Journal of Arrhythmia 31 (2015) 345–351

Contents lists available at ScienceDirect

Journal of Arrhythmia

journal homepage: www.elsevier.com/locate/joa

Original Article

Ability of magnetocardiography to detect regional dominant frequencies of atrial fibrillation

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ARTICLE INFO

Article history:
Received 26 March 2015
Received in revised form
5 May 2015
Accepted 11 May 2015
Available online 9 June 2015

Keywords:
Atrial fibrillation
Magnetocardiography
Dominant frequency

ABSTRACT

Background: Lead V1 on electrocardiography (ECG) can detect the dominant frequency (DF) of atrial fibrillation (AF) in the right atrium (RA). Paroxysmal AF is characterized by a frequency gradient from the left atrium (LA) to the right atrium (RA). We examined the ability of magnetocardiography (MCG) to detect regional DFs in both the atria.
Methods: Study subjects comprised 18 consecutive patients referred for catheter ablation of persistent AF. An MCG system with 64 magnetic sensors was used to perform MCG in the frontal, lateral, and back planes prior to the ablation procedure in each patient. DF_{MCG} and organization index (OI_{MCG}) were calculated using fast Fourier transformation. Intracardiac electrograms (ICEs) in both the atria and the coronary sinus (CS) were mapped at 17 sites. Regional DFs_{ICE} were also determined.
Results: Mean LA DF_{ICE} was higher than mean RA DF_{ICE} (6.40 ± 0.66 versus 6.16 ± 0.80 Hz, $P = 0.03$). DF_{MCG} in the channel having the highest OI_{MCG} was 6.61 ± 0.88 Hz in the frontal plane, 6.52 ± 0.64 Hz in the lateral plane, and 6.42 ± 0.62 Hz in the back plane ($P = 0.3$). In each plane, DF_{MCG} correlated with DF_{ICE} at the RA appendage ($R = 0.95$, $P < 0.0001$), the LA appendage ($R = 0.91$, $P < 0.0001$), and the CS ($R = 0.93$, $P < 0.0001$). DF_{ECG} in V5 modestly correlated with DF_{ICE} at the LA appendage ($R = 0.82$, $P < 0.0001$).
Conclusions: MCG could more precisely detect the DFs in the LA and the CS than ECG. However, the usefulness of pre-procedural detection of the AF frequency gradient for ablation therapy needs to be evaluated in future prospective studies.

1. Introduction

Catheter ablation of atrial fibrillation (AF) has rapidly evolved in this decade, and pulmonary vein isolation (PVI) is currently a well-standardized technique for treating paroxysmal AF. However, in patients with persistent AF, ablation therapy is still challenging because the arrhythmogenic substrate beyond the pulmonary veins (PVs) plays a role in the perpetuation of AF [1–3]. A tailored treatment approach for each AF patient seems reasonable owing to the multifactorial and progressive nature of AF. One factor that characterizes AF is the dominant frequency (DF). The DF is closely related to atrial refractoriness and degree of electrical remodeling [4]. A frequency gradient from the left atrium (LA) to the right atrium (RA) characterizes paroxysmal AF [5]. Patients with a rare type of AF with a right-to-left frequency gradient may suffer from a right atrial substrate and may be maintained on a right atrial driver. Therefore, measurement of regional DFs can be used as a guide to tailor an ablation strategy [6–8].

Magnetocardiography (MCG) is a body surface mapping method that noninvasively detects the magnetic field of the heart. Notably, the electrocardiography (ECG) signal is affected by interpatient differences in body characteristics and other physiological parameters, whereas the magnetic field is not distorted by its flow through the tissues such as lungs, muscles, and bones. This unique characteristic of magnetic fields results in better spatial resolution in MCG than in ECG [9]. Although it is well known that lead V1 on the ECG reflects RA DF [10,11], little is known about the ability of MCG to detect regional DFs in the atria. As the standard ECG leads are not specifically designed to record atrial activity, the multichannel and

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http://dx.doi.org/10.1016/j.joa.2015.05.003
1880-4276/

multiplane recording method of MCG (64 channels × 3 planes) might offer an advantage over the standard ECG method in detecting atrial DFs. This study evaluated the relationship between DFs in the atria measured by MCG mapping and those measured by multisite intracardiac mapping.

2. Material and methods

2.1. Study subjects

Study subjects comprised 18 consecutive patients referred for catheter ablation of persistent AF. Patients who had undergone a prior ablation procedure, those with structural heart disease, or those with a history of heart failure were excluded from the study. The clinical characteristics of the study subjects are listed in Table 1.

2.2. Measurement and analysis of MCG signals

The study protocol was approved by the local Institutional Review Board, and all patients provided their informed written consent. Antiarrhythmic drug therapy was discontinued 4–5 half-lives before the procedure. All patients underwent MCG during AF 1 day before the procedure. MCG methodology has been described in detail in a previous study [12]. We used an MCG system (MC-6400, Hitachi High-Technologies Corporation, Tokyo, Japan) with 64 magnetic sensors to measure the magnetic field. The magnetic field sensors were in an 8 × 8 matrix with a pitch of 25 mm, and the measurement area was 175 × 175 mm^2 (Fig. 1). The MCG signals for each subject in the resting state were recorded in 3 planes (frontal, lateral, and back) in a magnetically shielded room. For the frontal MCG measurement, the subject lay supine on the bed, and the (7, 4) sensor was placed above the xiphoid process (Fig. 1A). For the lateral MCG measurement, the subject lay on the right side, and the (7, 5) sensor was placed at the point of intersection of the line perpendicular to the xiphoid process with the midaxillary line (Fig. 1B). For the back MCG measurement, the subject was turned to the prone position, and the (7, 5) sensor was placed on the back side of the xiphoid process (Fig. 1C). A total of 3456 channels (64 channels × 3 planes × 18 patients) were analyzed. The sampling rate was 1 kHz, and the measurement period was 2 min. ECG leads II, V1, and V5 were simultaneously recorded throughout the procedure. The MCG signals were passed through a bandpass filter (0.1 to 50 Hz) and a power line noise filter (50 Hz). To analyze the MCG signals generated from an atrial electrical activation, we subtracted QRS-complex and T-wave signals from the measured MCG signals using the template QRS-T waveform (Fig. 2A) [13]. Furthermore, we calculated the power spectrum of the QRS-subtracted MCG signals using fast Fourier transform (FFT) techniques. The highest peak of the power spectrum in the range of 0.5 to 20 Hz was defined as the DF (Fig. 2B). Sites with DFs beyond the biological range (3–12 Hz) were excluded from further analysis [14]. To quantify the regularity of AF, the organization index (OI) was calculated as the ratio of the total area of the spectrum under the first five harmonic peaks to the total area of the spectrum [15].

2.3. Measurements and analysis of intracardiac electrograms (ICEs)

All patients presented to the laboratory in AF. After the transseptal puncture, electroanatomical mapping (CARTO, Biosense-Webster, Diamond Bar, CA) was performed during AF before ablation. An open-irrigation, 3.5-mm-tip deflectable catheter (ThermoCool, Biosense-Webster) was used for mapping. Electrograms of ≥6-s duration were recorded in 17 bi-atrial regions (Table 2).

The details of the spectral analysis have been described in a previous study [7]. In brief, bipolar electrograms recorded for 6 s were processed off-line in the MatLab environment (MathWorks, Inc., Natick, MA). The electrogram voltage was defined as the mean of a maximum of 10 electrogram amplitudes in a sampling window of 6 s [16]. The preprocessing steps in the spectral analysis included bandpass filtering with cutoffs at 40 and 250 Hz, rectification, and

Table 1
Characteristics of patients.

Characteristic	Study subjects (N=18)
Sex (Female)	6 (33%)
Age	60 ± 9
Body mass index (kg/m^2)	25 ± 3
Hypertension	10 (56%)
Diabetes mellitus	3 (17%)
Duration of AF history (months)	Median=7, IQR=8
LVEF (%)	62 ± 8
LAVi (mL/m^2)	38 ± 12

AF=atrial fibrillation, IQR=interquartile range, LAVi=left atrial volume indexed to body surface area, LVEF=left ventricular ejection fraction.

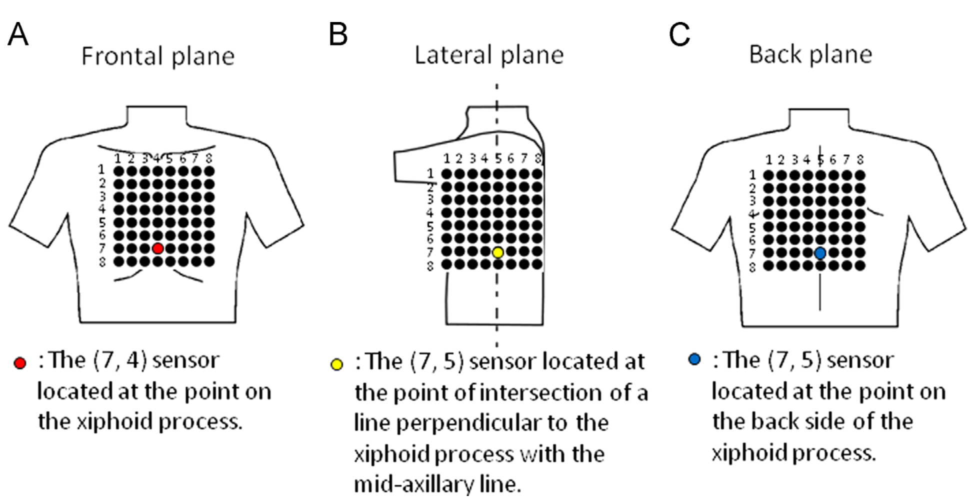

Fig. 1. Relative position of the marker sensor to the body in the frontal (A), lateral (B), and back (C) planes.