Relations between contact force, bipolar voltage amplitude, and mapping point distance from the left atrial surfaces of 3D ultrasound– and merged 3D CT–derived images: Implication for atrial fibrillation mapping and ablation

Naoko Sasaki, MD,* Yasuo Okumura, MD,* Ichiro Watanabe, MD, FHRS,* Kazumasa Sonoda, MD,* Rikitake Kogawa, MD,* Keiko Takahashi, MD,* Kazuki Iso, MD,* Shiro Nakahara, MD,† Ayako Maruyama, ME,‡ Saya Takemura, BA,‡ Atsushi Hirayama, MD*

*From the *Division of Cardiology, Department of Medicine, Nihon University School of Medicine, Tokyo, Japan, †Department of Cardiology, Dokkyo Medical University Koshigaya Hospital, Saitama, Japan, and ‡Johnson & Johnson, Biosense Webster, Inc., Diamond Bar, California.*

BACKGROUND Catheter tip-derived contact force (CF) and 3-dimensional (3D) maps are key to mapping and ablation of atrial fibrillation.

OBJECTIVE This study sought to determine the relation between CF and 3D map surfaces.

METHODS We conducted a validation study of Carto-based 3D ultrasound (3D-US) and 3D-US merged with computed tomography (3D-Merge-CT) left atrium/pulmonary vein images. Under fluoroscopic guidance, 1361 mapping points (20 patients) with CFs and electrogram information were randomly acquired around the PVs.

RESULTS CF correlated weakly with the distance of mapping points from the 3D-Merge-CT ($r = 0.27$; $P < .001$) and 3D-US ($r = 0.22$; $P < .001$) surfaces but not with bipolar voltage ($r = -0.01$; $P = .2400$). Low CF (0–4 g) yielded points close to the 3D-US surface; moderate (5–9 g) and high CFs (10–20 g) generated points beyond the surface (0.1 ± 3.9, 1.4 ± 3.4, and 2.3 ± 3.4 mm; $P < .05$ for each). Low, moderate, and high CFs yielded points below, close to, and beyond the 3D-Merge-CT surface (−1.2 ± 3.7, 0.4 ± 3.0, and 1.0 ± 2.9 mm; $P < .05$ for each).

CONCLUSION Poor correlation between CF and the distance of mapping points from the 3D map surfaces and electrogram information shows the limitation of 3D mapping and electrogram information for predicting good contact. In addition, mapping seems to require far less CF than ablation requires.

KEYWORDS Contact force; 3D ultrasound image; 3D CT image; Bipolar voltage amplitude

ABBREVIATIONS **2D** = 2-dimensional; **3D** = 3-dimensional; **AF** = atrial fibrillation; **CF** = contact force; **CI** = confidence interval; **CT** = computed tomography; **EEPVI** = extensive encircling pulmonary vein isolation; **GEE** = generalized estimating equation; **ICE** = intracardiac echocardiography; **IQR** = interquartile range; **LA** = left atrium/atrial; **OR** = odds ratio; **PV** = pulmonary vein; **SR** = sinus rhythm; **US** = ultrasound

(Heart Rhythm 2015;12:36–43)

Introduction

Over the past decade, complex anatomy-based ablation has been facilitated by evolving technologies aimed at fully "registering" cardiac activation to actual anatomic images. Electroanatomic mapping systems merge preacquired segmented computed tomography (CT) volume data sets with electroanatomic mapping data sets (CartoMerge, Biosense Webster, Inc, Diamond Bar, CA),[1–4] and a next-generation ultrasound (US)-based 3-dimensional (3D) imaging system (CartoSound, Biosense Webster) has been developed to guide catheter navigation.[4–6] Although displaying the ablation catheter and integrating its position with the 3D geometry are possible, successful mapping and ablation remain critically dependent on appropriate catheter tip-tissue contact. A recently developed contact force (CF) sensing catheter has been used clinically to establish ideal catheter tip-tissue surface contact.[7–9] However, no clinical data exist on the effect of catheter tip–derived CF on the location of mapping points in relation to the surface displayed on 3D maps. Clarifying the relation between catheter tip CF and point locations on 3D maps may aid mapping and ablation. We assessed the relations between CF and the distance of mapping points from the surface contours

Address reprint requests and correspondence: Dr Yasuo Okumura, Division of Cardiology, Department of Medicine, Nihon University School of Medicine, 30-1 Ohyaguchi-kamicho, Itabashi-ku, Tokyo 173-8610, Japan. E-mail address: yasuwo128@yahoo.co.jp.

1547-5271/$-see front matter http://dx.doi.org/10.1016/j.hrthm.2014.09.007

Table 1 Patient characteristics (n = 20)

Age (y)	60 ± 9
Sex: male	15 (75)
AF duration (mo)	37 (11–60)
AF type: paroxysmal/persistent	12/8
Left atrial diameter (mm)	37 ± 5
Left ventricular ejection fraction (%)	69 ± 8

Values are presented as mean ± SD, as median (interquartile range), or as n (%).
AF = atrial fibrillation.

generated by integrated 3D-US and 3D-US merged with CT (3D-Merge-CT) and bipolar voltage amplitudes of acquired mapping points in patients with atrial fibrillation (AF).

Methods

Study patients

Subjects were 20 patients with symptomatic drug-refractory AF who were referred for radiofrequency catheter ablation between May 2013 and April 2014. Patient characteristics are summarized in Table 1. Adequate oral anticoagulation was maintained for at least 1 month before the procedure. Upon admission, transesophageal and transthoracic echocardiograms were obtained. The study was approved by the Institutional Review Board of the Nihon University Hospital. All patients provided written informed consent for electrophysiologic study and ablation.

CT imaging and image segmentation

One day before the procedure, 320-row multidetector helical CT (dynamic volume CT scanner, Aquilion ONE, Toshiba Medical Systems, Tokyo, Japan) was performed during fasting. During the end-expiratory phase, volume image acquisitions were gated at 80% of the RR interval in electrocardiographic lead II during sinus rhythm (SR) or AF rhythm (8 [40%] patients had persistent AF). Segmented images of the left atrium (LA) with all pulmonary veins (PVs) derived from chamber volume data were used to reconstruct the structures.[1–5]

Creation of 3D-US–derived LA and PV images

All patients underwent clinical electrophysiologic evaluation and AF ablation under sedation with propofol and fentanyl. All procedures were performed as described previously[10] by 1 operator (Y.O.), who had performed over 500 PV isolation procedures. A 10-F intracardiac echocardiography (ICE) catheter (64-element, 5.5–10.0 MHz, SoundStar, Biosense Webster) was advanced into the right atrium. After single transseptal puncture, a 3.5-mm irrigated-tip ablation catheter (Navistar ThermoCool SmartTouch) and 2 Lasso catheters (all by Biosense Webster) were advanced into the LA. Heparin was given intravenously to maintain activated clotting time >300 seconds.

3D-US images of the LA and PVs were acquired and processed by a Carto 3 system (Biosense Webster) as previously reported.[5,10] In brief, 3-second segments of 2-dimensional (2D) ICE images were acquired during electrocardiographic gating to the P wave in lead II during SR. In the 8 patients with persistent AF, images were acquired after restoration of SR with a 14-pole cardioversion catheter (seven 4-mm proximal/seven 4-mm distal electrodes, 2-mm spacing, Irvine Biomedical Inc/St Jude Medical, Inc, Irvine, CA) placed in the coronary sinus (15–20 J). The 2D ICE images were automatically gated to respiration (ACCURESP, Biosense Webster), and images and mapping points for analysis were acquired during the expiration phase. Contour lines for each chamber of interest were drawn below the border to prevent image bloat. The ICE catheter was manipulated in the right atrium and right ventricular outflow tract for meticulous acquisition of multiple 2D ICE-based chamber contours to accurately establish 3D-US LA and PV surface volumes for the subsequent validation study.

3D-CT merge process

The reconstructed 3D-CT data sets were merged with the 3D-US–derived geometries via 3 registration processes. Visual alignment was performed with landmark pairs, that is, right PV carina landmarks established on the real-time 2D ICE images and the corresponding sites on the reconstructed CT image.[4] After surface registration,[1–5,10] a manual iterative process was used to minimize differences in individual PV positions and overall LA geometry.[5,10]

Relations between mapping point locations on 3D images, bipolar electrogram information, and CF

For validation, the first investigator (Y.O.), blinded to the 3D-US–derived LA and 3D-Merge-CT images, manipulated the mapping catheter (Navistar ThermoCool SmartTouch) around the PVs under fluoroscopic guidance. Multiple CF-based mapping points were randomly acquired under automatic gating to respiration, and the operator made a conscious effort to establish "no contact" while achieving consistent catheter tip-tissue surface contact solely under fluoroscopic guidance. For each mapping point, catheter tip–derived bipolar electrogram information (filter, 30–250 Hz), CF, and point location were stored on the Carto 3 system. To examine the locations of acquired mapping points in relation to the 3D map geometries, the shortest distance from each mapping point to the surface displayed on the 3D-US image was measured manually, but on the 3D-Merge-CT image the distance was measured automatically by the system (Figure 1A) retrospectively.[10] Positive values were obtained to indicate mapping points located beyond the virtual surface of the created 3D geometries and negative values to indicate points located below the surface. To ensure similar distribution of mapping points around the PVs, at least 3 points, representing low (0–4 g), moderate (5–9 g), and high (10–20 g) CFs, were chosen at each of 8 PV locations (superior, anterior, posterior, and inferior aspects of the right and left PVs; Figure 1B). We thereafter evaluated the relations between each mapping point location, CF, and bipolar voltage amplitude.