Pre-ablation magnetic resonance imaging of the cavotricuspid isthmus

Kang-Teng Lim1, Connor Murray2, Hao Liu1,3, and Rukshen Weerasooriya1,3*

1Department of Cardiology, Royal Perth Hospital, GPO Box X2213, Perth, Western Australia; 2Department of Medical Imaging, Royal Perth Hospital, Wellington Street, Perth, Western Australia; and 3Department of Medicine, University of Western Australia, Crawley, Western Australia

Received 9 August 2006; accepted after revision 16 November 2006; online publish-ahead-of-print 25 January 2007

Aims In this prospective pilot study, pre-procedural MRI was performed on patients undergoing radio-frequency ablation of the cavotricuspid isthmus (CTI) to assess variation in isthmus anatomy and its impact on catheter ablation.

Methods In 41 patients, 34 males, mean age 56 ± 11.5 years, pre-procedural MRI was performed prior to ablation. On the basis of the magnetic resonance imaging (MRI), isthmus length and description of isthmus morphology was determined. Catheter ablation of the CTI was then performed using a standard technique by an experienced operator without prior knowledge of the MRI findings.

Results The following morphological variants of isthmus morphology were demonstrated: long isthmus, concave isthmus shape, simple pouches, and eccentric septally directed pouches distinct from the coronary sinus. There was a trend towards longer RF times for long and concave shaped CTI. Eccentric septally directed pouches were associated with significantly longer radiofrequency energy delivery times (29.5 ± 24.5 min RF versus 14.5 ± 12.9 min RF; \( P = 0.037 \)).

Conclusion The anatomy of the CTI is highly variable. Ablation difficulty can be predicted by the presence or absence of morphological variants and the length of CTI demonstrated by cardiac MRI.

Introduction

Radiofrequency ablation of the cavotricuspid isthmus (CTI) is first line treatment for patients with isthmus-dependent atrial flutter. Occasional procedural difficulties may be related to the highly variable anatomy of the CTI.\(^1\) Previous reports have suggested correlation of RF difficulty with isthmus morphology and length.\(^2,3,4\) Isthmus anatomy has been based on post-mortem analysis, right atrial angiographic definition, and phased-array intracardiac echo.\(^2,6\)

Magnetic resonance imaging (MRI) is an alternative imaging technique which has not been previously used to define CTI anatomy. In this prospective pilot study, pre-procedural MRI was performed on patients undergoing radiofrequency ablation of the CTI to assess variation in isthmus anatomy and its impact on catheter ablation.

Methods

Study population

The study population consisted of patients undergoing CTI ablation for treatment of atrial flutter (13 patients) or as part of an atrial fibrillation ablation protocol (28 patients). There were 41 patients, 34 males, mean age 56 ± 11.5 years. Structural heart disease was present in 14 patients; 2 ischaemic cardiomyopathy, 5 dilated cardiomyopathy, 1 hypertrophic cardiomyopathy, 2 right ventricular dysfunction, and 4 mitral regurgitation. Ten patients had a history of hypertension. Before RF ablation, 25 patients were receiving antiarrhythmic therapy (predominantly amiodarone). Baseline flutter was observed in eight patients.

MRI protocol

Pre-procedure MRI was performed prior to radiofrequency ablation to determine isthmus size and morphology. All MRI examinations were performed using a Siemens Sonata 1.5 Tesla machine with a gradient strength of 40 mT/m and a slew rate of 200 (T/m)/s. Thin section (4 mm) cine imaging was performed using a steady-state free precession (TruFISP) technique in held expiration. Between 26 and 30 frames per heart beat were acquired. Radial images which approximated an RAO angiographic view were performed through the CTI and the plane for analysis chosen as the maximal CTI length which demonstrated both the inferior vena cava and the tricuspid valve apparatus (Figure 1). Cavotricuspid isthmus length and morphology were assessed on the latest diastolic frame, confirmed by opening of the tricuspid valve on the next frame. Static dark blood imaging was performed using a thin (3 mm) section T1-weighted turbo spin echo sequence. For the purpose of statistical analysis, we defined morphology based on

© The European Society of Cardiology 2007. All rights reserved. For Permissions, please e-mail: journals.permissions@oxfordjournals.org
The length of the CTI was determined by drawing a straight line from the inferior vena cava to the lower hinge point of the tricuspid valve. A long CTI was defined as \( \geq 35 \) mm, short CTI was \( <35 \) mm (Figure 2). The perpendicular distance between a line connecting the IVC to the tricuspid valve lower hinge point and the deepest point of the CTI was measured and based upon this measurement. Concave CTI was defined as a perpendicular distance \( \geq 2 \) mm, whereas a flat isthmus was defined as a perpendicular distance \( <2 \) mm (Figure 3). Presence of a pouch-like recess was subjectively defined by an investigator blinded to the ablation results. Pouches were further classified as symmetrical- or asymmetrical-septally directed (Figure 4). The definition of CTI morphology was blinded from the electrophysiologist performing the ablation procedure (RW).

Figure 1  A series of cine screen captures demonstrating the dynamic changes in isthmus morphology during the cardiac cycle. (A) During ventricular systole—note the ‘concertina’ effect on the CTI. (C) The frame just prior to tricuspid leaflet opening and (D) the frame immediately afterwards showing valve leaflet opening. Measurements of isthmus length and morphology in this case would be taken from (C).

Figure 2  Example of long (A) and short (B) CTI.
Catheter ablation

All ablation procedures were performed by a single operator (RW). A standard, previously described technique was used for CTI ablation. The ablation procedures were performed under light sedation using intravenous midazolam and fentanyl. The procedures were performed with patients fully anticoagulated. Two steerable electrode catheters were used; a pentapolar catheter was positioned within the coronary sinus and a 5 mm tip irrigated thermocouple catheter (Thermocool F-curve, Biosense-Webster, Diamond Bar, CA, USA) was used for ablation. An externally irrigated catheter was chosen for this study because of its recently demonstrated superiority in a randomized study, its operator preference, and its familiarity. The catheter was dragged from the tricuspid annulus to the IVC during ablation. Ablation was performed in power controlled delivery mode (EP Shuttle, Stokert, Frieberg, Germany) using a maximum power of 50 W with an irrigation flow rate of 17–30 mL/min. Bi-directional isthmus block was demonstrated using the technique of differential pacing as well as by demonstrating a complete line of double potentials mapping at three areas—ventricular end, middle isthmus, and IVC end during coronary sinus and lateral pacing. Bi-directional block was re-confirmed after an observation period of 30 min. After ablation, patients continued warfarin with an INR target of 2–3 for at least 4 weeks.

Statistical analysis

Data was analysed using the SPSS software package. Continuous variables were compared using the Student’s t-test, and categorical variables were compared using χ² test. The radiofrequency data and correlation with isthmus morphology was analysed using the Mann–Whitney U test (2-sided).

Results

Magnetic resonance imaging

Pre-procedure MRI revealed several distinct CTI morphologies (including in eight patients who were in atrial flutter at baseline). In addition, the living anatomy of this region was clearly demonstrated with a ‘concertina effect’
during systole (Figure 1). The mean CTI length was $38.6 \pm 7.8$ mm (range 27–51 mm). The majority of patients had a concave CTI (31/41, 76%). Pouches were seen which were distinct from the coronary sinus in 17/41 patients (41%), and were symmetrical in 9/41 (22%) patients and eccentric septally directed in 8/41 (19%) patients.

Catheter ablation
Bi-directional isthmus block was demonstrated in all 41 patients. The mean total radiofrequency energy delivery was $19.1 \pm 17.9$ min (range 1.8–62.7 min). The mean procedure time was $132.5 \pm 56.4$ min (range 35–235 min), with a mean fluoroscopy time of $30.4 \pm 16.5$ min (range 5.7–65.8 min). There were no complications of the ablation procedure.

Anatomy associated with difficult ablation
There was a trend towards long CTI being more difficult to ablate than short CTI ($20.2 \pm 9.9$ min RF versus $14.3 \pm 10.7$ min RF; $P = 0.35$). There was also a trend towards more difficulty ablating concave compared with flat CTI ($20.5 \pm 18.4$ min RF versus $10.5 \pm 9.3$ min RF; $P = 0.155$). Cavotricuspid isthmus demonstrating an eccentrically septally directed pouch required significantly more radiofrequency energy to achieve isthmus block ($29.5 \pm 24.5$ min RF versus $14.5 \pm 12.9$ min RF; $P = 0.037$).

Discussion
This is the first description of cardiac MRI of the CTI. Using this technique, high quality images which closely resemble the RAO angiographic view were obtained. Additional information was provided by MRI, as the images were of better fidelity than angiographic views. In this pilot study, MRI enabled measurement of isthmus length and demonstration of isthmus morphology analogous to angiography, but in a non-invasive manner. Asymmetrically septally directed isthmus pouches were demonstrated by MRI, and in this study this morphology was particularly difficult to ablate. The particular geometry of the septally directed pouch means that part of the isthmus is ‘protected’ during a standard pullback from the ventricular end of the isthmus, as there is a roof-like projection extending from the tricuspid end (Figure 4B). In these cases, it is likely that a variation of the standard pullback technique is required to achieve isthmus block. The variation in technique is demonstrated in Figure 5 and comprises the formation of a ‘u-turn’ of the ablation catheter followed by advancement of the catheter tip into the pouch.

Right atrial conventional angiography and autopsy reports reveal a variable CTI anatomy with an average length of $27 \pm 3.3$–$37 \pm 8$ mm and different morphologies. In addition, the CTI may be flat wherein the isthmus does not deviate more than 2 mm from a straight line drawn between junction of IVC to right atrium and hinge point of tricuspid valve, concave ($>2$ mm deviation), or aneurysmal. CTI lengths have been classified as short (<35 mm) or long ($>35$ mm). Recent reports have established a relationship between isthmus anatomy and efficacy of catheter ablation in the treatment of atrial flutter. From the electrophysiological perspective, the ease of creating linear CTI ablation will depend upon isthmus morphology, thickness, and size. This study describes the technique and results of MRI. Analogous to right atrial angiography, details of length, and a number of morphological variations of CTI in humans can be demonstrated. Eight patients were in atrial flutter at the time of MRI and this did not preclude imaging. Unlike phased-array intracardiac echo and direct angiography, cardiac MRI is non-invasive and can be performed for days, weeks, or months prior to any invasive procedure. In the present study, a significant proportion of patients had long and concave CTI, which may explain the relatively long ablation times despite the use of an irrigated-tip catheter. There was a trend towards direct correlation between isthmus length and RF delivery times which did not reach significance due to the small sample size.

Limitations
(i) This study was intended as a pilot to evaluate the possibilities of MRI, and it is relatively underpowered.

Figure 5 Proposed modification of standard pullback technique for abrating CTI with eccentric, septally directed pouch. The first step is to form a ‘u-turn’ of the ablation catheter (A), second, the catheter is deflected and advanced into the pouch (B).
and only demonstrated a trend towards more RF applications in longer and more complex isthmuses with the exception of eccentric pouches, where even in this small study, a significant increase in RF delivery was seen. Future randomized studies, with adequate power, are now planned to determine if MRI can prove useful for procedure planning by determining catheter selection and modifications to a standard pullback from tricuspid valve to IVC.

(ii) Although the MRI appears to be a reliable imaging modality to predict difficulty of the CTI ablation, an important caveat is that the thickness of the CTI, a potential marker of ablation difficulty, cannot be reliably determined using presently available MRI technology.

(iii) The cost of MRI scanning is high and this imaging modality may be most applicable in those patients undergoing combined CTI and AF ablation as an MRI can provide information about left atrial anatomy (including PV size and number) as well as important anatomical information about the CTI.

Conclusion

The anatomy of the CTI is highly variable. Procedural difficulties can be predicted by the presence or absence of morphological variants and the length of CTI. MRI provides accurate detail of the living anatomy of the CTI.

Acknowledgements


References