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RESEARCH ARTICLE

Three-Dimensional Electroanatomical Mapping to Guide Endocardial Occlusion of Stenotic Left Atrial Appendage

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ABSTRACT. Objective: Percutaneous endocardial occlusion of stenotic/incompletely ligated left atrial appendage (LAA) can pose unique access-related challenges. A novel approach for endocardial occlusion of stenotic/incompletely ligated LAA using three-dimensional (3-D) electroanatomical mapping (EAM) is described. Methods: The left atrial 3-D geometry was created using a circular mapping (LASSO) catheter and an EAM system. Although due to its severely stenotic neck the LAA itself could not be mapped, registration of the EAM to the left atrial computed tomography (CT) image allowed the integration of LAA anatomy. As such, this permitted endocardial LAA access under direct EAM visualization to guide LAA closure while obviating the need for fluoroscopy. Results: Four patients with atrial fibrillation, severely stenotic/incompletely ligated LAA (neck measurements: 4.3 ± 2.6 mm × 2.8 ± 0.5 mm) and intolerance to long-term anticoagulation underwent endocardial LAA occlusion using the proposed strategy. Complete LAA closure was successfully achieved in all patients (fluoroscopy time: 4.3 ± 0.5 min; procedure time: 64 ± 8 min). No acute/long-term adverse or embolic events occurred off anticoagulation during 14 ± 2 months of follow-up. Conclusion: 3-D EAM can be employed to facilitate percutaneous endocardial occlusion of stenotic LAA, while minimizing fluoroscopy. The display of detailed anatomical data as provided by a pre-procedural CT proved invaluable in guiding this approach.

KEYWORDS. 3-dimensional electroanatomical mapping, atrial fibrillation, computed tomography, left atrial appendage, surgical ligation.

Introduction

Surgical exclusion of the left atrial appendage (LAA) by suture ligation is commonly performed in patients who undergo mitral valve (MV) surgery or as an adjunct to a surgical Maze procedure for treatment of atrial fibrillation (AF). However, suture ligation can frequently yield an incompletely surgically ligated LAA (ISLL) with often severely stenotic necks (Figure 1). Several transesophageal echocardiography (TEE) studies have reported ISLL rates ranging between 10 and 80%. Also, it has been proposed that ISLL may further augment stasis within the stenotic LAA, in turn predisposing to thrombus formation...
in up to 50% of patients and thromboembolism in ~10%. Although no data are presently available in support of a specific treatment strategy, either a procedure designed for complete LAA closure or life-long oral anticoagulation (OAC) should likely be considered in these patients. While complete closure could offer a desirable therapeutic option in certain patients, such as those with elevated thromboembolic risk or intolerance to long-term OAC, a percutaneous approach aimed at ISLL closure can pose significant procedural challenges. For instance, an epicardial strategy would likely meet with technical difficulties due to the underlying pericardial adhesions commonly associated with prior cardiac surgery. Similarly, owing to the markedly stenotic ISLL necks that normally characterize these structures, endocardial occlusion using larger conventional LAA occlusion devices is also not feasible. The authors recently reported on the safety and feasibility of percutaneous endocardial ISLL occlusion using a Septal Occluder device (St. Jude Medical, St. Paul, MN). However, due to anatomical variations and the small-caliber necks commonly associated with ISLLs, in some cases this approach could prove arduous and require prolonged fluoroscopy and procedure times. Here, we describe a novel approach to guide and facilitate endocardial access and occlusion of stenotic LAA using three-dimensional (3-D) electroanatomical mapping (EAM). This strategy could possibly also provide utility in other cardiac interventions.

Methods

Patients with ISLL and non-valvular AF with/without stroke and intolerance to long-term OAC, were referred for percutaneous endocardial occlusion using an off-label procedure performed under general anesthesia by a single operator (AA) experienced in both percutaneous LAA and atrial septal closure. Approval for this case series was granted by the Mercy General Hospital institutional review board (Dignity Health institutional review board #14).

Procedural imaging

After obtaining informed written consent, patients were transported to the cardiac electrophysiology laboratory while receiving uninterrupted OAC therapy with warfarin (international normalization ratio goal: 2–3). A pre-procedural 64-slice multi-detector chest computed tomography (CT) angiogram was obtained to delineate the left atrial (LA) and ISLL anatomy. Additionally, intra-procedural TEE was used to reassess the anatomy and size of the ISLL neck (narrow channel connecting the ISLL to the LA).

3-D EAM

A 6-Fr decapolar diagnostic electrophysiology catheter (Bard Medical Division, Covington, GA) was advanced inside the coronary sinus via a femoral venous approach. This catheter was utilized as the reference for the impedance-based 3-D EAM system (Ensite Velocity™ v3.0.1.1, St. Jude Medical Inc, Saint Paul, MN). Following systemic anticoagulation and transseptal catheterization, a 7-Fr, 15-mm, 20-pole circular mapping catheter (LASSO, Biosense Webster Inc, Diamond Bar, CA) was placed inside the LA via a steerable 8.5-Fr long sheath (Agilis, St. Jude Medical Inc). Using this catheter and the EAM system, a 3-D geometry of the LA and pulmonary veins (PVs) was created (Figure 2a). However, the ISLL could not be mapped using this approach since the LASSO catheter was too large to advance inside the ISLL through its severely stenotic neck which often only measured 2–4 mm in diameter (Figure 2b). Next, the 3-D EAM was registered with the LA image segmented from the CT angiogram (Figure 2c). As such, the ISLL anatomy was integrated into the 3-D map, thereby completing the LA/LAA geometry (Figure 2d). In this series, CT segmentation was performed using the Ensite Verismo™ segmentation software v2.0 (St. Jude Medical Inc), and EAM-CT registration using the EnSite fusion™ registration module (St. Jude Medical Inc).

The circular mapping catheter was then replaced with a 260-cm, 0.035” Versacore guide wire (Abbott Vascular Inc, Santa Clara, CA). A standard connector cable with alligator clips, commonly used during pacemaker implantation (Boston Scientific Corp, Minneapolis, MN), was connected to the proximal end of the guide wire and directly into the 3-D EAM system. Henceforth, this provided real-time visualization of the guide wire tip inside the LA map (Figure 3). Next, guided by 3-D EAM, the precise location of the stenotic ISLL ostium was identified and cannulated using the guide wire, obviating the need for fluoroscopy (Figure 3a–c). Nonetheless, the position of the guide-wire tip within the ISLL was in most cases confirmed using real-time angiography (Figure 4c). Alternatively, a 0.035” percutaneous transluminal angioplasty (PTA) balloon catheter (EverCross, ev3 Endovascular Inc, Plymouth, MN) was advanced over the guide wire across the ISLL neck. Used as a sizing tool, the PTA balloon was inflated within the ISLL neck to determine precisely the size of its diameter (Figure 4d). This also aided with accurate sizing of the ISLL neck to guide closure device selection.

Approaching the ISLL

Depending on the ISLL neck size, either a 4.0 × 20- or an 8.0 × 20-mm PTA balloon catheter was used. The transseptal sheath was then carefully advanced over the wire and the PTA balloon into the ISLL. The distal tip of the sheath was positioned just beyond the ISLL neck, as the balloon catheter and guide wire were removed. Subsequently, a Septal Occluder device was loaded inside the transseptal sheath and advanced all the way to the tip. To ensure proper fixation, we normally select a device size measuring 1–3 mm larger than the ISLL neck diameter based on the measurements derived from the CT, TEE and angiography. The Septal Occluder device is subsequently ‘unsheathed’, such that the distal disc is...
3-D EAM for Stenotic LAA Closure

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A

B

C

Left atrium

LSPV

LIPV

RIPV

ISLL

RSPV

LSPV

Left atrium

ISLL
deployed inside the ISLL and the proximal disc overlying its LA surface (Figure 4E). Echocardiographic and angio-
graphic assessments were used to confirm optimal device deployment and absence of residual flow surrounding the device (Figure 4F–H).

Results

Four patients with AF and intolerance to long-term OAC (mean age: 68 ± 10 years, 75% male, left ventricular ejection fraction: 54 ± 13%) with ISLL and severely stenotic LAA were referred for percutaneous ISLL closure guided by 3-D EAM. Two patients were diagnosed with ISLL during an ischemic stroke work-up and two on a pre-procedural TEE prior to catheter ablation of AF. The mean ISLL neck diameter and length measured: 4.3 ± 2.6 (range: 2–8) mm and 2.8 ± 0.5 (range: 2–3) mm, respectively. The Septal Occluder used for ISLL occlusion included two 5-mm, one 6-mm, and one 9-mm devices. Altogether, 4.3 ± 0.5 (range: 3.8–4.9) minutes of fluoroscopy and 64 ± 8 (range: 55–74) minutes of total procedure time were required to complete these procedures. ISLL cannulation and percutaneous closure were successfully achieved in all patients using the described approach. No acute or long-term adverse events occurred. Follow-up TEE was performed in all patients prior to hospital discharge and at 4–6 weeks following procedure. Follow-up CT angiograms were also performed to verify complete ISLL closure (Figure 5). No device- or ISLL-related thrombi and no peri-device leaks were detected. OAC therapy was discontinued 6–8 weeks following procedure. No embolic events occurred off OAC during 14 ± 2 months of follow-up.
Discussion

The LAA has been identified as the primary source of intracardiac thrombi in 57% of patients with valvular AF and up to 90% of those with non-valvular AF. Efforts to exclude the LAA began early in the course of valvular surgery to reduce the incidence of thromboembolism. To date, a variety of surgical and percutaneous LAA exclusion techniques have been developed with varying success rates. Common surgical strategies include endocardial and epicardial suture ligation, stapled excision, and excision with oversew, whereas percutaneous techniques consist of either endocardial occlusion or epicardial suture ligation. Surgical suture ligation is among the most commonly utilized strategies in patients who undergo surgical MV or Maze procedures. However, an inherent limitation of suture ligation is that it can frequently result in ISLL in a vast number of patients. The incidence of ISLL varies widely across experiences and centers. Moreover, the clinical significance of incomplete LAA closure warrants further investigation. It seems that this phenomenon can occur not only following surgical but also percutaneous LAA exclusion techniques. Though the presence of ISLL has been associated with elevated thromboembolic risk, whether the same applies to incomplete LAA closure as a result of percutaneous techniques remains a subject of debate and deserves further examination. While it would be difficult to justify closure of every case of ISLL, as guided by individual patient risk and preference, the availability of a safe and effective closure technique would be of potential value in some patients. The authors have previously described a preliminary experience of percutaneous endocardial occlusion of ISLL. More recently, Pillai et al reported on a similar approach in patients with incompletely percutaneously ligated LAA (IPLL) following prior closure using the Lariat snare device (SentreHeart, Redwood City, CA).

In this manuscript, we have described a novel approach to guide and facilitate endocardial access and occlusion of stenotic LAA using 3-D EAM. To our knowledge, this is the first report on such an approach. Furthermore, this
strategy may have broader applicability to other similar cardiac procedures.

Role for imaging

Pre-procedural CT and magnetic resonance (MR) imaging have previously been used to guide neurosurgical and bronchoscopic procedures. Similarly, the use of registered CT/MR images in guiding catheter ablation has offered a significant advantage over the less detailed surrogate geometry as created by 3-D mapping alone. Yet, in the case of stenotic LAA closure pre-procedural CT or MR even play a more important role. Not only do these imaging techniques provide significant and helpful data about the overall anatomy to facilitate a successful procedure, but they can in fact deliver fundamental structural details that may be absent from the 3-D EAM (such as the ISLL itself), needed to guide the actual procedure.

Role for 3-D mapping

Given that fluoroscopy offers little soft tissue resolution, 3-D mapping systems have been developed to provide detailed anatomical reconstructions of cardiac chambers to guide cardiac procedures; namely, catheter ablation.

Figure 4: Endocardial occlusion of ISLL. a and b, TEE images depicting an ISLL, without (a) and with (b) color Doppler, showing turbulent flow into the ISLL. c, LAA angiogram performed through the transseptal sheath illustrating the ISLL anatomy on fluoroscopy. d, used as a sizing tool, an 8.0 × 20-mm PTA balloon catheter is inflated inside the ISLL neck via the transseptal sheath. e, a TEE image depicting deployment of the Septal Occluder device (arrow) delivered via the transseptal sheath. f and g, a 2-D (f) and a 3-D (g) TEE image of the Septal Occluder device (arrow) immediately following deployment inside the neck of the ISLL. h, the Septal Occluder device (arrow) following deployment and release, as visualized on fluoroscopy. Abbreviation: TSS sheath: transseptal sheath.

Figure 5: Confirmation of ISLL occlusion. a, a baseline CT of the LA in a patient with ISLL prior to closure. b and c, follow-up CT angiograms in the same patient obtained 6 weeks (b) and 4 months (c) post-ISLL closure illustrating near-total (arrow) and total (arrow) occlusion of this structure, respectively. d and e, the same findings in another patient at baseline and 3 months following ISLL closure, respectively. f, a cardiac CT angiogram obtained 3 months post-ISLL closure depicting a well-positioned Septal Occluder device (arrow).
Additionally, integration of imaging modalities such as CT, MR, angiography or intracardiac echocardiography with the 3-D map can greatly improve catheter ablation efficacy, reduce fluoroscopy and procedure times and enhance clinical outcomes.\(^6\) Indeed, the real-time enhanced visualization of detailed LA and PV anatomy has proven highly advantageous in guiding catheter ablation of AF.

Meanwhile, several features clearly differentiate a procedure intended for closure of a stenotic versus a patent LAA. Firstly, the dimensions of a stenotic LAA neck are often quite small measuring no more than 3–4 mm in many patients with ISLL.\(^5\) In the study of patients with IPLL, the LAA necks were of equally small caliber, measuring only 4.3 ± 0.6 mm.\(^10\) Hence, the ability to identify and gain endocardial access into the stenotic LAA can sometimes prove exceedingly difficult. Also, the LAA is generally a fragile structure susceptible to tears and perforations with repeated catheter manipulations. As such, by utilizing 3-D EAM to display precise real-time visualization and localization of the stenotic LAA ostium, excessive catheter/guide-wire manipulations can be minimized. Furthermore, as the direct consequence of improved guide-wire visualization within the LA geometry and more accurate localization of the LAA ostium, both fluoroscopy and procedure times may be reduced. In this small series, a mean of 4.3 ± 0.5 minutes of fluoroscopy and 64 ± 8 minutes of procedure time were required in total for successful completion of the procedures. These were significantly shorter when compared with the authors’ earlier experience that included a fluoroscopy time of 19.2 ± 9.5 minutes and a procedure time of 111 ± 19 minutes.\(^3\) This is noteworthy since methods that reduce radiation exposure during cardiac procedures are of clinical and public health consequence.

It is estimated that in the last two decades, radiation exposure through medical procedures has increased by 6-fold in the United States with cardiac procedures accounting for ~40% of the cumulative effective dose.\(^17\) In turn, this can confer increased risk on both patients and operators, including an estimated life-time attributable excess cancer risk of 1 in 100 among interventional cardiologists.\(^18\) Lastly, this modified approach also helped minimize the need for repeated intravenous dye injections and real-time angiography to guide the procedure. This too is of clinical relevance since many patients referred for cardiac procedures may suffer from chronic kidney disease and are susceptible to acute kidney injury.

**Other clinical implications**

The authors believe that the described strategy of stenotic LAA access and occlusion guided by 3-D EAM could also have utility in other clinical procedures, such as closure of IPLL as well as other cardiac interventions. For instance, one potential application may be in percutaneous closure of paravalvular leaks following transcatheter aortic valve replacement. Paravalvular leaks frequently occur following transcatheter aortic valve replacement, and even mild degrees of paravalvular leakage are associated with increased patient mortality.\(^19\) Luu et al recently reported on percutaneous closure of paravalvular leaks using a vascular plug device guided by fluoroscopy and TEE.\(^20\) We propose that there may be an analogous role for 3-D EAM to facilitate such a procedure, as well as access/closure of other types of cardiac structures and defects similar to that of a stenotic LAA.

**Limitations**

It should be emphasized that image integration techniques can exhibit several important limitations. As CT/MR imaging is commonly performed some time prior to the procedure, registration error can arise from interval changes in heart size due to differences in cardiac rhythm, rate, contractility, or fluid status. This may be significant since the accuracy of image registration (that is, the correct superimposition of reconstructed 3-D anatomy onto the 3-D map) can be directly influenced by the aforementioned variables. Additionally, the quality of CT/MR imaging can also drastically impact image registration. For instance, a poorly opacified ISLL captured on a CT/MR image could profoundly limit the accuracy and utility of image integration.

**Conclusions**

The use of 3-D EAM may in some cases greatly enhance the procedure of endocardial occlusion of stenotic or incompletely ligated LAA, and as such reduce the need for fluoroscopy. Furthermore, the display of accurate and detailed anatomical data as provided by a pre-procedural CT angiogram – specifically, the ISLL structural details that may be absent from the 3-D map – proved invaluable in facilitating this procedure. There may also be a possible role for this approach to facilitate other similar cardiac interventions.

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**References**


