Intraprocedure Visualization of the Esophagus Using Interventional C-arm CT as Guidance for Left Atrial Radiofrequency Ablation

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Rationale and Objectives: During radiofrequency catheter ablation for atrial fibrillation, the esophagus is at risk for thermal injury. In this study, C-arm computed tomography (CT) was compared to clinical CT, without the administration of oral contrast, to visualize the esophagus and its relationship to the left atrium and the ostia of the pulmonary veins (PVs) during the radiofrequency ablation procedure.

Materials and Methods: Sixteen subjects underwent both cardiac clinical CT and C-arm CT. Computed tomographic scans were performed on a multidetector scanner using a standard electrocardiographically gated protocol. C-arm computed tomographic scans were obtained using either a multisweep protocol with retrospective electrocardiographic gating or a non-gated single-sweep protocol. C-arm and clinical computed tomographic scans were analyzed in a random order and then compared for the following criteria: (1) visualization of the esophagus (yes or no), (2) relationship of esophageal position to the four PVs, and (3) direct contact or absence of a fat pad between the esophagus and the PV antrum.

Results: The esophagus was identified in all C-arm and clinical computed tomographic scans. In four cases, orthogonal planes were needed on C-arm CT (inferior PV level). In six patients, the esophageal location on C-arm CT was different from that on CT. Direct contact was reported in 19 of 64 of the segments (30%) examined on CT and in 26 of 64 (41%) on C-arm CT. In five of 64 segments (8%), C-arm CT overestimated a direct contact of the esophagus to the left atrium.

Conclusions: C-arm computed tomographic image quality without the administration of oral contrast agents was shown to be sufficient for visualization of the esophagus location during a radiofrequency catheter ablation procedure for atrial fibrillation.

Key Words: Atrial fibrillation; esophageal fistula; ablation; C-arm CT; computed tomography.

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Radiofrequency catheter ablation (RFCA) of atrial fibrillation has emerged as an important therapeutic option for patients refractory to antiarrhythmic medications. Although there are many approaches to the ablation of atrial fibrillation, isolation of the pulmonary veins (PVs) remains crucial for success of this procedure (1). Because the PVs are posterior structures, successful isolation requires ablation in the posterior left atrium (LA). In addition, RFCA may often be extended to other areas of the LA, in particular the posterior wall, the mitral isthmus, the atrial roof (2–4), and the interatrial septum (5).

Because of its proximity to the posterior wall of the LA, the esophagus may be at risk for thermal injury during RFCA (6,7). Atrioesophageal fistula has been reported (6,8,9) in the literature as a rare event (10) but one with a significantly high mortality rate.

Preprocedural imaging using computed tomography (CT) (11) or magnetic resonance imaging has commonly been used before ablation, because there can be significant anatomic variation of the pulmonary venous and left atrial anatomy between patients. Current electroanatomic mapping programs also allow registration of the electroanatomic map with the three-dimensional (3D) image obtained previously.
Using these 3D images, the esophagus can also be visualized and its location noted along the posterior wall of the LA (12).

One potential disadvantage of using the 3D images from pre-procedural CT or magnetic resonance imaging is that the images are often obtained days or weeks prior to the procedure, because the esophagus has been shown to move on occasion during ablation procedures (13,14), reliance on the 3D reconstruction of the esophagus may be misleading because it may not accurately depict the relationship between the esophagus, the posterior wall of the LA, and the ostia of the PVs.

3D images can be obtained at the time of the procedure using a ceiling-mounted C-arm system with the ability to acquire images during rotation of the C-arm (rotational fluoroscopic acquisition imaging or C-arm CT). This rotation can be gated to the electrocardiogram and has been shown to be accurate (compared to clinical gated CT) in both animals (15) and humans (16). C-arm CT adds approximately 10 minutes to the radiofrequency procedure and the images obtained can be reconstructed and rendered for visualization in less than 1 minute.

The subjects enrolled in this study were originally prospectively enrolled to compare the image quality of cardiac C-arm CT and clinical cardiac CT (reference standard). In the current study, in an attempt to evaluate future potential in imaging guidance of cardiac radiofrequency ablation, we retrospectively review the images of the same 16 subjects to evaluate whether the 3D reconstructed images obtained using C-arm CT provide adequate image quality for visualization of the esophagus and its relationship to the LA and the ostia of the PVs. Sixty-four-slice multidetector clinical cardiac CT of the same subjects was used as reference standard. The secondary goal of this retrospective study was to assess the temporal changes in the relationship between the esophagus and the LA between the time of clinical CT and of C-arm CT.

MATERIALS AND METHODS

Patients

From June 2006 to May 2008, 16 patients with histories of atrial fibrillation were enrolled in this study. All 16 patients agreed to undergo C-arm CT in addition to clinical CT. Creatinine levels were tested to ensure renal sufficiency, and no patients had histories of allergic reaction to iodinated contrast. All 16 subjects consecutively underwent clinical CT and C-arm CT of the heart. Of the 16 subjects, eight were candidates for RFCA of the LA, and the other eight were previously treated with RFCA for atrial fibrillation and agreed to undergo C-arm CT. Clinical computed tomographic scans and C-arm computed tomographic images of all 16 subjects were retrospectively reviewed. Informed consent was obtained, and the imaging protocols were approved by the institutional investigational review board.

Imaging Protocols

Cardiac CT. ECG-gated, multidetector CT (Somatom Sensation 64; Siemens AG Healthcare Sector, Forchheim Germany), referred to as clinical CT, was performed in all 16 patients. Initially, a scout scan from the neck to diaphragm was obtained, and then a monitoring scan at approximately 4 cm below the carina was performed (tube voltage, 120 kVp; effective tube current–time product, 20 mAs). Scanning time for the left atrial acquisition was obtained using automated bolus timing software (Care Bolus; Siemens AG Healthcare Sector), which uses a region of interest positioned in the LA to begin scanning when the contrast enhancement level corresponds to 150 Hounsfield units. Images were acquired during a single breath-hold of approximately 20 seconds (scan time ≤ 25 seconds) following an intravenous injection with a duration equal to scan time plus 5 seconds of iodinated contrast (Omnipaque 300; GE Healthcare, Milwaukee, WI) The injection rate ranged from 3.5 to 5.5 mL/s depending on patient body weight. The total volume of contrast varied accordingly. Acquisition parameters were 64 × 0.6 mm collimation at 330 ms rotation time, 120 kVp, 800 mAs, and 0.2 pitch, with a field of view of 500 mm. Using the dose-length product, as reported on the system, and the conversion factor 0.017 mSv/(mGy cm) for chest CT (17), the dose was 16 ± 5 mSv. Two sets of images were then reconstructed at 30% and 0% to 90% (10 reconstructed volumetric data sets) of the electrocardiographically triggered acquired images with a slice thickness of 1 mm and reconstruction diameter ranging from 160 to 280 mm depending on body habitus.

Cardiac C-arm CT

Electrocardiographically gated protocol (13 subjects). A Siemens Axiom Artis dTA C-arm system (Siemens Healthcare, AG) was modified to allow the acquisition of four bidirectional sweeps during synchronized acquisition of the electrocardiogram for retrospective gating. In subjects who underwent the scan prior to ablation, 100 to 150 mL (injection rate, 4–15 mL/s) of intravenous contrast (Omnipaque 300 or Visipaque 320; GE Healthcare) was given via a pigtail catheter placed in the inferior vena cava just below the level of the diaphragm.

In the subjects who underwent CT after RFCA, a total of 50 to 70 mL of iodinated contrast (Visipaque 320; injection rate, 3–4 mL/s) was administered via bilateral peripheral intravenous injection. Images were acquired at a fixed delay of 15 seconds and during a breath-hold of approximately 25 to 30 seconds.

During each 4-second sweep, 190 projection images were obtained, for a total of 760 images (detector resolution, 616 × 480 pixels; 60 frames/s), at 90 to 125 kVp, for a total of 1030 ± 280 mAs (referenced to 125 kVp for the purposes of comparison [18]). Given the measured tube current–time product from the scans and using a conversion factor of 0.01 mSv/mAs as calculated from Monte Carlo simulations (19), the dose is approximately 11 ± 3 mSv.

Retrospectively gated C-arm computed tomographic image volumes were reconstructed in all subjects using a 3D Feldkamp algorithm modified to account for irregular but stable scan trajectories with additional correction algorithms for scatter,
beam hardening, truncation, and ring artifact (Syngo DynaCT; Siemens AG Healthcare Sector). Technical details of the imaging, image processing, and reconstruction protocol for cardiac C-arm CT have been previously published (20).

**Non-gated protocol (three subjects).** A pigtail catheter was positioned in the main pulmonary artery, and a total of 89 mL of iodinated contrast was injected. First, a 20-mL bolus of contrast was injected at 5 mL/s through the pigtail catheter, and scanning was initiated when the iodinated contrast was visualized in the LA. Then, a single, 5-second rotational scan was acquired during the injection of the remaining 69 mL (injection rate, 15 mL/s), and images were obtained without electrocardiographic gating. A total of 235 projection images were obtained (detector resolution, 616 × 480 pixels; 60 frames/s) at 125 kVp for a total of 380 × 140 mAs, with a corresponding dose of approximately 4 ± 1.5 mSv.

**Image Analysis**

The clinical computed tomographic scan and C-arm computed tomographic images of each patient were transferred to a multimodality workstation (Syngo-X Workplace, 3D-Volume Task-Card; Siemens AG Healthcare Sector) for image analysis. The C-arm computed tomographic images were first evaluated, followed by evaluation of the clinical computed tomographic images, with clinical CT blinded to the results of the C-arm computed tomographic evaluation to ensure an unbiased interpretation of the C-arm computed tomographic scans. The C-arm and clinical computed tomographic findings of each patient were then compared at a later time. The average time elapsed between CT and C-arm CT was 98 days (range, 1–219 days).

For each scan, the following parameters were evaluated.

**Esophageal Visualization (Yes or No).** Images in multiple planes were used to accurately identify the esophagus (Fig 1).

**Localization and Proximity to a PV Antrum.** Each pulmonary antrum was identified on the axial plane, and this scan level, defined as the PV antrum plane, resulted in four planes (corresponding to the four main PVs) per study and a total of 64 ostia examined. On each of the four axial planes selected, the esophagus was identified, and its position was assigned to an area in the LA using the anatomic map previously used by Cummings et al (12) and as illustrated in Figures 2a to 2c. This anatomic map divides the LA into six predefined areas: (1) right superior PV antrum, (2) right inferior PV antrum, (3) superior-posterior left atrial wall, (4) inferior-posterior left atrial wall, (5) left superior PV antrum, and (6) left inferior PV antrum.

**Esophageal Movement.** Changes in esophageal position with respect to the preassigned areas of the LA between the CT scan and C-arm CT scan were identified.

**Absence of Fat Pad (Direct Contact Between Esophagus and LA/PV Ostia).** Direct contact between the esophagus and the antra of the PVs was defined as the nonvisualization of a defined bundle of fat tissue separating the esophagus.

**RESULTS**

A total of 16 patients, 11 men and 5 women with a mean age of 63 years (range, 44–75 years), underwent clinical CT and C-arm CT.

**Visualization of the Esophagus**

The esophagus was visualized in all 16 patients using both C-arm CT and clinical CT. From our limited sample size, electrocardiographic gating compared to no gating had no effect on the visualization of the esophagus (Figs 3a and 3b). The esophagus could be visualized posterior to the superior veins using the axial plane alone, but orthogonal planes were

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**Figure 1.** Visualization of the esophagus. On this C-arm computed tomographic reconstructed image of the heart, the cross-lines are centered on the esophagus on the three spatial planes (axial, sagittal, and coronal). The availability of three-dimensional planes helped confirm the findings on the axial plane.
needed to visualize the esophagus posterior to the inferior veins in four patients (25%) because the esophagus is more commonly compressed in the position posterior to the inferior veins.

**Relationship of Esophagus and the LA**

Findings on the relationship of the esophagus and the LA are presented in Table 1 and Figures 2a to 2c. For the right superior PV antrum region (area 1), in one subject (6%) on C-arm CT only, the esophageal position was found to be posterior to this region of the LA. For the right inferior PV antrum region (area 2), in two subjects (12%), the esophageal position was found to be posterior to this region on C-arm CT only.

For the superior-posterior LA wall (area 3), the esophagus was found to be posterior to this region of the LA in four of 16 subjects (25%) on clinical CT and three of 16 (19%) on C-arm CT. For the inferior-posterior LA wall (area 4), the esophagus was found to be posterior to this region of the LA in eight of 16 subjects (50%) on clinical CT and six of 16 (38%) on C-arm CT.

For the left superior PV antrum region (area 5), the esophagus was found to be posterior to this region in 11 of 16 subjects (69%) on both clinical CT and C-arm CT. Additionally, the esophagus was found to be posterior to the left superior PV antrum region in subject 7 on clinical CT and subject 16 on C-arm CT. In the left inferior PV antrum region (area 6), the esophagus was found to be posterior to this region in 10 of 16 subjects (63%) on clinical CT and 11 of 16 (69%) on C-arm CT.

**Esophageal Movement**

Findings on esophageal movement are presented in Figures 4a and 4b. In six different subjects (37%) (one with a non-gated study), a change in the relationship between the esophagus and the ostia of the four main PVs was observed in 21% (14 of 64) of the areas examined.

**Absence of Fat Pad (Direct Contact Between Esophagus and LA/PV Ostia)**

Of the 64 PV ostia analyzed for each technique, direct contact between the esophagus and the LA or PVs was
reported in 19 of 64 segments (30%) examined on clinical CT and 26 of 64 (41%) on C-arm CT, resulting in seven segments for which C-arm CT, but not CT, showed the esophagus in contact with the fat pad. In two of these cases, the esophagus moved to a different preassigned area of the LA. In the remaining five subjects, in whom the esophagus was located in the same area on both C-arm CT and CT, C-arm CT showed direct contact between the esophagus and the LA, while clinical CT showed the presence of a fat pad. Thus, C-arm CT underestimated the presence of a fat pad.

**DISCUSSION**

To our knowledge, this is the first report of esophageal visualization on C-arm CT without the administration of oral contrast agents. Although esophageal imaging can be obtained using other modalities, imaging is usually performed at a different time compared to the procedure, with the intrinsic limitation, due to dynamic esophageal changes, of not accurately depicting the esophagus location at the time of RFCA.

Ablation in the posterior wall of the LA has led to recognition of a rare but very serious complication, that of

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**TABLE 1. Esophageal Locations**

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CT, computed tomography; LIPV, left inferior pulmonary vein; LSPV, left superior pulmonary vein; RIPV, right inferior pulmonary vein; RSPV, right superior pulmonary vein.

The numbers in the boxes correspond to the anatomic areas where the esophagus was located on the axial plane at the level of each of the four main pulmonary veins.

*Cases in which discrepancies between C-arm CT and clinical CT occurred (14 segments in six patients).
atrioesophageal fistula (6,7). Although atrioesophageal fistula formation is rare, it is associated with a very high mortality and morbidity rate because of air embolism, sepsis, and endocarditis (21). For this reason, esophageal imaging in patients undergoing RFCA has become an important subject of investigation.

Several imaging techniques have been proposed for esophagus assessment prior to atrial RFCA. Traditionally, CT or magnetic resonance imaging has been performed with or without the administration of oral contrast medium for esophageal outline (2,11,12,14,22). Periprocedural echocardiography of the esophagus (23) has also been described as a monitoring technique to avoid atrioesophageal fistulas (24). This technique has the advantage of monitoring the esophagus location in real time, but esophageal visualization may be limited by the absence of distension by gas or saliva. Also, visualization of the esophagus by echocardiography requires highly experienced operators.

3D C-arm CT of the LA and PVs has recently been described for evaluation of the LA (15,25,26). Orlov et al (25) and Li et al (27) reported imaging of the LA and esophagus using non-gated C-arm CT (3D rotational angiography). These researchers used barium sulfate to outline the esophagus and examine the relationship with the posterior wall of the LA. However, patients with swallowing dysfunction or affected by airway diseases may have difficulty with this technique. Furthermore, although the administration of oral contrast allows for a better visualization of the esophageal lumen, and new software (28) may take advantage of high-density properties to create a virtual esophageal route, the passage of liquid through the esophagus may stimulate peristalsis, rendering the assessment of its position even less reliable. In a recent publication, an esophageal reconstruction using C-arm CT after the administration of oral contrast was compared to clinical CT. However, in 58% of the study population, a correlation between clinical CT and C-arm CT was not possible, because of insufficient amounts of oral contrast with either one or the other of the imaging techniques (29). Also, the administration of sufficient quantities of oral contrast to trace the esophageal outline may lead to artifacts in C-arm computed tomographic images, impairing image quality of left atrial and PV assessment. A balance between the two imaging goals of esophageal visualization and left atrial and PV visualization may be difficult to achieve.

Figure 5. Examples of visualization of the esophagus. Axial computed tomographic (a) and C-arm computed tomographic (b) images of the same patient show excellent visualization of the esophagus, comparable to the corresponding computed tomographic image. In a different patient, axial computed tomographic (c) and C-arm computed tomographic (d) images show how even in images affected by severe artifacts (worst case), the visualization of the esophagus was still possible.
In our series, the esophagus was visualized without administering oral contrast agents in all patients, and the quality of the images was considered satisfactory for the purposes of determining esophageal position and relationship to RFCA targets (Figs 5a–5d).

To our knowledge, this is the first study examining the temporal changes in the relationship between the position of the esophagus using cross-sectional images. Piorkowski et al compared the distance between the PVs and the center of the esophagus using cross-sectional images. The investigators compared the computed tomographic measurements from post-RFCA clinical CT to those obtained on preprocedural CT. No significant change in esophageal position was determined. However, as also acknowledged by the investigators, an accurate assessment of very short distances on clinical CT may be limited by the scan resolution, and this limitation, in addition to an arbitrary measurement of the distance between the PV ostium and the esophagus, can influence measurement accuracy.

We believe that our result showing the temporal change of esophageal position in six subjects (37%) highlights the importance of obtaining an intraprocedural anatomic map of the esophagus, with the advantage in the future of providing the physician with a more accurate and reliable guide for procedural safety. Because of the retrospective nature of the study, an evaluation of the temporal changes of esophagus position during the procedure was not determined, although multiple non-gated scans would be possible.

Recently, novel techniques such as esophageal temperature monitoring (31) and electroanatomic mapping of the LA (28,30) using different software such as CARTO (Biosense Webster, Diamond Bar, CA) or NavX (St Jude Medical, St Paul, MN) have been developed. Esophageal temperature measurement using dedicated probes may warn the operator about an increase in the physiologic temperature (31). However, because the thickness of the wall of the esophagus in normal subjects is not usually greater than 3 to 5 mm and the probe is measuring the temperature inside the esophageal lumen, an injury of the wall may eventually occur by the time an increase of the luminal temperature is detected (32).

A map of the LA and the esophagus can be displayed using software for electroanatomic mapping, but the map obtained is a “virtual” map and is usually fused to a 3D segmented volume of a preprocedural study, often a CT scan, to allow for improved anatomic correlation. A small number of reports describe the assessment of esophageal position using an electroanatomic map. For example, Kennedy et al (33) compared the position of the esophagus during repeat RFCA procedures as tagged on electroanatomic maps using cine fluoroscopic images of the esophagus during barium swallow. Using the electroanatomic maps from subsequent RFCA procedures, the position of the esophagus was classified as being adjacent to the left-sided or right-sided PVs or along the middle portion of the posterior LA, and the distance between the esophagus and the ostia of the PVs was measured. These investigators found stability in the esophageal position in 83% of their study group. This percentage is higher than our result (63%), but this could be attributed to the different techniques. Sherzer et al (28) also used an electroanatomic mapping system to create a virtual esophageal tube, and no changes in esophageal location were observed in six patients with repeated procedures.

With regard to the assessment of a fat pad, C-arm computed tomographic images seemed to overestimate a direct contact to the posterior wall of the LA (21%). This minor limitation does not affect the procedure safety but in fact influences the physician to adopt a more prudent approach, such as the use of decreased ablation power and/or temperature settings (6).

The main limitation of this study was the small number of subjects. Additionally, because a single C-arm computed tomographic scan was performed at the beginning of the procedure and the current study consisted of a retrospective analysis of the images obtained, an evaluation of the temporal changes of esophagus position during the procedure was not assessed.

Limitations of the C-arm computed tomographic application may include the need for intravenous contrast as well as the use of ionizing radiation. With respect to these two characteristics, C-arm CT is similar to clinical CT, with the advantage that C-arm CT can be performed in the electrophysiology suite (15). For the protocols used in this study, the dose from both non-gated and electrocardiographically gated C-arm CT was less than for clinical CT, and the ability to acquire 3D volumetric images at the time of the procedure may eventually replace the need for pre-CT. Also, although C-arm CT may delineate the esophagus at the time of imaging, movement of the esophagus during the procedure could lead to incorrect localization if image updates are not acquired. The risk associated with esophageal motion could be minimized by ablating the regions closest to the esophagus in close temporal proximity to the acquisition of the 3D C-arm computed tomographic images.

CONCLUSIONS

3D imaging using C-arm CT is a valuable technique with the ability to assess soft tissue structures, such as the esophagus, during the RFCA procedure. The possibility to fuse the volumetric C-arm computed tomographic images to an electroanatomic map may provide useful image guidance for RFCA, combining the real-time information of the electroanatomic mapping with an intraprocedural volumetric imaging study. When C-arm CT is performed for atrial RFCA planning and guidance, identification and accurate localization of the esophagus does not require the administration of oral contrast agents.

REFERENCES


