Atrial Reentrant Tachycardia After Surgery for Congenital Heart Disease

Endocardial Mapping and Radiofrequency Catheter Ablation Using a Novel, Noncontact Mapping System

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Background—The purpose of the present study was to determine the role of a novel, noncontact mapping system for assessing a variety of atrial reentrant tachycardias (ART) in patients after the surgical correction of congenital heart disease.

Methods and Results—In 14 patients, an electrophysiological study using the Ensite 3000 system was performed to assess ARTs resistant to medical treatment. Sixteen different forms of ART were inducible in the 14 patients studied. The reentrant circuit of all ARTs could be characterized and localized with respect to anatomic landmarks such as atriotomy scars, intraatrial patches/baffles, and cardiac structures. In 15 of the 16 ARTs (in 13 of the 14 patients), a target area of the reentrant circuit for radiofrequency current application (ie, an area of conduction between 2 anatomical obstacles such as surgical barriers and cardiac structures of electrical isolation) could be localized within the systemic venous atrium. Nine patients exhibited macroreentry, and 4 showed microreentry. In 12 patients, ART could be terminated by creating linear radiofrequency current lesions (75°C, 180 to 390 s). Completeness of linear lesions after radiofrequency current delivery was proven by analyzing color-coded isopotential maps of atrial activation while applying atrial pacing techniques. The mean duration of the procedures was 286 minutes (range, 130 to 435 minutes); fluoroscopy time ranged from 7 to 33.8 minutes (mean, 17.4 minutes).

Conclusions—In patients with ART after the surgical correction of congenital heart disease, the use of the noncontact mapping system allows for characterization of the tachycardia and guidance for effective radiofrequency current delivery. (Circulation. 2001;103:2266-2271.)

Key Words: tachycardia ■ heart defects, congenital ■ mapping ■ catheter ablation

Atrial reentrant tachycardias (ART) are frequently observed after the surgical correction of congenital heart defects.1-6 Results of antiarrhythmic therapy are often unsatisfactory.7-9 Therefore, in symptomatic patients, radiofrequency catheter ablation of the anatomic substrate of the tachycardia is indicated. Conventional endocardial mapping using multiple multipolar electrode catheters is associated with a low primary success rate and a significant number of tachycardia recurrences.10-14 In the past, systematic approaches to those tachycardias using a multipolar basket catheter15 and electroanatomic mapping16 have been described. Recently, a first report on the use of a novel noncontact mapping system (Ensite 3000) to guide radiofrequency ablation in 6 patients with ART after Fontan surgery was published.17

The purpose of the present study was to report our initial experience with the use of the noncontact mapping system in patients with a variety of ARTs after the surgical correction of congenital heart defects.

Methods

Patients

From June 1999 through October 2000, 14 patients with recurrent episodes of ART underwent electrophysiological study with the noncontact mapping system Ensite 3000. The study was approved by the scientific committee of the Children's Hospital of Hannover Medical School. Demographic data for the study patients are displayed in Table I (see http://www.circulationaha.org). The mean age of the patients was 18.4 years (range, 7 to 39 years), and body weight ranged from 17 to 79 kg (mean, 52.2 kg). The mean interval between the final surgical procedure and the electrophysiological study was 12.3 years (range, 2 to 23 years). All antiarrhythmic medication was discontinued for at least 5 half-lives before the study. In patients treated with amiodarone, the drug was discontinued at...
During the electrophysiological study, heparin was given repeatedly at least 2 months before the procedure, and patients were temporarily treated with sotalol.

**Noncontact Endocardial Mapping**

During the electrophysiological study, heparin was given repeatedly to keep the activated clotting time ≥300 s throughout the study. Angiography of the systemic venous atrium was performed initially to assess the radiographic features of the individual anatomy (Figure 1A). The 9F multielectrode array (Endocardial Solutions Inc) was introduced into the systemic venous atrium together with a steerable 20-pole electrode catheter (A20, Cordis Webster) and a steerable 7F mapping and ablation catheter (Marinr, Medtronic; Figure 1B). Signals from the standard electrode catheters together with the mapping and ablation catheter (patient 14; Tables I and II).

The anatomy of the systemic venous atrium was reconstructed by roving the steerable mapping and ablation catheter along the endocardial surface of the chamber while recording a 6 kHz locator signal (Enguide location signal). During aquisition of the endocardial anatomy, care was taken to identify and label anatomical landmarks, such as atriotomy scars and intraatrial baffles and patches, and their spatial relation to anatomical structures of electrical isolation, such as the orifices of the caval veins and the atrioventricular valve annuli. For this purpose, recordings from the standard electrode catheters were investigated for the presence of fractionated atrial electrograms, double potentials, and diminutive or absent atrial electrograms.

After determining the induction mode of the ART, the atrial activation sequence was investigated by analyzing color-coded isopotential maps and by analyzing reconstructed virtual atrial electrograms with high-pass filter settings between 0.002 to 0.016 Hz and low-pass filter settings at 300 Hz. Validation of the location signal (Enguide) and of the reconstruction of unipolar electrograms has been studied recently in animals and in humans.

Isopotential color-coded maps were studied to identify the propagation of atrial activation along the labeled anatomical landmarks and to identify a protected zone of the reentrant circuit between surgical barriers such as atriotomy scars and cardiac structures of electrical isolation like the orifices of the caval veins or the annuli of the atrioventricular valves (Figure 2). Findings were validated by analyzing the virtual atrial electrograms for the presence of fractionated signals at that location. Care was taken to separate atrial activation from artifacts and far-field potentials by adjusting filter settings, the amplitude of virtual electrograms, and color contrast settings. The participation of the protected zone in the reentrant circuit was verified by applying pacemapping and entrainment mapping techniques (Figure 3), as described previously.

The presence of a microreentrant circuit was inferred if atrial activation during ART could not be reconstructed by closing a loop within the systemic venous atrium. In these patients, however, a point of earliest endocardial activation was identified by the presence of a QS configuration of the local virtual electrograms, and mapping and entrainment criteria for the presence of reentrant circuit could be fulfilled at that location.

**Radiofrequency Current Application**

In patients with a macroreentry circuit, linear radiofrequency current lesions (500 kHz; maximum, 70 W; HAT 300 Smart, Dr Osypka).
GmbH) were created between anatomical obstacles (natural or surgical) serving as the borders of the protected zone at a target temperature of 75°C. Energy was delivered point by point for 30 s. In patients with microreentrant circuit tachycardia, the point of earliest endocardial activation was targeted.

The success of ablating any particular ART was defined by termination of tachycardia during energy application and lack of inducibility of ART by programmed atrial stimulation immediately and 30 minutes after energy application. Completeness of linear radiofrequency lesions was finally validated during spontaneous atrial rhythm and during pacing from adjacent sites along the induced radiofrequency line by the presence of double potentials in the virtual electrograms and analysis of isopotential maps.27

Follow-Up
After the procedure, all patients had a 2D echocardiogram performed to exclude adhesive intraatrial thrombi before discharge. During follow-up, patients were seen on an outpatient basis every 3 months. Follow-up examinations included physical examination, 2D echocardiography, surface ECG, and 24-hour Holter monitoring.

Results
In the 14 patients in this report, 16 sustained (>30 s) ARTs that were finally judged to be clinically relevant were studied. The mean cycle length of the ART was 299 ms (range, 260 to 440 ms). Anatomical reconstruction of the systemic venous atrium could be established in all 14 patients studied. In 15 of the 16 ARTs (from 13 of the 14 patients), a target area of the reentrant circuit for radiofrequency current application could be localized within the systemic venous atrium. In 12 of those 13 patients, ART could be terminated by creating linear radiofrequency current lesions.

Patients After Fontan Operation
In all 7 patients studied who had a Fontan operation, reconstruction of the endocardial surface of the right atrium, including labeling anatomical landmarks like the orifices of the caval veins and the orifice of the coronary sinus (if still draining into the right atrium, n=5), and anastomoses to the pulmonary artery could be accomplished.

Analysis of the color-coded isopotential maps of atrial activation allowed recognition of a macroreentrant circuit within the right atrium in 3 patients. In 2 of the 3 patients, a protected zone could be identified (1) between a polytetrafluoroethylene patch inserted to close an atrial septal defect and the inferior caval vein (patient 1; Table II) and (2) between the inferior portion of an atriotomy scar and the inferior caval vein (patient 2; Table II). In both patients, tachycardia terminated during energy application. In patient 1, pacing from the inferior septum demonstrated penetration of atrial activation through the induced radiofrequency current line, despite prior termination of ART. Finally, after applying additional radiofrequency current pulses at this location, complete conduction block was evident. The third patient (patient 3; Table II) exhibited 2 types of right ART, both using the anastomosis between the right atrium and the pulmonary artery as the area of slow conduction. None of the tachycardias, however, could be terminated during energy application.

In 3 patients who had a Fontan operation (patients 9, 10, and 12; Table II), color-coded isopotential maps did not demonstrate a closed loop of atrial activation within the right atrium. Instead, a site of earliest activation was noted preceding the onset of the P wave on surface electrogram by 15 to 25 ms. Atrial activation spread radially from this location. Virtual electrograms at this location exhibited a QS pattern. Because tachycardias in all 3 patients met the criteria for a reentrant mechanism and pacemapping and entrainment mapping were positive, a microreentrant circuit was inferred. Radiofrequency current application at the point of earliest atrial activation resulted in termination of the tachycardia. In the remaining patient who had a Fontan procedure, color-coded maps were unable to demonstrate a closed loop of electrical activation or a focal origin of the tachycardia within the right atrium (patient 6; Table II). Therefore, a left ART was inferred, with the right atrium serving as a by-

Figure 3. Pacemapping and entrainment mapping during ART at the location of endocardial breakthrough in same patient shown in Figures 1 and 2; surface ECG leads I, II, and V2 are displayed together with bipolar electrograms from the mapping and ablation catheter (MAP 1 to 4) placed at the junction of the intraatrial baffle to the posterior wall of the systemic venous atrium and from the 20-pole catheter placed along the intraatrial baffle (A 1 to 20). Pacing at the tip electrodes of the mapping and ablation catheter with a cycle length of 270 ms resulted in an identical spread of activation along the 20-pole catheter. After termination of pacing, the return cycle equals the spontaneous cycle length of the ART (326 ms). Positive pacemapping and concealed entrainment could be achieved at this location.
stander. No radiofrequency current application was performed.

**Patients After an Atrial Switch (Senning and Mustard) Procedure**

Five patients had undergone an atrial switch procedure for d-transposition of the great arteries. Because placement of the multielectrode array along the intraatrial baffle (superior-inferior orientation) resulted in severe obstruction of systemic venous blood flow, the balloon array was positioned in the systemic venous atrium in parallel to the mitral valve annulus, with the tip of the balloon pointing to the orifice of the atrial appendage (Figure 1). In 3 patients, the protected zone of a macroreentrant circuit was identified within the systemic venous atrium (patients 8, 11, and 14; Table II and Figures 2 through 4). The induction of linear radiofrequency current lesions resulted in termination of the tachycardias in all 3 patients. In the last 2 patients in this group, a microreentrant circuit was identified (patients 5 and 13; Table II); it was treated by successful energy application.

**Patients After Repair of Atrioventricular Septal Defect**

In the 2 patients studied who had an intracardiac repair of an atrioventricular septal defect, analysis of color-coded isopotential maps allowed the identification of right atrial mac reentrant tachycardia with the tricuspid valve annu-

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Figure 4. ART finally terminated during the induction of radiofrequency current lesions (same patient as in Figures 1 through 3).

Figure 5. Atrial activation sequence during ART displayed by color-isopotential map (60-degree left anterior oblique view) in a patient after repair of atrioventricular septal defect (patient 4; Tables I and II). The right atrium is virtually opened at the location of the tricuspid valve. CSO indicates coronary sinus ostium; HIS, His bundle position; IVC, orifice of the inferior caval vein; RAA entrance of the right atrial appendage; SVC, orifice of the superior caval vein; TK 3, tricuspid valve annulus at 3 o’clock position; and TK 6, tricuspid valve annulus at 6 o’clock position. Depolarization is depicted as colors on the isoelectric (purple) endocardium. A, Atrial activation at the roof of the right atrium; B, spread of activation along the lateral wall; C and D, spread of activation further through the tricuspid valve annulus/inferior caval vein isthmus; E and F, activation travels superiorly along the atrial septum and finally reaches the roof of the right atrium. An animated version of this figure can be found Online (http://www.circulationaha.org).
lus/inferior caval vein isthmus serving as the protected zone of the ART (patients 4 and 7; Table II and Figure 5).

In both patients, we induced a complete line of conduction block within the isthmus, as demonstrated by the color-coded isopotential maps (Figures I and II; can be found at http://www.circulationaha.org).

Procedural Notes
The mean duration of the mapping procedures was 286 minutes (range, 130 to 435 minutes), and fluoroscopy time ranged between 7 and 34 minutes (mean, 17 minutes). No bleeding complications related to heparin application were noted. The only major complication noted was the occurrence of transient 3-degree atrioventricular block during radiofrequency current application at the classical flutter isthmus region in patient 7 (Tables I and II).

Follow-Up
During follow-up (mean, 7 months), 1 of the 12 patients with an initially successful result had recurrence of ART (patient 4). A repeat study demonstrated recurrence of conduction through the tricuspid valve/inferior caval vein isthmus as the electrophysiological substrate of the tachycardia. Conduction block could be achieved by additional radiofrequency current applications.

Discussion
The present study demonstrates that radiofrequency catheter ablation is feasible and effective using noncontact mapping as a guide in a variety of ARTs in patients who have had surgical correction of congenital heart disease. Accurate assessment of the endocardial anatomy of the right atrium/systemic venous atrium could be accomplished, which allowed us to navigate the mapping and ablation catheter with a significantly reduced fluoroscopy time (mean, 17 minutes) in contrast to the long duration of the entire procedure (mean, 286 minutes). This contrast documents the amount of time spent during the studies analyzing and comprehending the color-coded isopotential maps and virtual unipolar electrograms displaying the pattern of atrial activation. With the use of the CARTO mapping system, conventional mapping criteria may often be fulfilled over a large part of the diseased atria.16 This may, in part, explain the poor results achieved with the conventional mapping using multipolar contact electrode catheters.10–14

In contrast to previous reports,16,17 a significant number of the patients in the present study did not exhibit a macroreentrant tachycardia within the right atrium/systemic venous atrium. Instead, a microreentry mechanism was present; this could be treated successfully. Accurate positioning of the ablation catheter at the identified anatomical obstacles protecting the critical zone was possible in each of the patients (a prerequisite for effective radiofrequency current delivery). This may, in part, explain the high success rate in the present study, as well as the low recurrence rate thus far.

Because our system was already equipped with the pace-blanking facility, bidirectional pacing to assess lesion continuity could be performed without any technical problems.17 This improvement may explain the different success and recurrence rates in patients who had a Fontan procedure.17 In addition, discrepancies in the results may be explained by the small number of patients studied, who may have had completely differently diseased atrial myocardium, which may resist effective heating of the tachycardia substrate.

Patients with d-transposition of the great arteries after an atrial switch procedure are a special challenge because of the anatomical configuration of the atria. Until now, only few reports on endocardial mapping using standard techniques were available.26,29 Success rates were impressive,29 but studies had a mean duration of 8.8 hours, and mean fluoroscopy times reached 80 minutes. Our preliminary results suggest that those tachycardias may be assessed with comparable accuracy and efficacy using the noncontact mapping system with significantly shorter procedure times and less use of fluoroscopy.

Conclusion
In patients who had surgical correction of congenital heart disease, noncontact mapping provides identification of atrial activation sequence and allows guidance of effective therapy by radiofrequency current application.

References
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