Real-Time 3-Dimensional Imaging of the Esophagus and Left Atrium With a Noncontact Mapping System

Koji Miyamoto, MD; Takeshi Tsuchiya, MD; Keichi Ashikaga, MD; Sumito Narita, MD; Shin-ichi Ando, MD†; Kiyoshi Hayashida, MD‡‡; Yoshito Tanioka, MD†; Naohiko Takahashi, MD††

Background: Recognizing the relative location of the esophagus to the left atrial posterior wall (LAPW) is required to avoid esophageal injury during atrial fibrillation ablation.

Methods and Results: The 24 patients undergoing circumferential pulmonary vein isolation (CPVI) each had the geometry of their left atrium (LA) and esophagus constructed by a noncontact mapping system with EnSite version 6.0J. The esophageal course relative to the LAPW was found to be to the left in 12, middle in 8, right in 2, and obliquely left-to-right in 2 patients, and in 13 patients (54%) it was located on or near either the left or right CPVI line. The mean distance between the esophagus and LAPW was shorter at the bottom line of the LAPW connecting both inferior pulmonary veins (3±3 mm) than at the LA roof line connecting both superior pulmonary veins (6±6 mm, P<0.01).

Conclusions: The location of the esophagus relative to the LAPW varies with the patient, but a close location to either CPVI line was found in approximately 50% and a close location between the esophagus and LAPW was found in the inferior and middle locations in most patients. (Circ J 2009; 73: 826–832)

Key Words: Ablation; Atrial fibrillation; Esophagus; Noncontact mapping system

An esophageal fistula is an uncommon but lethal complication of circumferential pulmonary vein isolation (CPVI) during atrial fibrillation (AF) ablation, and the mortality rate is reported to be approximately 75%1–4. Many efforts have been made to prevent any esophageal damage, including elucidating the esophageal course using esophageography, lowering the amount and/or duration of the radiofrequency (RF) energy applications to the left atrial posterior wall (LAPW), esophageal temperature monitoring, and esophageal cooling.5,6 In all, recognition of the location of the esophagus relative to the LAPW is an inevitable initial step. Although preprocedural computed tomography (CT) and magnetic resonance imaging (MRI) have been reported as useful for recognizing this relationship,7 the esophagus is mobile and thus the location at the time of imaging might not be the same as that during the ablation procedure8 so real-time 3-dimensional (D) visualization of the 2 organs during the RF ablation has been anticipated.

A noncontact mapping system (NCM) with EnSite version 6.0J provides real-time elucidation of both the esophagus and left atrium (LA) during RF ablation, which enables the operator to see the 3-D relationship of the 2 organs. In addition, the creation of the geometry is easy and inexpensive because no particular expensive catheter is required and any electrode catheter can be used to depict the given geometry of interest. The present study aimed to examine the real-time 3-D location of the esophagus and LAPW using the NCM as a method of avoiding esophageal injury during AF ablation.

Methods

Study Population

The study population comprised 24 patients with paroxysmal (n=19) or persistent (n=5) AF who were referred for RF ablation of AF between May 2008 and August 2008 (Table: 20 men, 4 women; age 62±8 years). All patients had symptomatic, drug-refractory AF and none had undergone prior AF ablation. Two patients had valvular heart disease (mitral regurgitation), 1 had a history of mitral valvuloplasty, 1 had ischemic heart disease, and 1 had idiopathic hypertrophic cardiomyopathy. Transthoracic echocardiography revealed that the mean left atrial dimension was 39±6 mm, and mean left ventricular fractional shortening was

Table. Patient Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Number</th>
<th>Range</th>
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</thead>
<tbody>
<tr>
<td>M/F</td>
<td>20/4</td>
<td></td>
</tr>
<tr>
<td>Age, years (range)</td>
<td>62±8</td>
<td>(44–76)</td>
</tr>
<tr>
<td>Paroxysmal/persistent</td>
<td>19/5</td>
<td></td>
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<tr>
<td>LA dimension, mm (range)</td>
<td>39±6</td>
<td>(26–51)</td>
</tr>
<tr>
<td>LVFS, % (range)</td>
<td>38±5</td>
<td>(23–53)</td>
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<td>Structural heart disease, n (%)</td>
<td>2 (8)</td>
<td></td>
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<tr>
<td>Mitral regurgitation</td>
<td>1 (4)</td>
<td></td>
</tr>
<tr>
<td>Ischemic heart disease</td>
<td>1 (4)</td>
<td></td>
</tr>
<tr>
<td>Idiopathic hypertrophic cardiomyopathy</td>
<td>1 (4)</td>
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LA, left atrium; LVFS, left ventricular fractional shortening.

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Ablation Strategy

RF ablation was performed during spontaneous (n=8) or induced AF (n=14) in 22 patients and during SR in 2 patients. The CPVI was performed under navigation using the NCM for both ipsilateral PVs together at sites 1.0 cm away from the PV ostium. The RF energy applications were performed with a temperature limit of 55°C and power limited to 40–50 W in general, but the power and duration were reduced to 30 W and 20 s at the LAPW sites near the esophagus in order to minimize the risk of esophageal injury! The operator determined whether or not the ablation site was near the esophagus by checking the distance between the LAPW and esophagus constructed on the 3-D image during the ablation procedure.

The primary endpoint of the ablation procedure was electrical PV isolation with a loss of all PV electrograms recorded by the 20-pole circular catheter placed at the PV ostium. If the AF was not terminated after CPVI, an LA roof line was created or additional RF applications to the areas with complex fractionated electrograms were performed. When the AF persisted despite completion of these procedures, AF was converted to SR by an intracardiac DC shock of 5–10 J.

Analysis of the Esophageal Course and Relationship Between the Esophagus and LAPW

The esophageal course was examined in relation to the LAPW in both the vertical and horizontal axes, and an additional analysis was made regarding the anatomical proximity of the esophagus to the CPVI line(s) and LA roof/bottom lines connecting the ipsilateral PVs. The LAPW was defined as the area bounded by the LA roof superiorly, the line between the top of the left superior PV and bottom of the left inferior PV laterally, bottom of the LAPW inferiorly and the line between the top of the right superior PV and bottom of the right inferior PV laterally (Figure 1). The PV ostia were each defined at the point of maximal inflection of the PV and the LAPW using both PV angiography and 3-D rendering as described previously.

The anatomical parameters were investigated to clarify the relationship between the esophagus and LAPW, which included the length and width of the esophagus along the LAPW, and the distance from the esophagus to the LAPW or CPVI line, respectively (Figure 2). Digital calipers were used to measure these parameters. The esophageal course was defined with 9 predetermined segments on the LAPW to describe the relationship between the esophagus and LAPW, and between the esophagus and CPVI line (Figure 1).
LAPW was sectioned into a grid with a sagittal plane in 3 different regions (left side, middle, and right side) and at 3 different levels (superior, middle, and inferior). Contact of the esophagus with the LAPW was defined as when the reconstructed esophagus directly contacted the reconstructed LAPW. Using a research segmentation software package, the surface area of the LA was calculated.

The relationship between the esophagus and the LAPW or the CPVI line was easily examined, and each parameter was successfully gained. The electrode catheter within the esophagus was kept in place during the ablation procedure and the electrode location was continuously displayed and monitored (Figure 3). No esophageal movement was detected in any patients during the ablation procedure.

In the 5 patients in whom esophageal images were depicted twice during the ablation procedure for data validation, the differences between the first and second esophageal images were 0.3±0.6 mm (range 0–2 mm) in the horizontal plane, and 0.3±0.5 mm (range 0–1 mm) in the sagittal plane.

Statistical Analysis
The continuous variables are expressed as the mean±SD or number and percentage, as appropriate. Differences among groups for the continuous variables were determined by an ANOVA followed by Bonferroni/Dunn post hoc test. The unpaired t-test was used to compare the data with continuous variables. Categorical variables were compared by a chi-square test. The results with a value of P<0.05 were considered statistically significant.

Results
Depiction of the Esophagus
In all patients, the standard quadripolar mapping catheter was safely inserted via the nose and placed into the esophagus without any difficulties. We advanced and withdrew the catheter within the esophagus along the LAPW and then moved it back and forth a few times, satisfactorily depicting a virtual image of the esophagus along the LAPW. It took only minutes to insert the catheter and depict the virtual esophagus. The relationship between the esophagus and LAPW or the CPVI line was easily examined, and each parameter was successfully gained. The electrode catheter within the esophagus was kept in place during the ablation procedure and the electrode location was continuously displayed and monitored (Figure 3). No esophageal movement was detected in any patients during the ablation procedure.

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Esophageal Course in Relation to the LAPW
In the LA geometry, 4 separate PVs, including the left superior/inferior on the left side PVs and right superior/inferior PVs on the right side, were found in 17 of the 24 patients (71%). Further, additional discrete ostia of both the middle lobes of the right and left PVs were found in 1 patient (4%), and a common ostium for the left superior and inferior PVs in 5 patients (21%) and for the left and right superior and inferior PVs in 1 patient (4%).

The course of the esophagus relative to the LAPW varied among the patients: on the left side in 12 (50%), on the middle in 8 (33%), on the right side in 2 (8%), at an oblique
angle from left to right in 2 (8%) and an oblique angle from right to left in 0 patients (0%) (Figure 4). None of the patient characteristics, including LA size, patient sex, duration of AF or distance from the LAPW to the esophagus, were related to the esophageal course.

**Location of the Esophagus Relative to the LAPW in the Sagittal Plane**

The length and width of the esophagus, which was located beneath the LAPW, were 45±7 mm (range: 33–57 mm) and 10±2 mm (range: 5–15 mm), respectively. The distance from the esophagus to the LAPW was variable at the different sites, and ranged from 0 to 21 mm. The site with the shortest distance from the esophagus to the LAPW was identified at the superior LAPW in 4 of 24 patients (17%), in the middle in 19 (79%, P<0.001 for the superior LAPW), and inferior in 13 (54%, P=0.007 for the superior LAPW). The mean distance from the esophagus to the superior, middle, and inferior portions of the LAPW was 6±6 mm (P<0.005 for middle LAPW; P<0.01 for inferior LAPW), 2±2 mm and 3±3 mm, respectively (Figure 5).

When the distance from the esophagus to the LAPW <5.0 mm was examined in order to identify risky sites for esophageal injury during AF ablation, all patients had such risky sites in a particular portion of the LAPW. The longitudinal length of those sites was 26±11 mm, and occupied 58% of the entire length (45 mm) of the esophagus beneath the LAPW, the distribution of which was at the superior LAPW in 13 of 24 patients (54%), in the middle LAPW in 22 of 24 patients (92%, P=0.004 for superior LAPW) and inferior LAPW in 19 of 24 patients (79%). Moreover, direct contact between the esophagus and LAPW occurred in 14 of 24 patients (58%), in whom the longitudinal length of the contacting portion was 24±10 mm and occupied 53% of the entire esophageal length beneath the LAPW. The distribution of direct contact with the esophagus was the superior LAPW in 4 of 14 patients (29%), the middle in 12 of 14 patients (86%, P=0.002 for superior LAPW), and the inferior portion in 9 of 14 patients (64%).

The mean surface area of the LA was 129±26 cm². None of

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**Figure 4.** The 3-dimensional images of the LA, PV and esophagus created by the EnSite version 6.0J noncontact mapping system in 4 patients. Each image is shown in the posteroanterior view. The esophagus, PVs and LAA are depicted as brown, green and yellow, respectively. The esophageal image and its relative course along the LAPW and PVs are shown. (A) The esophagus is on the left side of the LAPW in this patient, and the esophagus runs down near the left superior and inferior PVs. (B) The esophagus is on the right side of the LAPW in this patient. (C) The esophagus is in the middle of the LAPW in this patient. (D) The esophagus travels along an oblique angle from left to the right. Abbreviations as in Figures 1, 2.

**Figure 5.** The 3-dimensional images of the LA, PVs and esophagus in 2 patients. The esophagus and its course relative to the LA and PVs are shown in the right lateral view. (A) The esophagus is closer to the middle and inferior portions of the LAPW than to the superior portion. (B) The esophagus is closer to the superior portion of the LAPW than to the middle and inferior portions. Abbreviations as in Figures 1, 2.
the patient characteristics, including the LA size, sex, duration of AF or whether AF was paroxysmal or persistent, were related to the distance between the esophagus and the LAPW.

Location of the Esophagus Relative to the CPVI Line in the Horizontal Plane
The shortest distance from the esophagus to the left CPVI line or right CPVI line in each patient was $9 \pm 7$ mm and $20 \pm 11$ mm, respectively ($P<0.001$). When the distance from the esophagus to CPVI line $<5.0$ mm was examined in order to identify the risky sites for esophageal injury during AF ablation, an esophagus located on or near the left (n=10) or right CPVI line (n=3) was found in 13 of the 24 patients (54%). In those 13 patients, the length of the esophagus close to the CPVI line with a distance $<5.0$ mm was 16 mm (range: 8–31 mm) for the left CPVI line, and 9 mm (range: 4–15 mm) for the right CPVI line. In the remaining 11 patients (46%), the esophagus was located in the middle between the left and right CPVI lines (Figure 6). No patient characteristics, including the LA size, sex, duration of AF or whether AF was paroxysmal or persistent, were related to the distance between the esophagus and each CPVI line.

The power and duration of the RF energy applications were reduced at some ablation sites near the esophagus in 18 of 24 patients (75%). Electrical PV isolation was, however, achieved in all 24 patients. AF was terminated during the CPVI in 12 of 22 patients (55%) undergoing CPVI during ongoing AF. The percentage of AF termination during the CPVI did not differ between the patients in whom the RF energy was partially reduced at the sites near the esophagus and those in whom it was not.

Discussion
Main Findings
There are several main findings of this study. First, the NCM with EnSite version 6.0J enabled satisfactory real-time 3-D imaging of the esophagus beneath the LAPW during AF ablation without any difficulties or complications. The second is that there was a variation in both the esophageal course and the relationship of the esophagus to the LAPW, although some tendencies were noted for both the location and the relationship. Therefore, a real-time 3-D image of the esophagus should be visualized during AF ablation in order to understand the location of the esophagus relative to the LAPW in each case to avoid any esophageal injury. The third is that in all patients the distance from the esophagus to the LAPW in the sagittal plane was close for each of the superior, middle, and inferior portions, and it was closer to the middle and inferior LAPW than to the superior LAPW, with direct contact demonstrated in 58% of patients. On the other hand, in half of patients the distance from the esophagus to the CPVI line was closer on either the left side or right side, but in the remaining half of patients it was located in the middle between the left and right CPVI lines.
Clinical Utility of Real-Time 3-D Location of the Esophagus

Visualization of the esophagus is essential for avoiding esophageal injury during AF ablation. Preprocedural CT scanning or MRI is frequently used to understand the anatomical location of the esophagus and LAPW. These images are non-invasively gained and can be superimposed onto a 3-D navigation system during the ablation procedure. However, there are some concerns with these preprocedural imaging methods regarding the reliability of the esophageal location, because the esophagus is mobile and can migrate even during the ablation procedure. Other techniques used to visualize the esophagus are esophageography or placing a small-caliber probe within the esophagus, such as a radio-opaque marker. The former method requires the patient to swallow radiopaque contrast medium and for only a short time. In addition, it has the risk of aspiration pneumonia, and furthermore, the esophageal image might be adversely affected by the air mixed in the contrast medium. The latter, probe method may underestimate the extent of the esophagus because only a small-caliber probe can be used.

The esophageal image created by EnSite 6.0J has some advantages. First, it is a real-time image, and the entire esophageal course beneath the LAPW can be easily obtained by just pushing and pulling the given electrode catheter within the esophagus. Second, it is a non-fluoroscopic image and there is no risk of radio-exposure and no need to swallow contrast medium. Third, it is a 3-D image, which enables the operator to grasp the anatomical relationship between the esophagus and LA. Further, the technology to depict the esophagus is almost the same as that of the widely accepted EnSite NavX system. Similar non-fluoroscopic 3-D visualization of the esophagus can be obtained using an electroanatomical mapping system, but that method is expensive because in addition to a specially designed catheter (Navistar, Biosense-Webster, Waterloo, Belgium) introduced into the LA, it requires another expensive catheter to make the additional images of the esophagus. Any given diagnostic catheter, on the other hand, can be used with the EnSite 6.0J system, which makes it economically reasonable and practical for performing real-time monitoring of the esophagus during the ablation procedure.

Relationship Between the Esophagus and the LAPW

It is speculated that esophageal injury during RF ablation occurs at the site where the esophagus and LA are not separated by visceral and parietal pericardium, as well as because of the proximity of these organs. In fact, direct contact between the esophagus and LAPW was demonstrated in some of the present patients. In order to identify the patients with a close relationship between the esophagus and LAPW, some anatomical parameters, including LA size and LA surface area, were examined in relation to the distance between the esophagus and LAPW, because an enlarged LA or posteriorly extended LA might push the LAPW toward the esophagus, leading to a shortening of the distance between them. However, those anatomical parameters were not related to the distance, so these results warn us that any patient has a risk of esophageal injury.

It was reported that direct contact of the esophagus with the LAPW was demonstrated in all patients according to CT scans. In the present study, direct contact of the esophagus with the LAPW was demonstrated in 14 of 24 patients (58%) and the difference might be related to the methodology used, in which the geometry constructed in our study represented the endocardial surface or lumen of the organs and the wall thickness of the LAPW and esophagus were not taken into account, whereas the outer surfaces of the esophagus and LAPW are demonstrated in the CT image. Sanchez-Quintana et al., however, reported that the esophageal wall was a distance of over 5 mm from the endocardium of the LAPW in the analysis of their specimens. They reported that there were wide variations in the distance because of differences in the thickness of the connective tissue and fibrofatty tissues intervening between the esophagus and LAPW.

In the current study, we demonstrated that the distance between the esophagus and LAPW was shorter at the middle and inferior portions of the LAPW than at the superior portion, where the mean distance was 6±6 mm, suggesting that an LA roof line could be safely created in most patients whereas care should be taken in order to avoid esophageal injury during RF energy application in the middle or inferior portions of the LAPW.

Relationship Between the Esophagus and the CPVI Line

The CPVI is widely accepted as a standard approach for AF ablation, but there is a risk of esophageal injury when RF energy is delivered to the LAPW near the esophagus. The width of the RF lesion should be <5 mm at most, and thus sites on the LAPW within 5 mm of the esophagus are considered to be “close” and thus risky for esophageal injury. Using this method, 50% of the present patients had a CPVI line along the esophageal course.

The location of the atrio-esophageal fistula is related to the ablation lines of the left PV–LA junction and the esophagus is located more frequently near the left CPVI than the right CPVI. However, in that study the distance from the esophagus to the LAPW did not differ whether the esophagus was near the left CPVI or right CPVI, so it is also necessary to use caution when applying RF energy around right PVs.

Study Limitations

An esophageal temperature rise during ablation along the LAPW is a good indicator of injury. In the present study, the risk of any esophageal injury was examined only by the distance between the esophagus and the LAPW, and the esophageal temperature was not measured during the ablation. The insertion and placement of an electrode catheter within the esophagus has some risk of esophageal injury, even when the best efforts are made not to cause any injury, and the catheter is carefully pushed and pulled within the esophagus. The data measured for the esophagus and the LAPW or the CPVI lines might be affected by the contact strength of the catheter within the esophagus. The difference caused by the contact strength of the catheter was, however, thought to be acceptable for examining the location of the esophagus in relation to the LAPW and CPVI lines.

Conclusions

Real-time 3-D elucidation of the esophagus using EnSite version 6.0J is safe and easy, and provides a clear reconstructed esophageal image for its entire length beneath the LAPW. The relative location of the esophagus to the LA varies according to the patient, and in approximately 50% there is a close relationship to the CPVI line(s). In the middle
to inferior portions of the LAPW, attention should be paid to avoid any esophageal injury because of the proximity of the esophagus in that region.

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References