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Esophagus imaging for catheter ablation of atrial fibrillation: comparison of two methods with showing of esophageal movement

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Abstract
Aims This study aims to evaluate whether visualization and integration of the computed tomography (CT) scan of the left atrium (LA) and the esophagus into the three-dimensional (3D) electroanatomical map the day before ablation is accurate compared with integration of an esophagus tag into the electroanatomic LA map visualizing the anatomic relationship during the radiofrequency ablation or whether esophagus movement prohibits esophagus visualization the day before ablation.
Methods and Results Eighteen patients with highly symptomatic atrial fibrillation underwent cardiac CT imaging the day before pulmonary vein ablation. Before CT imaging, a gastric tube was introduced into the esophagus allowing its CT 3D reconstruction. During radiofrequency ablation, mapping of the esophagus was performed and integrated into the LA 3D map. By comparing the position of the gastric tube during CT on day 1 with real-time anatomical mapping using a 3D navigation catheter on day 2, an average distance of more than 10 mm was found in six of 18 patients (33%). In six of 18 (33%), the maximal distance between day 1 and day 2 was even more than 15 mm.
Conclusion Reliance on CT images, even if acquired within 24 h before ablation, does not ensure adequate intra-procedural localization of the esophagus or enhance recognition of esophageal motility.

Keywords Dual-source computed tomography · Atrial fibrillation · Esophagus · Electroanatomic mapping system

Trial registration: ClinicalTrials.gov identifier: NCT00650728.

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1 Introduction

Percutaneous catheter ablation with circumferential pulmonary vein (PV) isolation using radiofrequency (RF) energy has become an important therapeutic option to treat atrial fibrillation (AF) [1–5]. The improved outcomes may have resulted from acquired knowledge, increased clinical experience, and several important technological advances such as the widespread utilization of three-dimensional (3D) mapping systems [6]. Importing images from pre-acquired 3D computed tomography (CT) or MRI scans into the 3D mapping system with superimposition of the electroanatomical map is commonly used [7–10]. Despite these advances, the interventional electrophysiologist must be aware of potential complications that are associated with this procedure. Because the left atrium (LA) is in close vicinity to the esophagus, RF ablation in the LA may damage the esophagus and create esophageal perforations and esophageal left atrial fistula [11–14]. To prevent this lethal complication, integration of an esophagus tag into the electroanatomic LA map visualizing the anatomic relationship has been studied and reported [15]. Another possibility of visualization of the esophagus is to perform the CT after inserting a conventional radiopaque gastric tube, which provides information about the course of the esophagus in relation to the LA and may be scanned by CT [16, 17]. Sra et al. showed that, under normal conditions, if no barium is administered, there is little change in the anatomical relationship between the posterior LA and the esophagus during the entire cardiac cycle [18]. However, if barium is administered, relevant movement of the esophagus has been observed [19].

The aim of the present study is to evaluate whether visualization of the esophagus by inserting a conventional gastric tube before performing the CT scan and visualization and integration of the esophagus into the 3D electroanatomical map the day before ablation are accurate compared with integration of an esophagus tag into the electroanatomic LA map visualizing the anatomic relationship during RF ablation or whether esophagus movement prohibits esophagus visualization the day before ablation.

2 Methods

2.1 Study population

Eighteen patients with highly symptomatic paroxysmal or persistent AF and who had failed antiarrhythmic drug treatment were included in the study. The demographic characteristics of the patients are listed in Table 1. Low molecular weight heparin as bridging anticoagulation during interruption of warfarin was given before the ablation.

2.2 CT imaging technique

The patients underwent cardiac CT imaging using a DSCT system (Somatom Definition, Siemens Medical Systems, Forchheim, Germany) the day before PV ablation. Before CT imaging, a conventional gastric tube was introduced through the nose into the esophagus. Data acquisition was performed at a collimation of 32×0.6 mm with a z-flying focal spot for the simultaneous acquisition of 64 overlapping 0.6-mm slices. Images were reconstructed with a slice thickness of 1.5 mm and a reconstruction increment of 1.2 mm using a medium smooth-tissue convolution kernel (B30f). Coverage was completed within one breath-hold period (5–7 s). A contrast injection protocol with injection of 80 ml of nonionic contrast material (Omnipaque 350, Bayer) at a flow rate of 4 ml/s followed by a saline chaser bolus of 50 ml at the same flow rate was used.

Table 1 Patient characteristics

Number of patients	18
Age (years)	56±8
Males/females	14/4
Paroxysmal/persistent atrial fibrillation	10/8
Left ventricular ejection fraction (%)	56±12
Left atrial diameter (mm)	43±5

2.3 Three-dimensional reconstruction

Raw multislice CT data were loaded into the 3D electroanatomic system (Carto® XP System, Biosense Webster, Diamond Bar, CA, USA) equipped with an image integration module. The accuracy of this technique has been validated in previous studies [10, 20]. The segmentation process has been described elsewhere [10, 20]. The 3D structures of the LA and esophagus (by mean of the gastric tube) were segmented. The CT reconstructed LA was then registered to the LA 3D electroanatomical map using the landmark registration and surface registration features of the 3D electroanatomic system. In brief, with the landmark registration, points on the 3D electroanatomic system are selected, and their counterparts on the CT 3D structure are identified. The system adapts the position of the CT 3D structure to minimize the distance between the pairs of points. The surface registration algorithm utilizes all points of the 3D map and assesses the best position of the CT 3D structure, so that the cumulative distance of these points to the CT surface is minimum (least square method). It is important to note that the translation and rotation of the CT 3D structure used for the registration process are applied to all other CT structures, so that their relative position remains the same.

2.4 Mapping/tagging and ablation procedure

Mapping and catheter ablation were performed under conscious sedation.

2.4.1 Mapping of the LA

A 3D electroanatomical mapping system (Carto® XP System, Biosense Webster, Diamond Bar, CA, USA) was used to perform the reconstruction of the LA, as well as to navigate with the mapping catheter (NaviStar™, Biosense Webster). A minimum of 50 homogeneously spread points were acquired to insure the completeness of the map. All PVs were mapped with the system using the vessel tag function.

2.4.2 Mapping of the esophagus

A 16F nasogastric tube was introduced into the esophagus, and then a 3D navigation catheter especially designed to map the esophagus (EsophaStar™, Biosense Webster) was inserted in the gastric tube until its tip height was approximately 2 cm under the lowest part of the LA. The position of the catheter was monitored on the 3D electroanatomic system screen. The acquisition of the catheter tip was performed while pulling the catheter out, and points

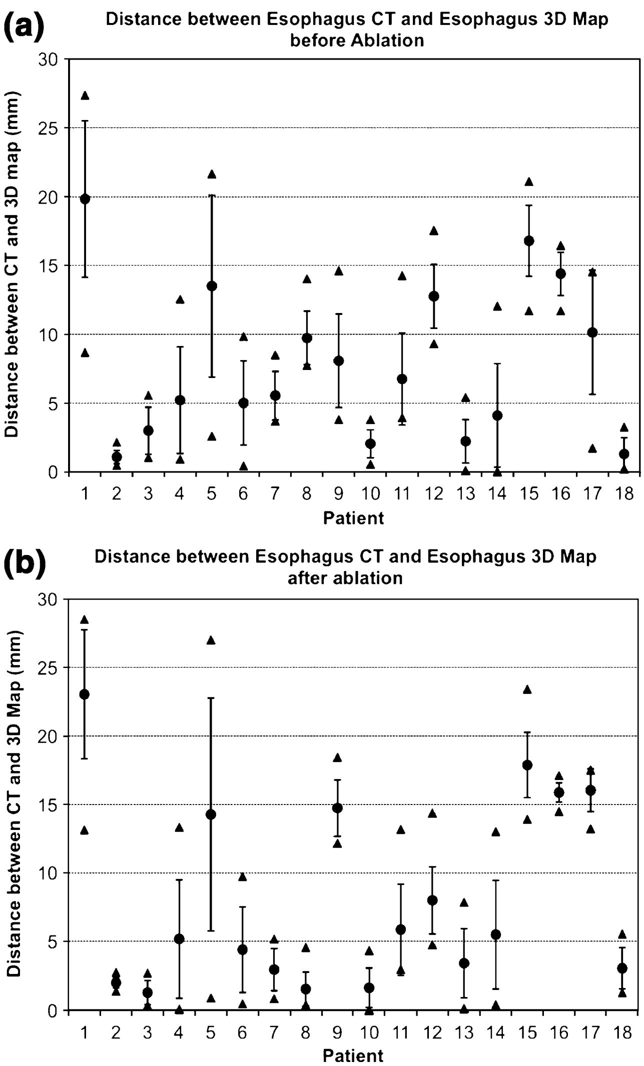

Fig. 1 Distance between CT esophagus and esophagus 3D map before ablation (**a**) and after ablation (**b**). On the *X-axis*, each individual patient is represented (*1–18*). *Dots with bars* represent mean distance with standard deviation of all 3D mapping points to the esophagus in the CT in each subject. *Triangles* represent minimal and maximal distances between 3D map and CT

were acquired on average every 5 mm. These points were saved as a separate map on the 3D electroanatomic system.

Ablation RF energy was delivered using a 3.5-mm-tip open irrigation ablation catheter (ThermoCool, Biosense Webster). For patients with paroxysmal AF, antral PV isolation was performed, and for patients with persistent AF the procedure consisted of antral PV isolation and linear ablation. RF energy was delivered with a maximal power of 25 W along the posterior LA, 30 to 35 W at the anterior wall/septum. The catheter was moved every 20 to 30 s during energy delivery or when the local atrial electrogram was abolished.

2.5 Statistics

The registration quality was measured by means of the distance of each point to the reconstructed CT 3D structure. In order to enhance the registration, points that were obviously far from the surface (>6 mm) and could therefore introduce biases were deleted from the 3D map. The surface registration process was applied until all points were <6 mm away from the surface.

To assess the localization of the esophagus, the distances between the points of the esophagus mapped with the 3D mapping system and the surface of the CT 3D esophagus were measured with the statistic tools of the 3D electroanatomic system, based on the registration of the LA. Thus, the mean and standard deviation of these distances could be calculated.

Continuous variables were compared by use of the Student *t* test assuming normal distributions or by the Wilcoxon rank sum test for variables with nonnormal distributions. In all tests, values of $P<0.05$ were considered significant. Software used for statistical analysis was STATA 9.2 (StataCorp, College Station, TX, USA).

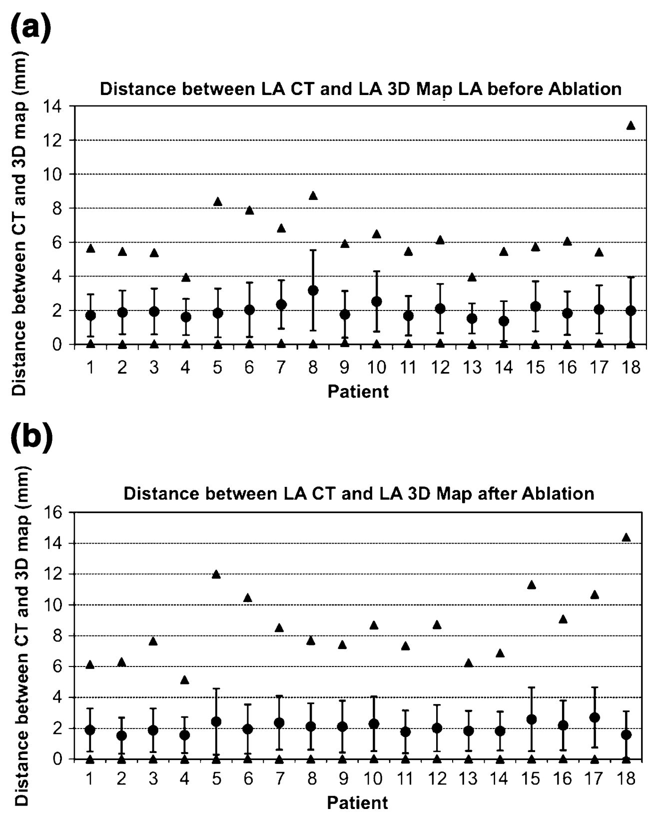

Fig. 2 Distance between left atrium (*LA*) CT and LA 3D map before ablation (**a**) and after ablation (**b**). On the *X-axis*, each individual patient is represented (*1–18*). *Dots with bars* represent mean distance with standard deviation of all 3D mapping points of the LA to the LA in the CT in each subject. *Triangles* represent minimal and maximal distances between 3D map and CT

Table 2 Distances between CT and 3D-Map (LA and esophagus)

Distance between LA CT and LA 3D map before ablation	1.97±0.4	mm
Distance between esophagus CT and esophagus 3D map before ablation	7.86±5.7	mm
Distance between LA CT and LA 3D map after ablation	2.00±0.3	mm
Distance between esophagus CT and esophagus 3D map after ablation	8.14±6.9	mm

3 Results

Use of a conventional gastric tube before performing the CT scan allowed visualization and integration of the esophagus into the 3D electroanatomical map in all patients. The course of the esophagus assessed by real-time mapping using a 3D navigation catheter before ablation was near the left-sided PVs in eight patients, near the right-sided PVs in three patients, and posterior to the mid-LA in seven patients. If the position of the gastric tube during CT on day 1 was compared by real-time mapping using a 3D navigation catheter on day 2, an average distance of more than 10 mm was found in six of 18 patients (33%). In ten of 18 patients, the maximal distance was more than 10 mm, and in six of 18 the maximal distance between day 1 and day 2 was even more than 15 mm (Fig. 1). Mean distances between the CT and the LA 3D Map are depicted in Fig. 2. Table 2 summarizes the mean distances between the CT and the 3D maps for both the LA and the esophagus. The aberrations did not occur at a defined level of the left atrial wall.

Acquisition of additional mapping points in the LA should theoretically improve the concordance of the CT and 3D map. However, there was no difference (P=0.924) between esophagus distance before and after ablation. Furthermore, there was a significant correlation (P<0.001) of measurements before and after ablation (Spearman's rho=0.781). Figure 3 shows two examples of LA maps with the esophagus displayed by CT and 3D tagging.

3.1 Complications

One patient presented with epistaxis after removal of the gastric tube. However, the bleeding stopped after treatment by nasal tamponade, and it was not hemodynamically compromising. No other complications (i.e., tamponade, thromboembolic events, femoral vascular access complications, esophageal fistula, pulmonary vein stenosis, or phrenic nerve palsy) were observed.

4 Discussion

Real-time imaging of the esophagus during ablation has been achieved with barium in the esophagus. However, it is still under debate as to whether ingestion of barium promotes esophagus motility. The present study shows that the esophagus may show a relevant shift within a period of 24 h even without use of barium in an important proportion of patients. If, according to Daoud et al. [21], the maximum diameter of the esophagus is 16.3 mm, then in our study in six out of the 18 patients a maximal shifting of the esophagus was observed that was bigger than the diameter of the esophagus. Therefore, CT images of the esophagus using a conventional gastric tube acquired the day before ablation may offer false assurance of the esophagus position during application of RF energy.

The present study confirms the findings of Daoud et al. [21], in the sense that reliance on remotely acquired CT images neither ensures adequate intraprocedural localiza-

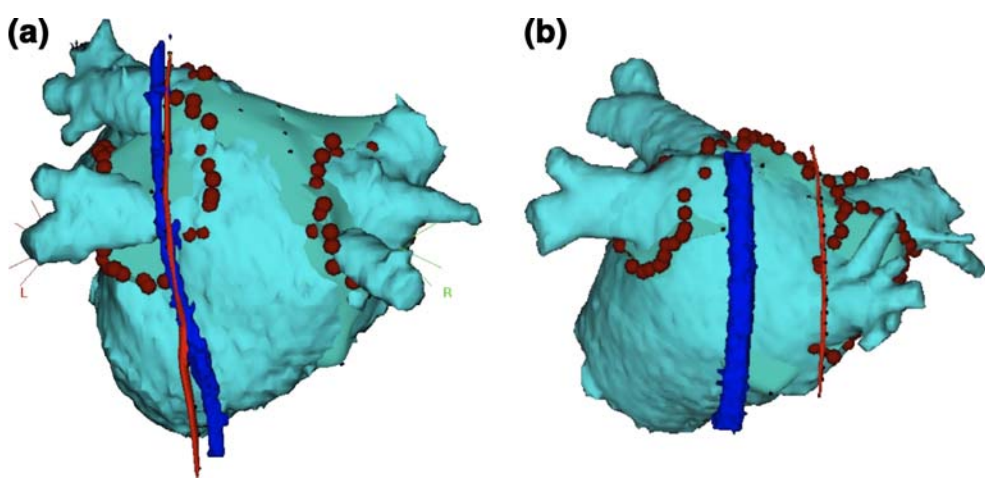

Fig. 3 Example of a LA 3D map in a posterior–anterior view without shifting of the esophagus (**a**) and with shifting of the esophagus (*blue esophagus* by CT and *red esophagus* by 3D mapping)

tion of the esophagus nor enhances recognition of esophageal motility. However, in the study of Dound et al., the CT scan was performed 1 week before ablation, whereas in the our study the CT scan was performed in all patients 24 h prior to ablation. One could argue that if the CT is taken on the day prior to the ablation, then the esophagus is still at the right place, which our results show to be incorrect.

Use of a 3D navigation catheter carries the advantages that the patient does not have to swallow the contrast and that there is less risk of aspiration. Ingestion of barium induces motility as already shown previously and increases the risk of patient movement due to unease of the patient [19]. However, when using the technique of real-time mapping with a 3D navigation catheter, the electrophysiologist must be aware that the gastric tube does not correctly express the esophageal width.

It has to be pointed out that there is no evidence that visualization of the esophagus makes any difference to the incidence of esophageal injury. Nevertheless, there are several options as to how the esophageal visualization could be used by the interventional electrophysiologist: (1) avoiding any RF energy delivery near the esophagus, i.e., to adjust the circumferential and linear lesions to the individual esophageal course; (2) delivering RF energy but with a much more conservative approach, such as reduction in power amount and duration. However, power reduction during energy delivery on the posterior wall might not sufficiently decrease esophageal injury as it could be demonstrated that esophageal mucosal damage occurred despite a significant reduction of RF power [22]; (3) delivering RF energy but with esophageal protection and/or moving the esophagus away from the site by mechanical displacement; (4) using a different energy source for the region overlying the esophagus, such as cryoablation.

A limitation of the use of multidetector row CT is the radiation dose, although this radiation dose is not related to the visualization of the esophagus since the CT scan is performed for image integration to guide the circumferential PV isolation [23]. The electroanatomic mapping of the esophagus does not increase the radiation dose substantially because the 3D navigation catheter is visualized on the 3D mapping system without radiation.

Using a gastric tube during PV isolation may increase the risk for epistaxis, as occurred in one of our patients. The risk for epistaxis may be elevated by administration of heparin during the procedure, given to reduce the risk of systemic thromboembolism. This also applies to the placing of the gastric tube before the CT imaging when low molecular weight heparin is given as bridging anticoagulation during interruption of warfarin. Many operators perform AF catheter ablation without interruption of the oral anticoagulation with warfarin and should therefore be aware of the potential risk of epistaxis if a gastric tube is placed under anticoagulation.

Real-time imaging of the esophagus by tagging the esophagus with a navigation catheter prolongs the procedure by only 5 to 10 min. A variety of other strategies are used in an attempt to reduce the risk of serious injury to the esophagus during the ablation procedure for AF. These include intracardiac echocardiography, esophageal cooling, administration of proton pump inhibitors after the procedure, and mechanical displacement of the esophagus [24]. However, none of these strategies is likely to be proven to be safer than the others given the extremely low prevalence of atrial-esophageal fistula. The mode of attempting to reduce the risk of esophagus injury during the ablation procedure remains the preference of the operator.

5 Limitations

A limitation of this study is that there was no way of knowing whether the gastric tube on the two different days was located in the midportion, the left lateral portion, or the right lateral portion of the esophagus. Part of the variance noted in this study has to be explained merely by the relative location of the tube within the esophagus. In addition, physiological deviations of the esophagus such as breath-dependent and peristaltic changes might partially explain the results.

6 Conclusion

Reliance on CT images, even if acquired within 24 h before ablation, does not ensure adequate intraprocedural localization of the esophagus or enhance recognition of esophageal motility.

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