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Interatrial Septum Pacing Guided by Three-Dimensional Intracardiac Echocardiography

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OBJECTIVES Currently, the interatrial septum (IAS) pacing site is indirectly selected by fluoroscopy and P-wave analysis. The aim of the present study was to develop a novel approach for IAS pacing using intracardiac echocardiography (ICE).

BACKGROUND Interatrial septum pacing may be beneficial for the prevention of paroxysmal atrial fibrillation.

METHODS Cross-sectional images are acquired during a pull-back of the ICE transducer from the superior vena cava into the inferior vena cava by an electrocardiogram- and respiration-gated technique. Both atria are then reconstructed using three-dimensional (3D) imaging. Using an "en face" view of the IAS, the desired pacing site is selected. Following lead placement and electrical testing, another 3D reconstruction is performed to verify the final lead position.

RESULTS Twelve patients were included in this study. The IAS pacing was achieved in all patients including six suprafossal (SF) and six infrafossal (IF) lead locations all confirmed by 3D imaging. The mean duration times of atrial lead implantation and fluoroscopy were 70 ± 48.9 min and 23.7 ± 20.6 min, respectively. The IAS pacing resulted in a significant reduction of the P-wave duration as compared to sinus rhythm (98.9 ± 19.3 ms vs. 141.3 ± 8.6 ms; $p < 0.002$). The SF pacing showed a greater reduction of the P-wave duration than IF pacing (59.4 ± 6.6 ms vs. 30.2 ± 13.6 ms; $p < 0.004$).

CONCLUSIONS Three-dimensional ICE is a feasible tool for guiding IAS pacing. (J Am Coll Cardiol 2002; 40:2139–43) © 2002 by the American College of Cardiology Foundation

Recently, nonconventional pacing approaches have been proposed for the treatment of patients with paroxysmal atrial fibrillation (AF) (1–5). Pacing the interatrial septum (IAS) has been reported to be effective to attenuate the progression of AF (6–8), but the optimal atrial pacing site remains controversial (9,10). Fluoroscopy does not allow the visualization of anatomically important structures including the fossa ovalis (FO), aortic arch, aortic valve, crista terminalis, and tricuspid valve. Thus, selection of the septal pacing site using X-rays may be inadequate for both optimal pacing and for avoiding problems related to lead fixation (acute and long-term). The aim of the present study was to develop a novel approach for IAS pacing based on three-dimensional (3D) intracardiac echocardiography (ICE) and to test its feasibility.

METHODS

Study patients. Twelve consecutive patients (six women) who underwent dual chamber ($n = 11$) or atrial pacemaker ($n = 1$) implantation were included in this study (Table 1). Their mean age was 65.5 ± 13.4 years (range, 32 to 77 years).

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ICE. The ClearView system (CardioVascular Imaging Systems, Fremont, California) was used with an 8F sheath-based ICE imaging catheter that incorporated a 9-MHz beveled single-element transducer rotating at 1800 rpm (model 9900, EP Technologies, Boston Scientific, San Jose, California). A custom-designed electrocardiogram (ECG)- and respiratory-gated pullback device and a 3D-ultrasound workstation (EchoScan, TomTec GmbH, Munich, Germany) were used to acquire and process the ICE images (11).

ECG- and respiration-gated image acquisition. The pullback device is controlled by the 3D workstation and uses a stepping motor to move the catheter stepwise and linearly through the right atrium. The workstation receives video input from the ICE system and an ECG- and respiration-signal (impedance measurement) from the patient. Before the acquisition run, the range of RR and breathing intervals are measured to define both upper and lower limits. The workstation starts acquisition of two-dimensional images after detecting the peak of the R-wave and in the same phase of respiration, at a speed of 25 images/s (image interval 40 ms). After acquiring one cardiac cycle, the workstation stores the images, and the catheter is then pulled back by 0.5-mm axial increment. This process is repeated until the inferior vena cava (IVC) is reached. The acquisition time is much shortened when all cardiac cycles are of the same length. Therefore, the right ventricular apex is paced at 100 beats/min.

Abbreviations and Acronyms

ECG = electrocardiogram
FO = fossa ovalis
IAS = interatrial septum
ICE = intracardiac echocardiography
IF = infrafossal
IVC = inferior vena cava
SF = suprafossal
SVC = superior vena cava
3D = three-dimensional

The 3-D image processing. In accordance to their timing in the cardiac cycle, all images are formatted in volumetric data sets (256•256•256 pixels/each 8 bits). During postprocessing, several algorithms are applied to reduce noise, enhance edges, and reduce spatial artifacts (ROSA filter).

Insertion of ICE transducer and pacemaker implantation. Initially, a 12-lead ECG is recorded with a high-resolution electrophysiology system (Prucka Engineering, Houston, Texas) using 1-kHz sampling frequency with 30- to 500-Hz filtering. The ICE catheter is advanced into the superior vena cava (SVC) through the right femoral vein. After an ICE catheter pullback, the right atrium is 3D reconstructed. Using a reconstructed "en face" view of the IAS the position of the FO is determined, serving as a landmark for the selection of the septal pacing site (Fig. 1). The chosen pacing sites are defined according to their relation to the FO (suprafossal [SF] and infrafossal [IF] pacing sites). At the level of the selected pacing site a horizontal cross-sectional template is reconstructed from the data set for real-time guiding of the implantation procedure. The active fixation lead is introduced into the right atrium by standard technique. The ICE operator moves the ICE catheter to the level of the tip of the atrial pacing lead. In the SF pacing sites an anterior spot is targeted. After the atrial pacing lead is fixed into the muscular IAS, standard pacing tests are performed to assess sensing, pacing threshold, and pacing impedance. If the values are acceptable the ICE transducer is repositioned in the SVC and a second catheter pullback is performed during dual chamber pacing at 100 beats/min. This second 3D reconstruction allows verifying the final lead position (Fig. 2).

Table 1. Demographic Data of the Patients

	Total Group	Suprafossal	Infrafossal
No. of patients	12	6	6
Age (yrs)	62.7 ± 16	65 ± 18.8	61.1 ± 15.1
Gender (M/F)	6/6	4/2	2/4
Indication for PM implantation			
SND (n)	6	4	2
AV block (n)	6	2	4
Medication at implant			
Ca channel-blocker (n)	1	1	0
Beta-blocker (n)	2	1	1
Amiodarone (n)	2	1	1
Diuretics (n)	3	2	1
ACE inhibitor (n)	3	1	2

ACE = angiotensin-converting enzyme; AV = atrioventricular; n = number of patients; PM = pacemaker; SND = sinus node disease.

The ECG measurements. Simultaneous 12-lead ECG was displayed on the screen, doubled in amplitude at a speed of 100 mm/s. The P-wave duration was defined as the difference between the first atrial activity and the last atrial activity including all surface leads in sinus rhythm. During atrial pacing the onset of atrial activation was measured from the stimulus artifact.

Echocardiographic measurements. Distances between the FO and IVC, the FO and SVC, and the FO and right atrial lateral wall (at the level of the SF region) were measured from 3D reconstruction of the right atrium.

Statistical analysis. Continuous variables are expressed as mean ± SD. Nonparametric data are compared using the Wilcoxon rank-sum test. Comparisons were made between sinus rhythm and paced rhythm for the total, the SF, and for the IF groups using paired Student *t* test. The level of significance was set at a p value of 0.05.

RESULTS

Implantation results. The SF pacing site was achieved in six patients and IF site in the other patients. All procedures were successful. Pacing data are summarized in Table 2. There were no complications related to ICE catheterization and/or pacemaker implantation. The atrial threshold was higher in the SF group. No differences were seen in other pacing parameters between the SF and IF groups. The atrial lead implantation time was significantly longer in the SF group than in the IF group (75.2 ± 37.6 min vs. 27.1 ± 10.2 min; p = 0.01). The fluoroscopy time was similar in SF and IF groups (26.9 ± 13.4 min vs. 16.9 ± 6.4 min; p = NS). There was no lead dislodgment or significant change in pacing parameters after a three-month follow-up period.

Results of 3D ICE. After 3D reconstruction the SVC, IVC, FO, crista terminalis, aortic arch, and left atrium were visualized in all 12 patients (100%). The location of the tip of the atrial lead could be identified in all cases after lead implantation. The desired spot and the final pacing spot were virtually identical in all patients. The distance between the FO and the lateral wall of the right atrium was 28.1 ± 8.9 mm (range, 20 to 42 mm). The distance between the FO and the IVC was 46.1 ± 15.4 mm (range, 16 to 56 mm), and between the FO and the SVC was 25.1 ± 9 mm (range, 15 to 31 mm). Tissue thickness between the septal part of the high RA and the ascending aorta was small (range, 2 to 8 mm).

The P-wave duration after septal pacing. The findings related to changes in P-wave duration are shown in Table 3. The duration of the P-wave showed significant reduction after septal pacing in the total group (sinus rhythm: 141.3 ± 8.6; septal pacing: 98.9 ± 19.3; p = 0.002). Reduction of the P-wave duration was greater in SF patients than in IF patients (59.4 ± 6.6 ms vs. 30.2 ± 13.6 ms; $p < 0.004$).

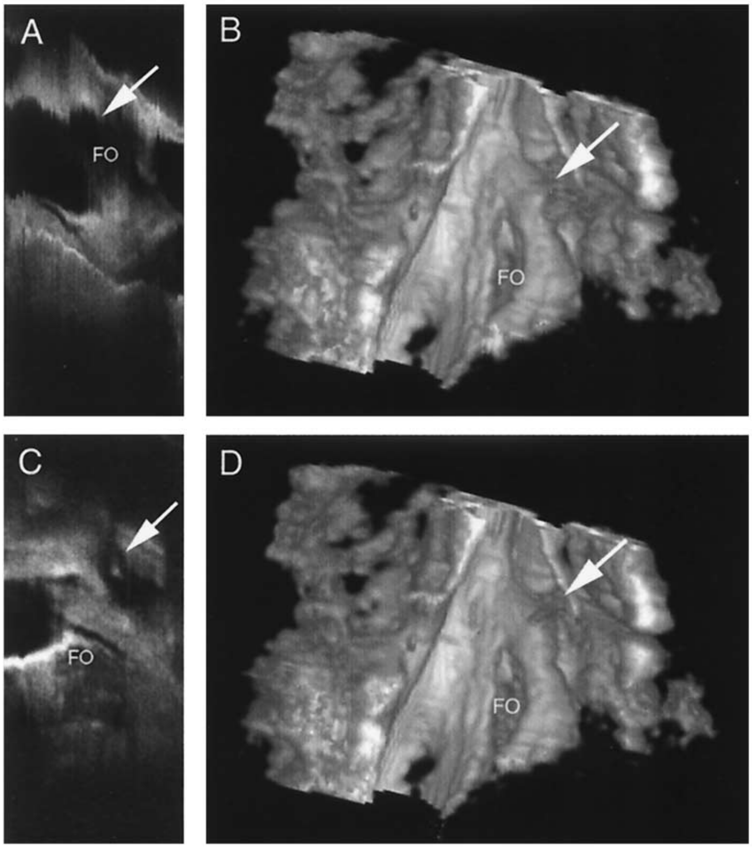

Figure 1. An "en face" view of the interatrial septum (IAS) before **(A, B)** and after **(C, D)** pacemaker lead implantation. The fossa ovalis (FO) is clearly visible in both situations. **Arrows (A, B)** show the selected spot for pacing of the IAS. A virtually perfect positioning of the atrial lead was achieved in this case, as the **arrow** on panels **C** and **D** indicate the cross-section of the atrial lead in front of the anterior-superior edge of the muscular interatrial septum and the membrane of FO. The achieved spot is identical to the desired spot shown by two-dimensional and three-dimensional images.

DISCUSSION

This is the first study demonstrating a practical application of 3D ICE in clinical cardiac electrophysiology. It appears from this study that 3D ICE is a safe and feasible tool to guide placement of IAS pacing electrodes. Our findings further indicate that an anatomically based localization of the atrial pacing lead results in a substantial reduction of the P-wave duration.

The importance of guided septal pacing. Although promising results are reported with septal pacing for the prevention of paroxysmal AF, the optimal pacing site still

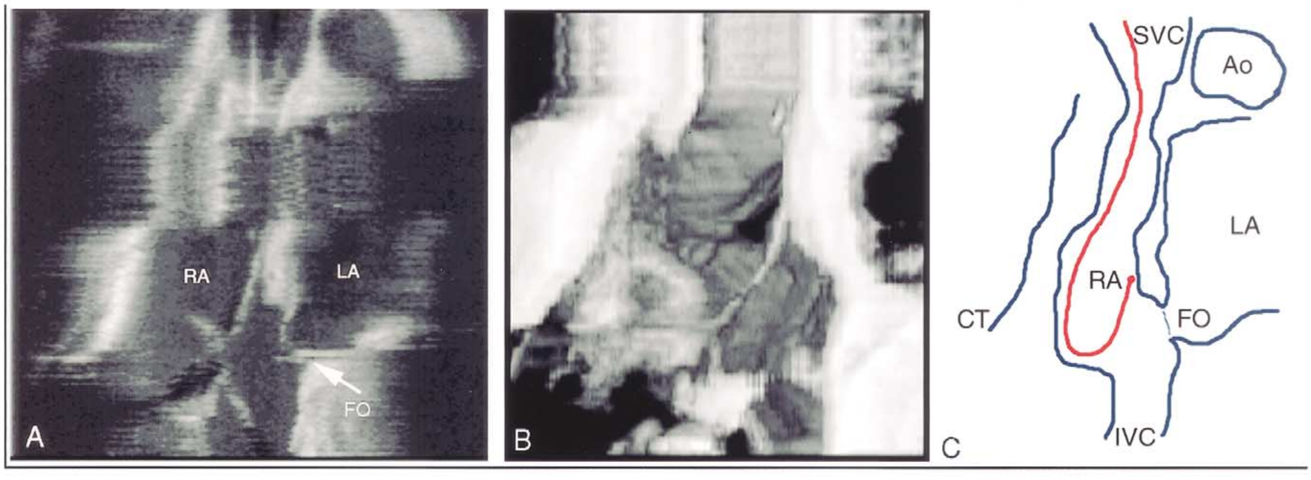

Figure 2. A longitudinal cross-sectional **(A)** and a real three-dimensional image **(B)** reconstructed from a volumetric data set with a schematic representation **(C)** shows the right atria (RA) and left atria (LA) in a patient after suprafossal pacing. In this case the fossa ovalis (FO) is placed fairly downward. Ao = aorta; CT = crista terminalis; IVC = inferior vena cava; SVC = superior vena cava.

Table 2. Implantation Data

	Total Group	Suprafossal	Infrafossal	p Value Suprafossal vs. Infrafossal
Procedure time (min)	157.7 ± 48.4	156.2 ± 52.3	158.4 ± 49.9	NS
Fluoroscopy time (min)	35.3 ± 20.3	38.1 ± 23.4	33.2 ± 19.2	NS
Atrial lead implantation time (min)	70 ± 48.9	90 ± 75.2	27.1 ± 10.2	0.01
Atrial lead fluoroscopy time (min)	23.7 ± 20.6	26.9 ± 13.4	16.9 ± 6.4	NS
Atrial lead sensing (mV)	2.0 ± 1.0	2.3 ± 1.5	1.8 ± 0.7	NS
Atrial lead threshold (V)	0.8 ± 0.9	1.3 ± 1.4	0.6 ± 0.3	0.02
Atrial lead impedance (Ω)	601.2 ± 139.8	584.6 ± 108.1	611.2 ± 167.5	NS

NS = nonsignificant.

remains unknown. Stimulation at the conventional site (right atrial appendage) delays both intra-atrial and interatrial conduction (9,10,12). Therefore, alternative pacing sites within the right atrium have been investigated. The antifibrillatory effect of Bachmann's bundle pacing was demonstrated in both an acute and chronic setting (3,6). Alternative pacing sites were also tested, such as the posteroseptal region just above the ostium of the coronary sinus (7). The optimal lead positioning technique is still being searched for. Spencer et al. (1) showed the feasibility of transesophageal echocardiography and 12-lead ECG-guided septal pacing. The transesophageal echocardiography is uncomfortable for patients during long-lasting procedures, has its own complications, and the visualization of intracardiac structures is less accurate. The ICE allows visualization of important anatomical landmarks with an excellent accuracy and can effectively guide interventions in clinical electrophysiology (13–15). With 3D reconstruction, ICE provides an outstanding opportunity for online evaluation of the anatomy. Our experience indicates that by using 3D echocardiography the most relevant right atrial structures are readily recognized. In addition, after implantation the atrial lead can be accurately visualized. The results of our intracardiac measurements demonstrate that significant variations exist in right atrial anatomy and distances between structures. The location of the FO is quite unpredictable. Therefore, visualization of this landmark has advantages during the implantation procedure.

In former reports on septal pacing, the reduction of the P-wave duration ranged widely from 9 ms to 36 ms (6,7,12). Interestingly, the technically difficult pacing of the BB decreased the P-wave duration to a less extent than the early study pacing near the ostium of the coronary sinus (6,7). Using our technique we achieved a remarkable 43 ms mean reduction of the P-wave duration, which is more than reported by previous studies.

Table 3. The Effect of Septal Pacing on P-Wave Duration

	Total Group	Suprafossal	Infrafossal	p Value*
Sinus P-wave (ms)	141.3 ± 8.6	142.4 ± 6.1	140.5 ± 10.5	NS
Paced P-wave (ms)	98.9 ± 19.3	83 ± 9	110.2 ± 16.3	0.005
p Value†	0.002	0.04	0.01	

*p = suprafossal vs. infrafossal; †p = sinus vs. paced.
NS = nonsignificant.

Study limitations. Intracardiac echocardiography with 3D-reconstruction software is currently available in a limited number of centers; it requires additional training, experience, and the extra cost of the technique is considerable. Our data suggest that, whereas SF pacing yields the shortest P-waves, it is associated with a higher pacing threshold and longer procedure time. It is to be expected that the latter can be reduced in the near future by using improved reconstruction software. This also implies the need for development of dedicated tools such as steerable stylets and vascular sheaths with specially designed curves for pacing in this region. Furthermore, the correlation between the magnitude of P-wave reduction and the value for prevention of paroxysmal AF necessitates further investigation.

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