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Left atrial appendage closure guided by 3D computed tomography printing technology: A case control study

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ABSTRACT

Background: We sought to evaluate the additional value of left atrial appendage (LAA) 3D printing derived from computed tomography (CCT) in determining the size for LAA occlusion (LAAO) devices as compared to standard measurement by using occurrence of LAA leak as endpoint.

Methods: We evaluated 6 patients with LAA leak (cases) and 14 matched patients without LAA leak (controls) after LAAO. For each group, a patient-specific 3D printed model of LAA was manufactured using CT pre-operative images. The size recommended by the 3D printed model was compared with the size of the implanted device.

Results: Compared to the 3D printed model, 55% of the devices were underestimated, the two sizing approaches agreed in 35% of the patients, while the 3D printed model overestimated the size in 10% of patients. The prevalence of LAA leak was significantly higher in the subset of patients with underestimation of prosthesis implanted with the standard approach as compared to the other patients ($p = 0.019$).

Conclusion: 3D printing of the LAA may provide additional value to standard practice for LAAO device prosthesis sizing with the potential impact to reduce LAA leak.

1. Introduction

Percutaneous left atrial appendage (LAA) occlusion (LAAO) has been introduced as a measure to prevent thromboembolism in patients with atrial fibrillation (AF) who cannot tolerate anticoagulants. Controlled trials (PROTECT AF and PREVAIL) and initial registry reports for the Amplatzer Cardiac Plug (ACP) demonstrated non-inferiority of LAAO compared to anticoagulant therapy, and others showed superiority of LAAO over warfarin therapy.[1–4]

3D printing is a novel technology able to create a patient specific model of any given anatomical portion of the heart.

We sought to evaluate the additional value of 3D printing of LAA sizing in preventing LAA leak in AF patients treated with percutaneous LAAO, compared to standard evaluation with transesophageal echocardiography (TEE), cardiac computed tomography (CCT) and cardiac angiography (CA). Authors have declared that this study was performed in accordance to the research ethical guidelines.

2. Methods

From a cohort of 82 patients treated with percutaneous LAAO between 2014 and 2017, we identified 6 consecutive patients with

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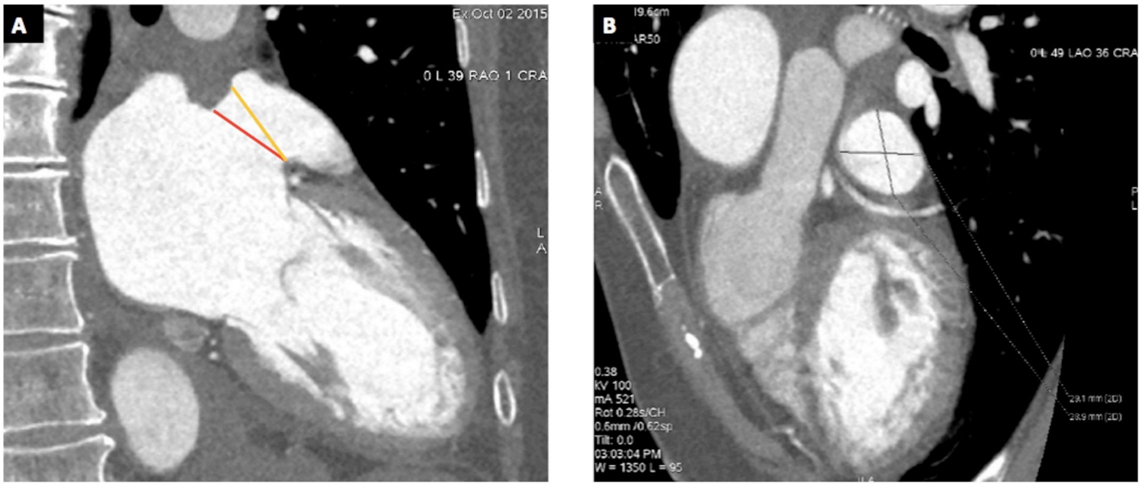

Fig. 1. Panel A: CCT measures of ostium (red line) and landing zone (yellow line) in 2 chamber view. Panel B: CCT image showing the measures of the show axis view of landing zone. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

evidence of leak and matched this population with 14 control patients from the same cohort without LAA leak. All patient before the LAAO procedure underwent CCT and TEE.

CCT was performed with a Revolution CT scanner (GE Healthcare, Milwaukee, Wisconsin). The landing zone plane was detected as a plane between a point 10 mm distal to the center of the ostium on the midline and the circumflex artery, perpendicular to the long axis of the LAA neck. (Fig. 1).

TEE was performed documenting the absence of thrombi within the LAA, determining the ostium and landing zone diameters, shape, number of lobes and location.

The LAAO procedure was performed with TEE and cardiac angiography (CA) monitoring and the sizing of the device was decided on the basis of TEE, CCT and CA.

Amplatzer Cardiac Plug (ACP) (St. Jude Medical, Minneapolis, Minnesota) was deployed in 15 cases and the Coherex *WaveCrest* (Salt Lake City, UT) LAAO System in the remaining 5 cases.

Post-procedural follow-up TEE was performed 45 days after the implantation. The presence of peridevice leaks was assessed by Color Doppler images, sizing the vena contracta of the jet in each plane and choosing the widest measure.

Starting from pre-operative CCT images, we performed a segmentation procedure to extract a 3D virtual model of the structure of interest through the open source software ITK-SNAP.[5]

The model was finally 3D printed using a Form 2 Desktop printer (Formlabs Inc., MA, USA), based on vat-photopolymerization technology. LAA landing zone was then measured manually by a digital caliper. Visual inspection of the LAA occluder apposition was used to confirm the selection. Finally, the size recommended by the 3D printed model was compared with the size of the implanted device to assess agreement, overestimation, or underestimation and its relation with post-operative leak.

3. Results

The baseline characteristics of the population are listed in Table 1. The measurements of the 3D derived models are listed in Table 2.

The comparison of the implanted prosthesis size versus the sizing performed by the 3D printed model showed underestimation in 11 patients (55%), agreement in 7 patients (35%) and overestimation in 2 cases (10%). For cases with an implant size of 22 mm (n = 8), 75% of 3D printed models matched the implanted size.

The prevalence of LAA leak was significantly higher in the subset of patients with underestimation of prosthesis implanted (6 out of 11 patients vs 0 out of 9 patients, p = 0.019).

Table 1
Baseline characteristics.

	Controls	Cases	P value
Baseline characteristics			
Age, years (mean ± SD)	67 ± 12	68 ± 11	0.8
Male, n (%)	6 (42)	4 (67)	0.6
Risk Factors			
Hypertension, n (%)	10 (71)	3 (50)	0.6
Diabetes, n (%)	1 (7)	1 (16)	1.0
Dyslipidemia, n (%)	2 (14)	2 (33)	1.0
Clinical History			
History of heart failure, n (%)	1 (7)	1 (16)	1.0
Intracranial hemorrhage, n (%)	0 (0)	0 (0)	1.0
Digestive hemorrhage, n (%)	0 (0)	0 (0)	1.0
Other major hemorrhage, n (%)	2 (14)	1 (16)	0.5
Previous ischemic stroke, n (%)	2 (14)	0 (0)	0.5
Previous hemorrhagic stroke, n (%)	0 (0)	0 (0)	1.0
History of atrial fibrillation, n (%)	14 (100)	6 (100)	1.0

Fig. 2 represents a case of a patient with underestimation of LAA measurements resulting in LAAO leak where 3D-printing suggested a larger size for LAAO.

4. Discussion

Using LAA leak as the primary endpoint, 3D-printed models of LAA derived from CCT appear more accurate for sizing of LAAO compared to standard evaluation based on pre-operative TEE, CCT and CA independently by the implanted device.

Despite the small sample size of this study population, our is one of the first studies testing the impact of CCT based 3D-printing models on the occurrence of LAA leak over the standard pre-procedural approach for LAA evaluation. Pellegrino and colleagues[6] described two cases of LAAO using different systems, the WaveCrest device (Coherex Medical, Inc, USA) and the Amplatzer Amulet device (St Jude Medical, St Paul, MN), in which a 3D printed LAA model, derived from CCT, was used for the correct device sizing and for the identification of the ideal position within the LAA.

Liu and colleagues[7] reported the clinical feasibility of generating 3D printed models of LAA using real-time 3D TEE data for LAAO. Interestingly, the 3D printed model predicted operating difficulty and the presence of a peridevice leak.

Obasare and colleagues[8] reported that 3D printing derived from CCT was superior to 2D TEE for pre-procedure planning in LAAO. Absence of peri-device leak was also more likely when the model was used.

Table 2
Size suggested by 3D printed LAA models vs size of implanted device for LAAO.

Patient ID	Size of implanted device	3D printed LAA model			Comparison				Clinical observation
		Major axis [mm]	Minor axis [mm]	Device Size	Difference	<	>	=	
1	22	20,8	18,6	22	0%	0	0	1	
2	25	24,1	18,7	28	−11%	1	0	0	Leak and device migration
3	22	19,5	18,4	22	0%	0	0	1	
4	22	23	18	26	−15%	1	0	0	Leak
5	18	20	20	22	−18%	1	0	0	Leak
6	20	18,9	17,7	22	−9%	1	0	0	Leak
7	28	28,5	22,3	31	−10%	1	0	0	
8	22	17,6	15	20	10%	0	1	0	
9	25	23,3	25	28	−11%	1	0	0	Leak
10	25	21	19,5	25	0%	0	0	1	
11	22	23	19	22	0%	0	0	1	
12	22	22,4	17,5	22	0%	0	0	1	
13	25	24	17,7	28	−11%	1	0	0	Leak
14	18	20,3	19	22	−18%	1	0	0	
15	22	20	17,6	22	0%	0	0	1	
16	22	21	18,2	22	0%	0	0	1	
17	25	23,6	19	28	−11%	1	0	0	
18	20	17,2	17,6	18	11%	0	1	0	
19	20	20,1	19,1	22	−9%	1	0	0	
20	28	26,5	21	31	−10%	1	0	0	

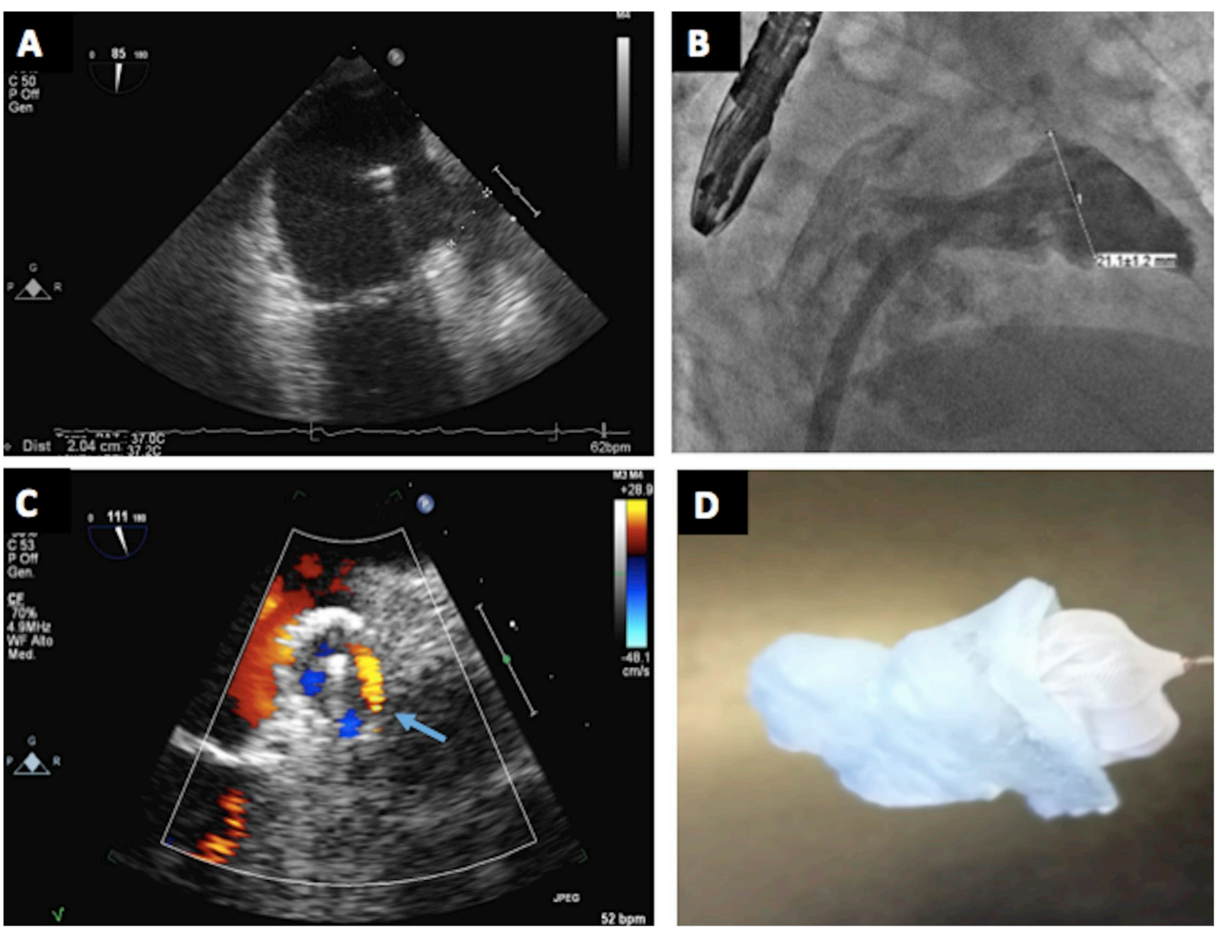

Fig. 2. 73 year-old male with AF and contraindication to anticoagulation therapy. On the basis of TEE (A) and CA measurements (B) the LAAO was chosen. Follow-up TEE showed a PLL (blue arrow) (C). Measurements with digital calipers using the 3D printed LAA (D) showed an underestimation of device size. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Limitations

This is a pilot, retrospective case-control study with a small number of patients; more extensive prospective studies are needed. No conclusions can be derived in terms of cost analysis for the introduction of 3D printed models on routine workflow. Our models are 3D printed using a transparent photopolymer which is rigid. Consequently, the LAA models are not deformable reducing the capability of the LAA model and the occluder to fit closely together. Other authors used gelatin,[7] Latex material[8] or a rubber-like material[9] to mimic LAA tissue elasticity without any specific standard or control of the mechanical response. Therefore, a prospective comparative study testing different material for appropriate device sizing is warranted.

Conclusions

3D printing of the LAA derived from CCT is feasible and may add value to CCT, TEE or CA derived LAAO device prosthesis sizing by reducing LAA leak.

Conflict of interest

G.P. received institutional fee as speaker or institutional Research grant from GE Healthcare, Bracco, Bayer, Medtronic, Heartflow.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jcct.2018.10.024.

References

1. Reddy VY, Doshi SK, Sievert H, et al. Percutaneous left atrial appendage closure for stroke prophylaxis in patients with atrial fibrillation: 2.3-year follow-up of the PROTECT AF (Watchman left atrial appendage system for embolic protection in patients with atrial fibrillation) trial. *Circulation.* 2013;127:720–729.
2. Holmes Jr DR, Kar S, Price MJ, et al. Prospective randomized evaluation of the Watchman Left Atrial Appendage Closure device in patients with atrial fibrillation versus long-term warfarin therapy: the PREVAIL trial. *J Am Coll Cardiol.* 2014;64:1–12.
3. Park JW, Bethencourt A, Sievert H, et al. Left atrial appendage closure with Amplatzer cardiac plug in atrial fibrillation: initial European experience. *Cathet Cardiovasc Interv.* 2011;77:700–706.
4. Urena M, Rodes-Cabau J, Freixa X, et al. Percutaneous left atrial appendage closure with the AMPLATZER cardiac plug device in patients with nonvalvular atrial fibrillation and contraindications to anticoagulation therapy. *J Am Coll Cardiol.* 2013;62:96–102.
5. Yushkevich PA, Piven J, Hazlett HC, et al. User-guided 3D active contour segmentation of anatomical structures: significantly improved efficiency and reliability. *Neuroimage.* 2006;31:1116–1128.
6. Pellegrino PL, Fassini G, DIB M, Tondo C. Left atrial appendage closure guided by 3D printed cardiac reconstruction: emerging directions and future trends. *J Cardiovasc Electrophysiol.* 2016;27:768–771.
7. Liu P, Liu R, Zhang Y, Liu Y, Tang X, Cheng Y. The value of 3D printing models of left atrial appendage using real-time 3D transesophageal echocardiographic data in left atrial appendage occlusion: applications toward an era of truly personalized medicine. *Cardiology.* 2016;135:255–261.
8. Obasare E, Mainigi SK, Morris DL, et al. CT based 3D printing is superior to transesophageal echocardiography for pre-procedure planning in left atrial appendage device closure. *Int J Cardiovasc Imag.* 2018;34(2013):821–831.
9. Otton JM, Spina R, Sulas R, et al. Left atrial appendage closure guided by personalized 3d-printed cardiac reconstruction. *JACC Cardiovasc Interv.* 2015;8:1004–1006.