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Echocardiographic Detection of Cardiac Ectopy: A Possible Alternative to Electrophysiological Mapping?

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ABSTRACT

Purpose: Three-dimensional (3-D) visualization of ventricular activation sequence is imperative for the diagnosis and treatment of malignant cardiac arrhythmias. Modern mapping systems that serve as the gold standard for detection and localization of the focus are costly and require an invasive approach into the cavity of the ventricles. The aim of our study was the development of a noninvasive and 3-D mapping system based upon echocardiography.

Methods: In a porcine model, animals underwent ablation of the atrioventricular node (AV-node). 3-D electrophysiological cardiac mapping was performed using the ENSITE™ electro-anatomical system (St. Jude Medical, Minneapolis, MN, USA). Simultaneously, transesophageal echocardiography (TEE) including pulse wave (Pw) tissue Doppler was performed, and time to peak early diastolic velocity (PEDV) was measured. Both ENSITE-mapping and tissue Pw-Doppler were compared as to their ability to pinpoint the origin of ventricular ectopic focus.

Results: PEDV corresponded well with the results as determined by noncontact mapping with ENSITE.

Conclusions: Tissue Doppler is a reliable method to deliver information about the topography of first onset of myocardial excitation. Further development of this method with a higher regional resolution and integration of color Doppler as well as 3-D echocardiography may eventually lead to the development of a completely noninvasive and echo-based electromechanical mapping system.

INTRODUCTION

Ventricular arrhythmias account for 400,000 deaths per year in the United States [Myerburg 1993]. Increasingly, cardiac ablation techniques are being used to eliminate ectopic focuses as the source of arrhythmia [Stevenson 2000]. Imaging the myocardial activation sequence is of utmost importance for understanding, diagnosis, and treatment of cardiac arrhythmias. Modern noncontact mapping systems such as CARTO™ (Biosense Webster, Diamond Bar, CA, USA) and ENSITE™ (St. Jude Medical, Minneapolis, MN, USA) serve as the gold standard for diagnosis of cardiac arrhythmia by associating electrical activity at a particular localization with corresponding anatomic structures [Gepstein 1997; Kroll 2003]. Despite the facilitations of these diagnostic tools they remain invasive due to the transarterial approach and intracavitary mapping that may again cause arrhythmia. Breathing movements, electrical interference, high costs, and especially the long procedure durations are additional drawbacks of the introduced mapping systems. Hence the development of a less invasive mapping system that would completely replace the current system or help to reduce procedure risks and duration is desirable [Zhang 2005].

Transoesophageal echocardiography (TEE) is a semi-invasive technique that allows for a real time evaluation of cardiac anatomy and regional and global function. It is also a bedside, low-cost technique that can be rapidly applied in the operating room as well as intensive care unit. TEE combines functional

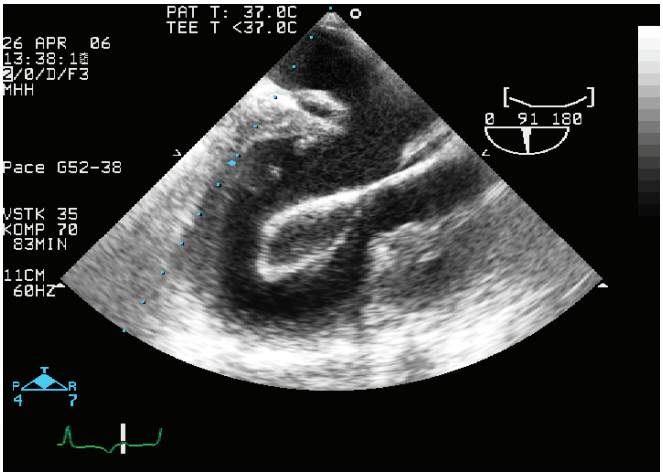

Figure 1. Transesophageal echocardiography (TEE) imaging shows the ENSITE™ system catheter (St. Jude Medical, Minneapolis, MN, USA) introduced from the aorta and crossing the aortic valve with a balloon placed inside of the left ventricle.

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and morphological data with a high diagnostic accuracy [Mügge 2000]. Tissue Doppler imaging (TDI) using a pulse wave (Pw)-Doppler allows for accurate assessment of not only global systolic and diastolic function, but also regional function in different segments of the heart. Further development in tissue-velocity imaging has made it possible to quantify myocardial shortening within an individual segment [Krishnamoorty 2007]. Classic indications for TDI are an assessment of left ventricular (LV) systolic and diastolic function. Alternative approaches as estimation of LV filling pressures, differentiation between constrictive and restrictive physiology, assessment of cardiac dyssynchrony, and assessment of right ventricular function are still under investigation [Ho 2006].

The aim of our study was the development of a novel noninvasive and 3-dimensional (3-D) mapping system based upon echocardiography including tissue Doppler imaging.

Methods

During all experiments, the "Principles of laboratory animal care" (NIH publication No. 86-23, revised 1985) as well as the specific German Law on the Protection of Laboratory Animals were followed.

Noncontact Mapping Procedure

A small sensor located in the tip of a catheter, which is introduced into the cavity of the left ventricle, scans the endocardial spatial geometry in relation to a magnetic field and creates a virtual 3-D image of the heart in the computer. Moreover, the electrical excitation of the ventricle is recorded simultaneously, so that an electrical cartography is created within the virtual heart.

Electrophysiological Studies and Radiofrequency Catheter Ablation

Four animals were anesthetized, and introducer sheaths were placed in the right femoral artery and vein as well as in the right jugular vein and carotid artery. After administration of Heparin, the multielectrode array balloon (ENSITE) was introduced over a 0.035-inch exchange guidewire into the left ventricle in a retrograde fashion under fluoroscopic guidance. Creation of an adequate, 3-D image of the left ventricle could be completed in several minutes, and all catheters could be freely maneuvered and visualized within the left ventricle (Figure 1). By projecting the fluoroscopy image onto the ENSITE image, the apex and basis of the heart could be transferred and identified on the ENSITE image. A 7F hexapolar catheter was placed at the His bundle region, and a 7F steerable ablation catheter was positioned at the presumed compact atrioventricular node (AV-node) based on anatomical and electrophysiological guidance. After 1 to 3 temperature-controlled radiofrequency applications, total AV-block was induced. Subsequently, rapid ventricular pacing (120 beats/min) and administration of 0.5 mg Isoproterenol was performed in order to provoke the initiation of a LV escape rhythm. Detailed activation mapping of the left ventricle was performed, monitored by the ENSITE system. All data obtained with the ENSITE system were stored on optical disks for further off-line evaluation.

Transesophageal Echocardiography

Simultaneously, in all animals TEE (SONOS 7500, Philips, Amsterdam, The Netherlands) was performed in general anesthesia. The TEE was performed with a multiplane, 5-MHz esophageal probe (T 6210, Agilent Technologies, Santa Clara, CA, USA), and all data digital recorded on a magneto-optical disc for subsequent analysis. All examinations were performed standardized in long-axis 4- and 2-chamber view, as well as so far available in short-axis views (mitral valve, papillary muscle, and apical level). TDI was performed during the whole procedure, placing the gate of the Pw-Doppler consecutively in all clear recognized segments at the 4-chamber or 2-chamber view respectively for the long-axis motion of the heart as previously described [Pai 1998]. Two-dimensional echocardiography with color tissue Doppler imaging was additionally performed. The imaging angle was adjusted to ensure a parallel alignment of the sampling window with the myocardial segment of interest. Gain settings, filters, pulse repetitive frequency, sector size, and depth were adjusted to optimize the Pw-Doppler signal or color

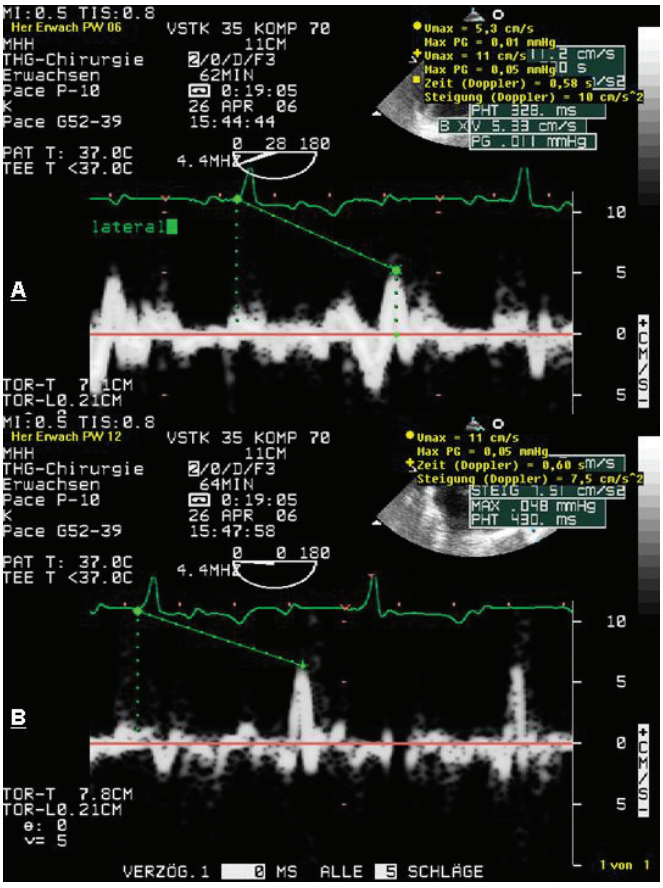

Figure 2. Pulse wave (Pw) tissue Doppler imaging (TDI) in an animal with a focus of escape rhythm placed in the middle of the anterior wall. In a lateral wall segment the measured time to peak early diastolic velocity (PEDV) is 580 ms [a]. Because of distance to the focus, the time to PEDV in the posterior-lateral segment is longer (600 ms), despite a little higher heart rate (64 bpm versus 62 bpm) [b].

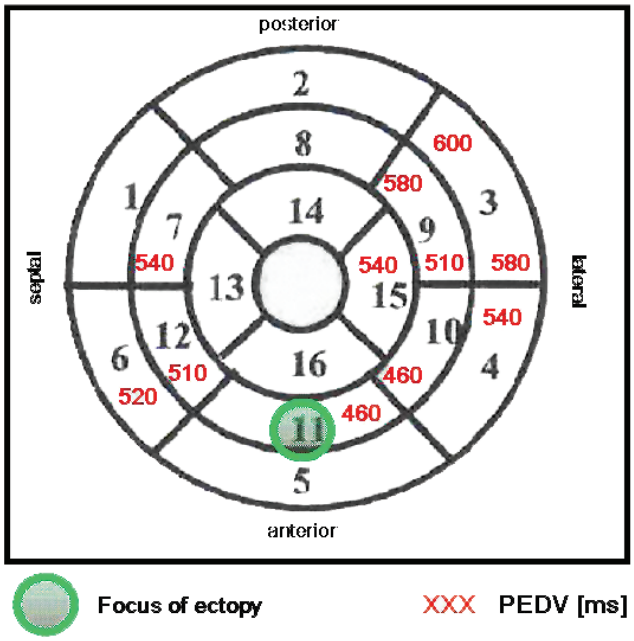

Figure 3. Results of the pulse wave (Pw) tissue-Doppler measurement registered in a 16-segment model of the left ventricle (according to recommendations of American Society of Echocardiography).

saturation, respectively. Upon sampling of each segment the longitudinal myocardial velocity was detected, received, and recorded. Echocardiography-triggered images were acquired, and at least 3 consecutive beats were stored. The images were digitized and analyzed off-line with cardiac analysis and calculation package (Revision D.1 and EnConcert, Philips). The peak early diastolic velocity (PEDV) was measured in order to each segment. The color tissue Doppler images were not evaluated quantitatively, only qualitatively.

Analysis

Polar maps of the left ventricle representing the entire LV myocardium were divided into a 16-segment model of the left ventricle according to recommendations of American Society of Echocardiography [Schiller 1989]. PEDV was identified and assigned to a segment of the polar map, then superimposed and compared with the 3-D image of the left ventricle as created by the intravascular mapping by the ENSITE system.

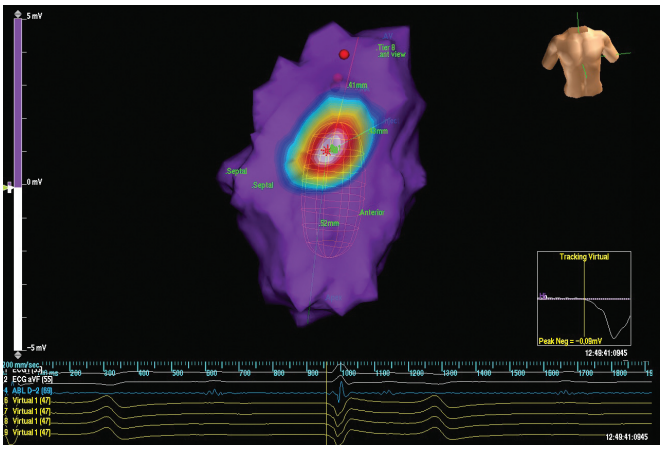

Figure 4. Activation map of the left ventricle during the escape rhythm with a 3-D anterior projection of the left ventricle as reconstructed by the ENSITE™ system (St. Jude Medical, Minneapolis, MN, USA). The multi-electrode array balloon is visualized within the left ventricle. The electrophysiological information was color coded. The earliest site of activation (dark circle) is located in the anterior wall. The activation then spreads over the rest of the myocardium (bright circle). The EKG-pattern of the stable escape rhythm is presented at the bottom of the screen. AV indicates atrioventricular node.

RESULTS

All animals survived the operative and diagnostic procedures. The time to PEDV could easily be identified by TEE and Pw-TDI (Figure 2). The origin of the ectopic focus as diagnosed by the ENSITE system was transferred to the polar map used for the localization of the shortest PEDV. The source of the escape rhythm as diagnosed by ENSITE corresponded well to the location of the shortest PEDV as diagnosed by TDI using TEE (Table; Figures 3 and 4).

DISCUSSION

Noninvasive imaging of the ventricular activation sequence would present a significant diagnostic relief concerning the localization of malignant cardiac arrhythmias and consequently accelerate the treatment decision. Body surface potential mapping and electrocardiographic imaging of ventricular activation sequence have been performed to address this issue. Echocardiography has important advantages over conventional mapping systems. Its use as an additional tool

The source of the escape rhythm as diagnosed by ENSITE™ (St. Jude Medical, Minneapolis, MN, USA) corresponded well to the location of the shortest peak early diastolic velocity (PEDV) as diagnosed by tissue Doppler imaging (TDI) using transesophageal echocardiography (TEE).

Animal Number	Shortest PEDV, ms (segment number)	Location by TEE	Location by ENSITE
1	460 (11 and 10 [anterior])	mid-anterior wall (lateral part)	mid-anterior wall (upper part)
2	570 (6)	anterior-septal (basal)	anterior-septal (basal)
3	600 (7)	middle of posterior septum	middle of posterior septum
4	510 (3 [posterior])	posterior-lateral	posterior

for arrhythmia diagnostics would provide precise anatomic and spatial insights, and thus it represents an additional advantage over other diagnostic systems that measure mere electric activation. It has been proposed to use intracardiac echocardiography in order to aid mapping and ablation procedures; however, this approach would also be invasive and have only a descriptive character [Morton 2005]. The use of TDI would yet constitute a new tool for electrophysiology studies. In the present study, we have demonstrated experimentally in a small cohort of animals that 3-D cardiac activation mapping with respect to localization of a LV escape rhythm can be performed noninvasively using TEE and TDI. All results derived from TDI-localization of the escape rhythm corresponded well with the control mapping analysis, where we used an invasive and sophisticated 3-D mapping system (ENSITE). In this well-controlled experimental setting, both systems were equally able to pinpoint the origin of the LV escape rhythm. We expect further improvement of our method by involving 3-D echocardiography, which should give the examiners more spatial information about the origin of the escape rhythm and further narrow it down to the point that guidance of catheter ablation, our ultimate goal, becomes a realistic option.

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