

Noninvasive Study of Ventricular Preexcitation Using Multichannel Magnetocardiography

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FENICI, R., ET AL.: Noninvasive Study of Ventricular Preexcitation Using Multichannel Magnetocardiography. *In clinical practice, noninvasive classification of ventricular preexcitation (VPX) is usually done with ECG algorithms, which provide only a qualitative localization of accessory pathways. Since 1984, single or multichannel magnetocardiography (MMCG) has been used for three-dimensional localization of VPX sites, but a systematic study comparing the results of ECG and MMCG methods was lacking. This study evaluated the reliability of MMCG in an unshielded electrophysiological catheterization laboratory, and compared VPX classification as achieved with the five most recent ECG algorithms with that obtained by MMCG mapping and imaging techniques. A nine-channel direct current superconducting quantum interference device (DC-SQUID) MMCG system (sensitivity is 20 fT/Hz^{0.5}) was used for sequential MMCG from 36 points on the anterior chest wall, within an area 20 × 20cm. Twenty-eight patients with Wolff-Parkinson-White syndrome were examined at least twice, on the same day or after several months to test the reproducibility of the measurements. In eight patients, the reproducibility of MMCG was also evaluated using different MCG instrumentation during maximal VPX and/or atrioventricular reentrant tachycardia induced by transesophageal atrial pacing via a nonmagnetic catheter. The results of VPX localization with ECG algorithms and MMCG were compared. Equivalent current dipole, effective magnetic dipole, and distributed currents imaging models were used for the inverse solution. MMCG classification of VPX was found to be more accurate than ECG methods, and also provided additional information for the identification of paraseptal pathways. Furthermore, in patients with complex activation patterns during the delta wave, distributed currents imaging revealed two different activation patterns, suggesting the existence of multiple accessory pathways. (PACE 2003; 26[Pt. II]:431–435)*

magnetocardiography, ventricular preexcitation, Wolff-Parkinson-White syndrome, accessory pathway

Introduction

Since the beginning of antiarrhythmic surgery,^{1,2} preoperative noninvasive localization of accessory pathways (APs) has been a major challenge for the clinical electrophysiologist. In clinical practice, 12-lead electrocardiography (ECG), which remains the simplest noninvasive method of localizing APs, has gained better accuracy with algorithms based on the outcome of catheter ablation. Nevertheless, other methods, like body surface potential mapping, single photon emission computed tomography (SPECT), and echocardiography have been used as well.^{3–18} Since the 1980s, magnetocardiographic (MCG) mapping has also been proposed as a noninvasive

method for three-dimensional localization of arrhythmia foci and ventricular preexcitation (VPX) pathways.^{19–26} Until recently, most MCG studies were carried out in magnetically shielded rooms, the number of patients studied was limited, and a systematic comparison of MCG and ECG was lacking. To bring MCG to the bedside for routine clinical examination, the authors recently installed the first multichannel MCG (MMCG) instrumentation operating in an unshielded, “hybrid” catheterization laboratory for cardiac electrophysiology. The successful performance of the system was validated in a preliminary study.²⁷ In the present study, prospective MCG evaluation of patients with VPX was performed to compare MCG classification of VPX with that achieved with five ECG algorithms.^{13–17}

Methods and Patients

The MCG Mapping System

The multichannel system (CardioMag Imaging, Inc., Schenectady, NY, USA) used in the

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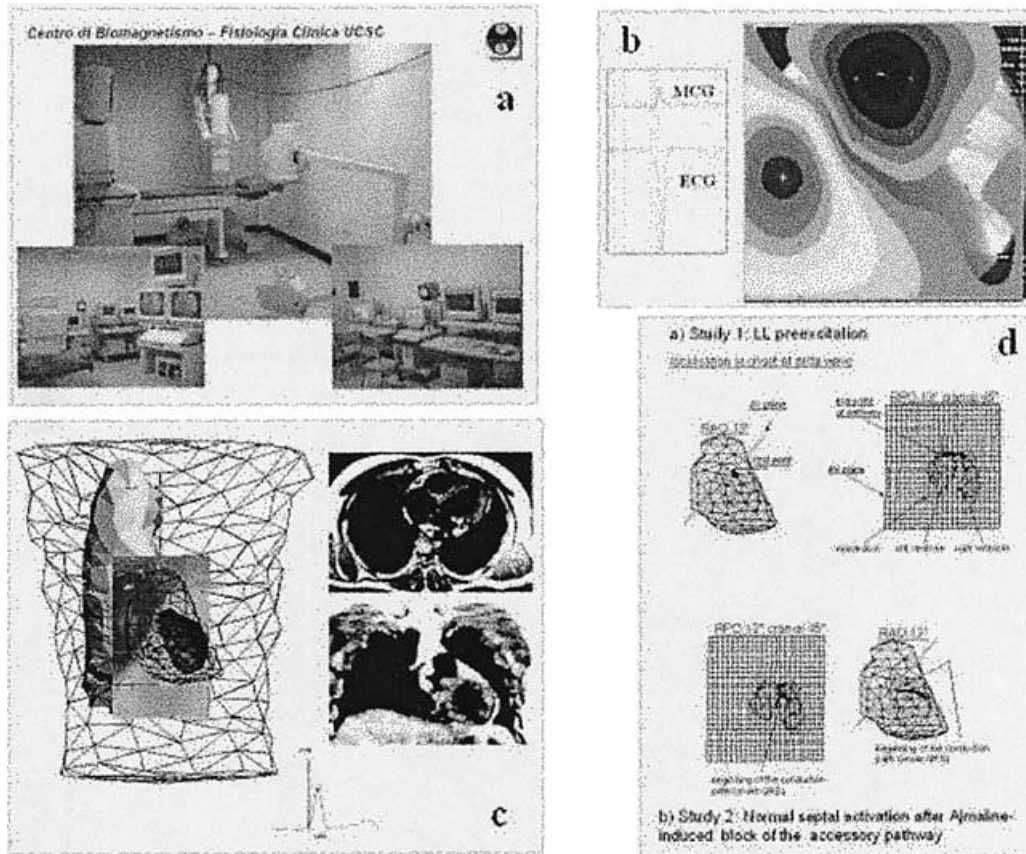


Figure 1. (A) Overview of the biomagnetism laboratory. (B, C) Multimodal integration of magnetocardiogram (MCG) imaging with fluoroscopy, a three-dimensional model of the heart, and magnetic resonance imaging (MRI). (D) Example of three-dimensional multichannel MCG (MMCG) localization of a ventricular preexcitation (VPX) substrate at the onset of the QRS complex (Study 1) and after ajmaline induced anterograde block of a left-sided accessory pathway (Study 2). For both studies, frontal three-dimensional views of the heart model and “tagged” views of the atrioventricular ring are shown. ECG = electrocardiogram.

unshielded electrophysiological BioMag catheterization laboratory of the Catholic University of Rome to measure the z-component of local magnetic fields at 36 positions in a plane (Fig. 1A) features nine direct current superconducting quantum interference device (DC-SQUID) sensors coupled to second order axial gradiometers with a 55-mm baseline, enclosed in a cylindrical cryostat small enough to avoid interfering with the operational capability of the cardiologist during invasive electrophysiological interventions. The intrinsic sensitivity of the system is about $20 \text{ fT}/\text{Hz}^{0.5}$ in the frequency range of clinical interest (1–100 Hz). Signals are recorded with an acquisition system (24-bit analog-to-digital conversion at a 1–2 kHz sampling frequency with electromagnetic interference filtering) based on Windows NT (Microsoft Corp., Redmond, WA, USA). MCG mapping is recorded from a 36-point (6×6) grid cov-

ering an area of 20×20 cm, with four sequential data acquisition scans. By moving the patient's couch between the fluoroscope and the MCG mapping system, it is possible to combine images obtained with MCG, intracardiac mapping, and two-dimensional digital radiology in a multimodal fashion (Fig. 1). The recording time for a 36-position scan is 4–6 minutes. In this study, equivalent current dipole (ECD), effective magnetic dipole (EMD), and distributed currents imaging (DCI) models were used for the inverse solution. The intrinsic accuracy of MMCG for three-dimensional localization and imaging of intracardiac sources had previously been evaluated with the nonmagnetic catheter technique.^{28,29} After MCG recording, localization and imaging takes less than 5 minutes. MCG localization results can be integrated with fluoroscopy, magnetic resonance imaging (MRI), and three-dimensional

models of the patient's torso and heart image (Fig. 1, B–D).

Patient Population

Twenty-eight patients with the Wolff-Parkinson-White syndrome (WPW) were studied with MCG at least twice, on the same day or with an interval of several months, to test the reproducibility of the measurements. The study protocol had been approved by the institutional review board, and all patients gave their written, informed consent to participation in the research. In eight patients, the reproducibility of MCG localization of VPX was also evaluated during maximal VPX induced by transesophageal atrial pacing via a nonmagnetic catheter (i.e., one containing no ferrous metal that would interact with magnetic fields). Localization of VPX with ECG algorithms was arbitrarily classified as *certain* when agreement was found among at least four

of the five algorithms used, *uncertain* when two to three algorithms agreed, and *unreliable* when each algorithm yielded different results. Limited invasive data were available (i.e., the outcome of radiofrequency catheter ablation was carried out in four patients at other hospitals); the study described herein was approved only as noninvasive research.

Results

An example of a typical magnetic field distribution during the delta wave (1–2 ms time resolution) of APs at nine different locations is shown in Figure 2. According to the ECG algorithms, the overall localization of the APs was certain in 19 (67.8%) of the 28 patients, uncertain in 6 (21%), and unreliable in 3 (10.7%). MCG localization of VPX substrates was certain in 25 (89.3%) patients and agreed with ECG results in 20 (71.4%). In nine patients with conflicting results between the

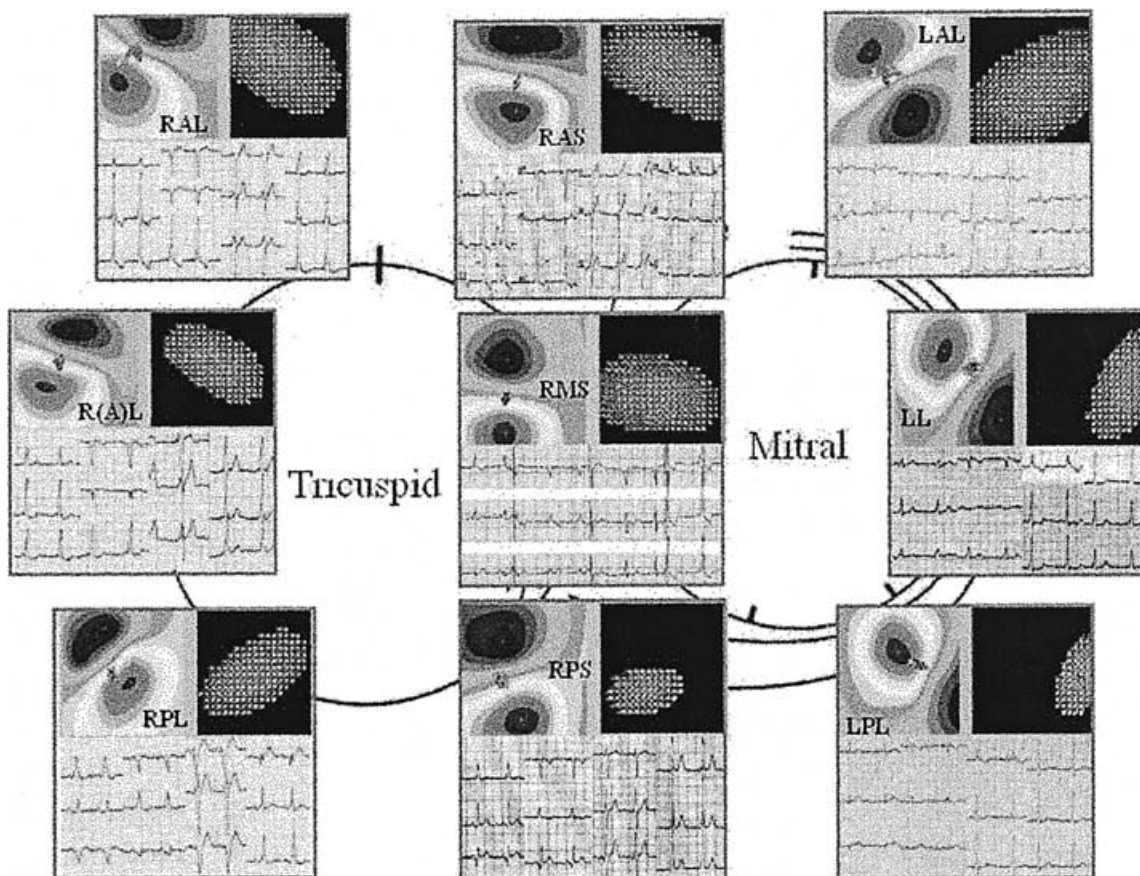


Figure 2. Representative examples of the magnetic field patterns generated during preexcitation by nine different accessory pathway (AP) locations, superimposed on a schematic representation of the atrioventricular ring. RAL= right anterolateral; RPL= right posterolateral; RAS= right anteroseptal; RMS= right mid-septal; RPS= right posteroseptal; LAL= left anterolateral; LL= left lateral; LPL= left posterolateral.

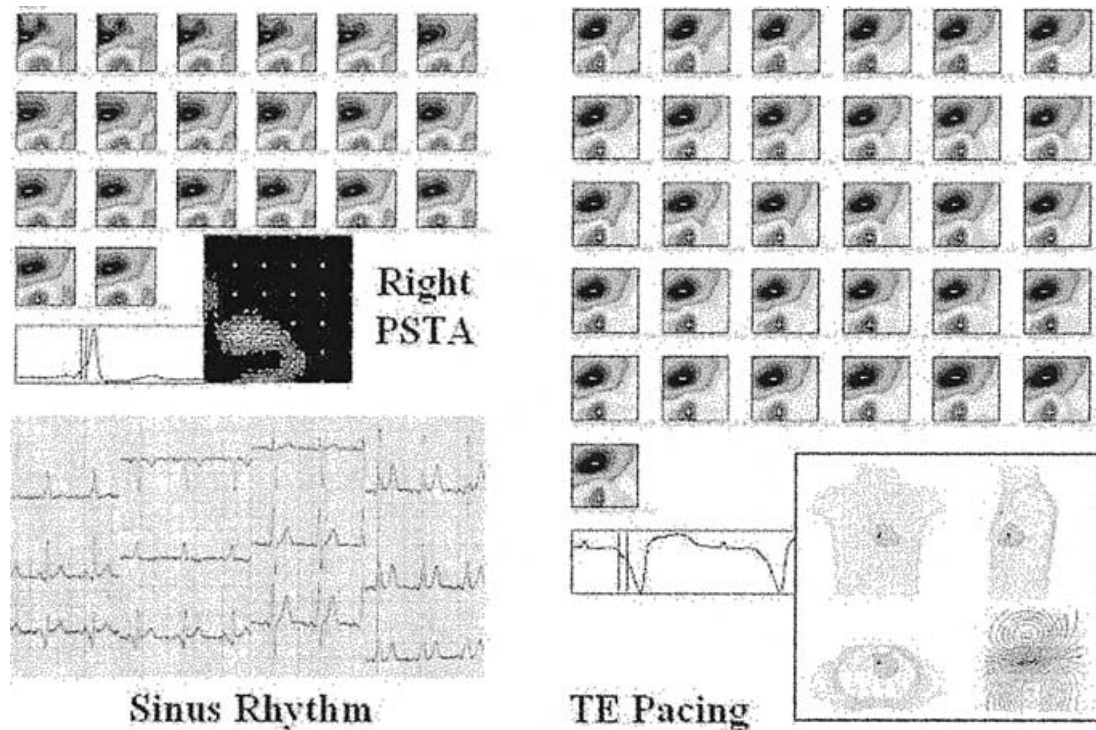


Figure 3. Reproducibility of the magnetic field pattern generated during the delta wave in two multichannel magnetocardiogram (MMCG) studies, performed first in normal sinus rhythm and then during transesophageal atrial pacing, in a patient with a right paraseptal tricuspid annulus accessory pathway (AP) (PSTA). Three-dimensional localization of the AP, imaged with the equivalent current dipole (ECD) model in a realistic torso, is shown in the insert at the lower right. Distributed currents imaging (DCI) (black insert to the left of center) demonstrates that the activation pathway is from right to left during the delta wave.

different ECG algorithms, MCG provided definitive AP localization. Furthermore, MCG gave immediate information about more complex activation of the posteroseptal area in patients with ECGs diagnostic of left posteroseptal VPX. In three of those patients, MCG disclosed a sudden change of direction of the major current depolarizing the posteroseptal area during the delta wave, suggesting dual APs and/or prevailing right-sided input to the septum. Interestingly, in one patient who underwent radiofrequency catheter ablation in another hospital, a left paraseptal approach failed to ablate the AP, which had been classified as left paraseptal on the basis of ECG analysis and intracardiac mapping, and produced only a partial modification of its conduction properties.

Figure 3 shows the results of two MCG studies carried out in a patient with a right paraseptal tricuspid annulus AP, one performed in normal sinus rhythm and the second during maximal preexcitation induced by transesophageal atrial pacing. The reproducibility of the magnetic field distribution during the delta wave is clearly evident. Three-dimensional localization of the AP and imaging

during the delta wave with the ECD- and CDI-based models are also shown.

Discussion

Accurate preoperative localization and imaging of arrhythmogenic substrates can reduce the time required for invasive mapping and avoid unsuccessful interventions, especially when the clinical arrhythmia is not inducible during the procedure. For this reason, noninvasive localization of VPX has been attempted since the 1970s,³⁻¹⁸ and in the early 1980s a first attempt was made to obtain accurate three-dimensional localization of APs using body surface potential mapping and a mathematical inverse solution based on the single moving dipole model.⁶ Because the inverse solution is simpler with magnetic data, MCG studies of WPW patients began in 1985.^{20,21} Although those preliminary single channel MCG investigations were performed in an unshielded laboratory, all subsequently reported work with MCG systems was performed in magnetically shielded rooms because it was thought that MMCG required shielding. However, this study demonstrates that MMCG

mapping can be performed in an unshielded electrophysiological catheterization laboratory with adequate quality for noninvasive classification and imaging of VPX (Fig. 2). Furthermore, the results show that MCG is more precise than ECG analysis for classification of VPX, and provides three-dimensional electroanatomic integration of the VPX sites with fluoroscopic or MRI images and three-dimensional models of the patient's heart (Fig. 1). The reproducibility of MCG localization using point-like ECD and EMD models and with DCI models had already been established in previous experiments and clinical studies.^{28,29} Dynamic interventions like pacing (Fig. 3) may enhance the specificity of MCG imaging of VPX.

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Conclusions

At the present state of the art, MMCG is feasible in unshielded hospital laboratories and provides three-dimensional localization and imaging of the site of VPX. Therefore, this resource might improve the diagnostic accuracy and classification of the site of origin of paraseptal and multiple APs.

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