18 there were only two instances of persistent first-degree heart block.13,16 Although the cryoablation data only represent a small percentage of all the AVJRT ablation experience, it appears to be safe. In the future, more data from multicentre trials or international registries may provide further evidence to support the safety profile of cryoablation for AVJRT.

The initial experience with cryoablation in treating paediatric AVJRT showed a variable success (83-95%) and high recurrence rates of up to 23%.5-7,14 These outcomes were inferior to those following RF ablation, but over the years the acute success rate has improved (Table 3).5,7,12-18 Other than the learning curve effect, a number of factors contributed to the improved success rate, these included use of catheters with larger tips and different ablation strategies.

Some of the early studies that used 4-mm tip cryoablation catheters achieved success rates of less than 85%.6 Larger-sized tips created bigger lesions and provided better targeting of the arrhythmia substrate. This was observed in a paediatric study comparing 6-mm and 4-mm tip catheters, which showed that larger tips achieved a 98% versus 93% success rate and a 9% versus 18% recurrence rate.14 The effect of using 6-mm tip catheter in adults also demonstrated less recurrence of AVJRT (6.9% vs 16.9%).19 In a recently published multicentre trial of paediatric cases, an 8-mm tip catheter was used with an acute success rate of 91% and recurrence rate of 2.8% over a mean follow-up of 12 (SD, 3) months.18

Modification of the cryoablation strategy entailed increasing the duration of energy delivery and creation of bonus or ‘insurance’ lesions. In a paediatric study of cryoablation for SVTs—including AVJRT—this strategy achieved an acute success rate of 100%, and recurrence rate of 1% over a mean follow-up of 12 months.15 Delivery of ‘insurance’ lesions has also contributed to the high success rates in other

<table>
<thead>
<tr>
<th>Study (reference no.)</th>
<th>No. of patients</th>
<th>Success rate (%)</th>
<th>Incidence of transient atrioventricular block (%)</th>
<th>Long-term complications</th>
<th>Mean or range of follow-up duration (months)</th>
<th>Recurrence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kirsh et al, 2005 (6)</td>
<td>30</td>
<td>83</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Miyazaki et al, 2005 (7)</td>
<td>22</td>
<td>95.5</td>
<td>32</td>
<td>0</td>
<td>8.2</td>
<td>4.8</td>
</tr>
<tr>
<td>Kriebel et al, 2005 (12)</td>
<td>13</td>
<td>84.6</td>
<td>23</td>
<td>0</td>
<td>8.9</td>
<td>0</td>
</tr>
<tr>
<td>Drago et al, 2005 (5)</td>
<td>14</td>
<td>93</td>
<td>7.1</td>
<td>0</td>
<td>1-22</td>
<td>23</td>
</tr>
<tr>
<td>Drago et al, 2006 (15)</td>
<td>19</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>6-30</td>
<td>0</td>
</tr>
<tr>
<td>Papez et al, 2006 (17)</td>
<td>53</td>
<td>94</td>
<td>22.6</td>
<td>0</td>
<td>8.1</td>
<td>12</td>
</tr>
<tr>
<td>Collins et al, 2006 (2)</td>
<td>55</td>
<td>98</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Avari et al, 2008 (13)</td>
<td>37</td>
<td>97.4</td>
<td>24</td>
<td>1/37 (2.6% with 1°HB*)</td>
<td>9.6</td>
<td>2</td>
</tr>
<tr>
<td>Chanani et al, 2008 (14)</td>
<td>154</td>
<td>95</td>
<td>6</td>
<td>0</td>
<td>12</td>
<td>14.4</td>
</tr>
<tr>
<td>Silver et al, 2010 (18)</td>
<td>76</td>
<td>91</td>
<td>6.5</td>
<td>0</td>
<td>11.6</td>
<td>2.8</td>
</tr>
<tr>
<td>LaPage et al, 2010 (16)</td>
<td>61</td>
<td>100</td>
<td>17</td>
<td>1/61 (1.6% with 1°HB)</td>
<td>18</td>
<td>6.5</td>
</tr>
</tbody>
</table>

*1°HB denotes first-degree heart block
paediatric series.\textsuperscript{13,15,37} In our centre, we have used the 6-mm tip cryoablation catheter in all the procedures, together with the delivery of bonus lesions around the initial successful cryoablation. Thus, our 100% acute success rate with cryoablation was similar to that in other recent studies on paediatric AVJRT.\textsuperscript{12,13-37}

In our series there was no recurrence of AVJRT after cryoablation after a mean follow-up duration of 2.2 years. The medium-term recurrence rates were similar in the cryoablation and RF ablation groups. This has also been reported by Avari et al\textsuperscript{13} and Collins et al\textsuperscript{2} who compared the results of cryoablation with RF ablation for paediatric AVJRT.

In our experience, cryoablation entailed a significantly shorter fluoroscopy time than RF ablation (mean ± SD: 31 ± 13 mins vs 38 ± 18 mins; \(P=0.03\)). Similar observations have been reported by Avari et al\textsuperscript{13} and in a study on adults.\textsuperscript{20} In most centres, continuous fluoroscopic monitoring of the catheter position during ablation is a standard practice. For cryoablation, with the catheter tip adhering to the endocardium during energy application, the likelihood of catheter tip dislodgement is reduced, and therefore continuous fluoroscopy is not required. By reducing radiation exposure to the patient, the potential increase in lifetime risk of malignancy may be decreased, which is another possible advantage of cryoablation over RF ablation.

Putting all the evidence together, cryoablation has a similar acute success rate, but a higher recurrence rate compared to RF ablation. It offers a better safety profile and a potential of less radiation exposure, and is therefore a reasonable alternative to RF ablation in young patients.

**Study limitations**

Since the RF ablation group consisted of historical controls, their follow-up was significantly longer than that for the cryoablation group. A comparably shorter follow-up of the cryoablation group would inevitably have increased the chance of detecting recurrence and complications. From reported paediatric series, the median time to recurrence of AVJRT after cryoablation ranged from 2.5 months to 1 year,\textsuperscript{5,13,16} with very occasional cases of late recurrence ensuing up to 2 years post-ablation.\textsuperscript{16} We therefore believe our mean follow-up period of 2.2 (SD, 1) years would have picked up most if not all recurrences. The small number of patients recruited in each arm of our study also limited its power to detect differences in recurrence and complication rates between the two groups.

**Conclusions**

Transcatheter cryoablation for AVJRT in children and adolescents is highly effective and comparable to RF ablation over the medium term. From our preliminary experience, the safety profile of cryoablation was excellent. Persistent atrioventricular block after cryoablation was not observed. Cryoablation also has the potential advantage over RF ablation of minimising radiation exposure during transcatheter ablation.

**References**