Usefulness of three-dimensional non-fluoroscopic mapping in the ablation of typical atrial flutter

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Background. **Catheter ablation of the cavo-tricuspid isthmus is rapidly becoming the first line of treatment in the management of atrial flutter. The standard procedure is usually performed under fluoroscopy guidance and relays on multisite endocardial recordings to assess the completeness of the isthmus conduction block. Despite the high rate of success there is, at follow-up, a considerable number of recurrences which could reflect the limitations of conventional assessment of conduction block across the isthmus. This new non-fluoroscopic mapping system allowing high density mapping along the entire length of the ablation line, could provide a more accurate way of verifying complete conduction block. The aim of the present study was to describe our overall results and long-term follow-up using a three-dimensional mapping system to guide radiofrequency ablation of typical atrial flutter.**

Methods. **A multipoint three-dimensional map of the cavo-tricuspid isthmus, septal and lateral atrial wall was performed in 87 patients prior to and following ablation for typical atrial flutter. Evidence of persisting gaps in the line of block was identified by visual inspection of the color-coded activation maps and these sites were re-ablated. The conduction sequence was also assessed with conventional bidirectional pacing and recording. To assess the reduction in fluoroscopy time, two groups of patients were compared: group A (14 patients) in whom the entire mapping-ablation procedure was guided by the three-dimensional system (Carto, Biosense-Webster, Diamond Bar, CA, USA) and group B (32 patients) in whom the same protocol was used but the procedure was guided by standard fluoroscopic imaging.**

Results. **Acute success was achieved in every patient. During bilateral isthmus pacing, the mean local activation time increased from 20.3 ± 13.3 ms pre-ablation to 148.3 ± 53.2 ms ($p < 0.01$) post-ablation with a mean difference of 120 ± 31 ms. In 11 patients (9.2%) there was evidence of persisting conduction across the line of block despite evidence of reverse activation of the cavo-tricuspid isthmus by conventional pacing. A gap in the ablation line was identified and re-ablated. At a mean follow-up of 16.3 ± 2.2 months, there were 5 (4.2%) recurrences of atrial flutter and 12 (10%) recurrences of isolated atrial fibrillation. Four of the 5 recurrences occurred in patients in whom ablation was guided by conventional fluoroscopy (group B). The fluoroscopy time was 4.2 ± 1.5 min in group A and 27.2 ± 8.2 min in group B ($p < 0.001$).**

Conclusions. **Multipoint mapping of the ablation line following radiofrequency ablation of typical atrial flutter performed using the Carto system allows a more accurate assessment of the isthmus conduction block. This has the potential to reduce the recurrence rate to the level observed for other supraventricular tachycardias.**

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Introduction

Typical atrial flutter is a common arrhythmia which has been the object of a substantial body of research[1-6]. As a result of this concerted effort, the mechanism of this tachycardia has been largely elucidated. Atrial flutter is considered to be a right atrial macroreentry tachycardia[5,7,8] which is bounded by well-defined anatomical barriers[5,9] including the crista terminalis extending to the level of the Eustachian ridge and, anteriorly, the tricuspid annulus. A critical zone of the reentrant circuit is identified in the narrow isthmus delimited by the inferior vena cava (IVC), the tricuspid valve (TV) and the Eustachian ridge. Numerous studies[10-12] have shown how radiofrequency (RF) applications delivered in a linear fashion to this region can achieve a permanent conduction block leading to long-term cure in the majority of patients. The demonstration of continuity in the line of conduction block across the isthmus is therefore critical for the prevention of late recurrences.

The purpose of the present study was to evaluate a non-fluoroscopic three-dimensional mapping system in the guidance of RF ablation of typical atrial flutter and to assess the efficacy of the procedure.

Methods

Patient population. Consecutive patients with electrocardiographic documentation of typical atrial flutter (sawtooth flutter waves negative in II, III, aVF), referred to the Arrhythmia Service of the University of Kentucky because of symptomatic, sustained tachycardia unresponsive to medications, were considered for enrollment in this study.

Electrophysiological study. The study was performed in the fasting post-absorptive state after written informed consent was obtained. The patients were sedated with midazolam and a continuous infusion of fentanyl adjusted to obtain a stable level of sedation while the blood pressure and peripheral oxygen saturation were continuously monitored. A multipolar recording catheter was advanced through a 7F sheath introduced via the right jugular vein into the coronary sinus to serve as a reference for the mapping and to pace the atrium at a cycle length of 500 ms. Through the femoral vein, a sensor equipped catheter (Carto, Biosense-Webster, Diamond Bar, CA, USA) was positioned into the right atrium for mapping, pacing and delivery of the RF current. In addition, conventional multielectrode catheters were placed to map the activation sequence along the crista terminalis and across the isthmus during coronary sinus and lateral isthmus pacing.

The three-dimensional maps were obtained using the EP Navigation System (Biosense-Webster), which enables one to detect the position of the mapping catheter in the electromagnetic field generated by a triangular frame mounted below the fluoroscopy table. A second sensor-equipped catheter was positioned between the scapulae of the patient to provide dynamic corrective reference for the spatial location of the mapping catheter during phasic respiratory motion.

The electrograms sensed by the rowing catheter were transmitted to the Carto processor and incorporated with reference to a stable atrial signal (in our protocol the atrial electrogram of the coronary sinus catheter) within this electromagnetically coded space. The color-coded three-dimensional maps were constructed by sequential mapping incorporating the activation times and spatial coordinates from each of the multiple sites within the right atrial endocardium. The position and the orientation of these maps, displayed on the monitor of the workstation (Silicon Graphic, Mountain View, CA, USA), could be rotated by moving the workstation mouse in such a way as to alter the viewing perspective.

Radiofrequency ablation. After the arrhythmia mechanism was elucidated using conventional pacing techniques, ablation energy generated at 550 kHz by a voltage controlled RF generator (Boston Scientific, San Josè, CA, USA), was delivered in unipolar fashion between the distal electrode of the mapping catheter and a cutaneous electrode placed below the left scapula. The duration of the application as well as the wattage and impedance were continuously displayed on the monitor of a computer-based digital amplifier-recorded system (General Electric Marquette, Milwaukee, WI, USA). A 4 mm tip (Biosense-Webster) was initially employed in every patient to sequentially deliver a variable number of RF energy pulses, in linear fashion, at the narrowest point of the IVC-TV isthmus (Fig. 1).

Each delivery site was tagged with a roundel, which allowed the observer to visualize the progression of the ablation line and ensure overlap between consecutive RF pulses (Fig. 1). The delivery of RF current was continued until the disappearance of the unipolar atrial electrogram recorded at the site. The wattage of the pulses was progressively increased to a maximum of 40-50 W while the impedance was closely monitored. This process was continued until a line of closely spaced lesions spanning the entire width of the isthmus was visually documented on the three-dimensional maps (Fig. 1). In case of an impedance rise the ablation was interrupt-

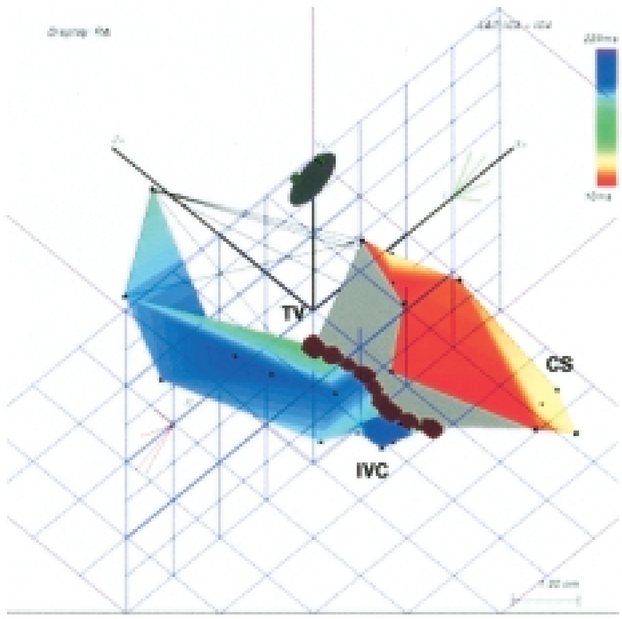

Figure 1. *Post-ablation high density map limited to the inferior vena cava (IVC)-tricuspid valve (TV) isthmus during coronary sinus (CS) pacing in the left oblique view with a caudo-cranial tilt. Multiple radiofrequency applications were delivered from the TV to the IVC. Red tags mark the site of each radiofrequency energy delivery during the catheter pullback. The ablation line is seen bridging the entire width of the isthmus. The early activation front (yellow-red color) emerging from the CS across the isthmus is blocked at the level of the ablation line. The other side of the line is activated by a wavefront (blue-purple color) proceeding from the lateral isthmus and reaching the line 130 ms later. A homogeneous calorimetric transition is observed across the ablation line with a gray area (where the early meets the delayed artifact) separating the two activation wavefronts.*

ed, the catheter removed, its tip inspected and cleared from any accumulated debris. In case of frequent excessive impedance rises using the 4 mm tip, despite resetting the delivered energy at lower levels, this catheter was exchanged, after completing the initial ablation line, for an 8 mm tip RF ablation catheter (Boston Scientific). The catheter was positioned, under fluoroscopic guidance, across the isthmus and the previous ablation line was identified by searching for areas with low or absent atrial electrograms. The ablation over the initial line was completed using the same protocol.

In every patient, a multipoint map of the IVC-TV isthmus was obtained using the 4 mm tip catheter in order to assess the functional line of block during coronary sinus and lateral isthmus pacing, 1 hour post-ablation. A variable number of endocardial recordings were acquired at both sides of the ablation line, visually identified by tags placed at the ablation sites (Figs. 1 and 2). The color-coded activation map generated by the Carto system allowed visual inspection of the line of conduction block by depicting the early activation front from coronary sinus pacing (yellow-red) completely separated from the delayed front (blue-purple) reaching the lateral aspect of the ablation line from counter-clockwise activation of the tricuspid ring (Fig. 1). Successful IVC-TV isthmus conduction block was felt to be present if there was no color transition across the line and if the latest activation was recorded on the lateral aspect of the line. Persistent conduction across the ablation line was visualized as spikes of intermediate color bridging the line in correspondence of the gap

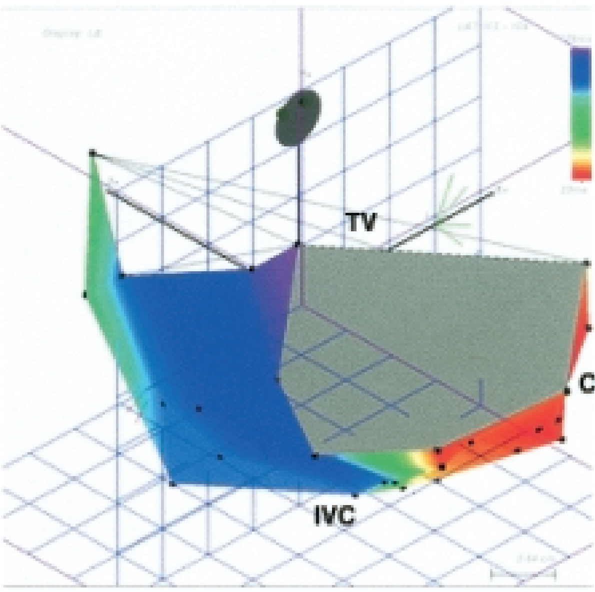

Figure 2. *Projection similar to figure 1. The activation front from the CS pacing (yellow-red) meets the delayed front (blue-purple) revolving clockwise around the tricuspid ring at the site of the ablation line. The two fronts are separated by an area of no conduction (gray area) in the TV region where spatially closed points are activated with a delay of 150 ms. More proximally, towards the IVC, the gray area is interrupted by a slow activation front (green) proceeding across a gap in the ablation line and fusing with the delayed front. Abbreviations as in figure 1.*

(Fig. 2). These areas were targeted and repeated ablation pulses were delivered to complete the line of block. Mapping was then repeated to ensure successful conduction block.

To assess the reduction in radiation exposure achieved with the Carto system, the total fluoroscopy time during mapping and ablation was compared in two groups of randomly selected patients. In group A (14 patients) both mapping and ablation were performed using only the 4 mm sensor equipped catheter (Carto, Biosense-Webster). In group B (32 patients), the mapping was performed using the same catheter but the ablation was guided by conventional fluoroscopic imaging.

Statistical analysis. Data are presented as mean ± SD. The increase in local activation time, pre and post-ablation and fluoroscopy exposure in groups A and B were performed using a paired Student's t-test. The Mann-Whitney U-test for differences between independent samples was used to compare the rates of recurrences observed using Carto and conventionally guided ablation[13].

Results

Patient population. One hundred and nineteen consecutive patients (88 males, 31 females) with a mean age of 60 ± 15 years, underwent RF ablation of atrial flutter at the University of Kentucky between August 1997 and January 1998.

This arrhythmia had been present for a mean of 21 ± 20 months and every patient had been treated, unsuccessfully, with a mean of 1.6 ± 1.3 drugs. Structural heart disease was present in 77 patients with a large predominance of coronary artery disease (49 patients). Forty of these 49 patients had undergone previous coronary artery bypass. Fifty-seven patients had more than one documented arrhythmia (atrial fibrillation in 37, atrial tachycardia in 20). Forty-two individuals had been submitted at least once to external electrical cardioversion.

Right atrial mapping and radiofrequency ablation. The mean atrial flutter cycle length was 245.5 ± 24 ms. A mean of 12 ± 5 RF pulses of variable duration and energy were delivered in a linear fashion between the tricuspid annulus and the IVC. In every patient an ablation line bridging these two anatomical structures was successfully completed. The position of the catheter and the relation of the RF lesions to these anatomical structures were displayed on the mapping system (Fig. 1) during the procedure. It was thus possible to ensure a linear and contiguous delivery of the lesions constituting the line of block. Atrial flutter, present in 75 patients (63%) at the moment of ablation, was terminated during the ablation in all cases.

The mean length of the IVC-TV isthmus at its narrowest point was 2.4 ± 0.7 cm. The mean local activation taken at two sites spanning the line of block before and after ablation increased from 20.3 ± 13.3 to 148.3 ± 53.2 ms ($p < 0.01$) with a mean difference of 120 ± 31 ms. The completeness of the line of block was confirmed, post-ablation, by performing a high density map, with a mean of 49 ± 11 points, of the medial and lateral aspects of the ablation line during coronary sinus pacing. Interruption of conduction was visually demonstrated by the presence of a sudden calorimetric transition from blue-purple (delayed activation) to red-yellow (early activation) without intermediate colors at any point of the ablation line (Fig. 1). Following ablation, conventional multielectrode mapping showing a change in activation of the septal and lateral right atrial walls during coronary sinus and lateral isthmus pacing consistent with conduction block[13] was present in all patients. In 11 patients (9.2%) a similar change in right atrial activation was documented by conventional mapping despite the visualization of gaps in the ablation line (Fig. 2) during Carto system mapping. Ablation of these sites was accomplished in all these cases.

In Carto-guided ablation, the fluoroscopy time was 4.2 ± 1.5 min. This was statistically shorter ($p < 0.001$) than the 27.2 ± 8.2 min total mean fluoroscopy time recorded in the group undergoing fluoroscopy-guided ablation while the total procedure time (52 ± 11 vs 49 ± 18 min) was comparable in the two groups.

Follow-up. At a mean follow-up of 16.3 ± 2.2 months, there were 5 (4.2%) recurrences of typical atrial flutter occurring at a mean of 32 ± 16 days and 12 (10%) recurrences of atrial fibrillation occurring at a mean of 62 ± 28 days.

Four of these recurrences occurred in the 32 patients in whom ablation was guided by fluoroscopy (12.5%) compared to only 1 among the 87 patients submitted to Carto-guided ablation (1.1%, $p < 0.01$). None of the 5 patients with previously documented atrial fibrillation presented with recurrences of this arrhythmia following the procedure. All the atrial flutter recurrences were again successfully re-ablated using the three-dimensional mapping system while the patients with recurrent atrial fibrillation were placed on antiarrhythmic drugs. Analysis of the initial procedures in patients with recurrences could not identify any fault in the line of block. However, the length of the isthmus in these patients was longer than the average length of the entire population (2.4 ± 0.7 vs 4.2 ± 0.8 cm, $p < 0.05$).

Discussion

Our understanding of the mechanism of atrial flutter has greatly improved following the publication of recent studies correlating endocardial mapping with ultrasound imaging of anatomical structures[5]. These and previous investigations[1-11], have demonstrated that the IVC-TV isthmus represents an obligatory route for typical atrial flutter. Fluoroscopy-guided RF ablation resulting in conduction block across the isthmus, is becoming the preferred approach in the treatment of this arrhythmia. Block can be demonstrated by a change in activation of the septal and lateral right atrial walls during pacing, respectively, from the coronary sinus and the low lateral right atrial wall[14]. Conventional assessment of the global right atrial activation may misdiagnose complete isthmus block in the presence of persisting slow conduction through the ablation line[15]. An incompletely damaged isthmus can later recover conduction explaining the discrepancy between the excellent early and the not so satisfactory delayed ablation results[10-12,16]. Endocardial recordings of split potentials along the entire length of the ablation line should enable us to identify more precisely the persisting gaps in the line of block[17]. Unfortunately, very often, fragmented potentials of low voltage are observed in this region, rendering assessment of the conduction block by this method unreliable[18].

Although enlarging the tip electrodes increases the lesion size and depth[19], clinical studies comparing 4 and 8 mm tipped ablation catheters have yielded conflicting results[20,21].

Higher resolution mapping and more accurate definition of the anatomical substrate could, on the other hand, improve the efficacy of the procedure thus increasing the success rate and lowering the number of recurrences. A number of non-conventional mapping technologies have become available in the last few years although the advantages offered by these costly systems in the ablation of common arrhythmias are still unclear[22]. In this study we attempted to define the benefits to patient and operator of the Carto mapping system compared to a conventional approach.

The advantage of high density mapping of the IVC-TV isthmus using three-dimensional activation maps, compared to more traditional mapping protocols, consists of the fact that it enables a more systematic and accurate assessment of the line of block by providing precise electro-anatomical information in a simplified mapping protocol without fluoroscopic aid[23]. The sensor-equipped catheter and its relation to the IVC-TV isthmus can be visualized three-dimensionally thus allowing the operator to choose the shortest and most convenient path connecting the IVC and the tricuspid ring and to avoid sites of less than optimal endocardium-catheter interface. By tagging each site of RF energy delivery (Fig. 1) it becomes possible to guide the ablating catheter in the delivery of overlapping pulses along a line bridging the isthmus. Isthmus conduction block, following ablation, can be demonstrated, during coronary sinus pacing, by a high density map along the entire length of the ablation line[24]. Should conduction persist through an incomplete ablation line, the net calorimetric demarcation shown in figure 1 is lost and color fusion between yellow-red (early activation) and purple-blue (delayed activation) appears at the site of persistent conduction. The catheter can be very accurately maneuvered to the gap, due to the system's capability to spatially identify points within the map with a high degree of precision[25]. As shown in our series and as previously reported[24], marked conduction delay across the ablation line and inversion of the activation front across the isthmus can be recorded in patients with evidence, at high density mapping, of gaps in the ablation line. In such patients, the procedure would, according to standard techniques[14,15], have been considered successful. It is likely, as suggested by others[26] that these gaps would have, in time, regained full conduction properties leading to arrhythmia recurrences.

This is also in keeping with the higher recurrence rate in the group of our patients in whom ablation was guided by standard fluoroscopy (group B).

Documentation of a successful line of block can be acutely accomplished in almost all patients. In this respect, our acute success rate was not different from previous reports[10-12,16]. On the other hand, the low arrhythmia recurrence rate observed in our series represents an improvement and is well within the range reported with other supraventricular tachycardias[27]. Recently, a similar recurrence rate was reported in a smaller study[24] using local electrogram-based criteria of IVC-TV block. This approach could be facilitated by the Carto system which allows precise re-navigation of the mapping catheter to the ablation site.

The sensor-equipped catheter for mapping and ablation provides an opportunity to reduce the fluoroscopy time. In agreement with others[28], we confirm the reduction in the fluoroscopy time observed in the electromagnetic mapping group as compared to that required when the standard method is employed. Our data suggest that, pre-ablation maps limited to the IVC-TV isthmus, ablation of this region and post-ablation maps can all be performed, by operators familiar with the system, in less than 4 min of fluoroscopy time. This is a considerably lower radiation exposure than previously reported for similar procedures guided by fluoroscopy[27,29].

In summary, our experience on the use of a three-dimensional non-fluoroscopic mapping system to guide ablation of typical atrial flutter suggests that this approach allows a more accurate evaluation of the line of isthmus conduction block leading to a reduction in the delayed flutter recurrence rate together with a marked decrease in radiation exposure for the patient and operator.

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