Etiology and Relevance of the Figure-of-Eight Artifact on Echocardiography after Percutaneous Left Atrial Appendage Closure with the Amplatzer Cardiac Plug

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Background: The Amplatzer Cardiac Plug (ACP) device, used for percutaneous left atrial appendage closure, frequently presents as an unexplained figure-of-eight on echocardiography. The aim of this study was to clarify the figure-of-eight display of the ACP device during echocardiography and to relate this finding to device position and function.

Methods: A mathematical model was developed to resemble device geometry and predict the echocardiographic appearance of the ACP device. In addition, an in vitro setup was used to validate the model. Finally, echocardiographic images of consecutive patients referred for percutaneous left atrial appendage closure (n = 24) were analyzed for the presence of a figure-of-eight display.

Results: Because the ACP device resembles an epitrochoid curve, those points with tangent vector perpendicular to the ultrasound waves are emphasized, resulting in a figure-of-eight display, which can be replicated in vitro in the coronal imaging position. We found the figure-of-eight display in 100% (11 of 11) of three-dimensional periprocedural transesophageal images and in 87% (34 of 39) of postprocedural transthoracic echocardiographic images.

Conclusions: The figure-of-eight display of the ACP device during echocardiography is the result of the specific epitrochoid geometry of the device mesh and its interaction with ultrasound waves. It is important to recognize the figure-of-eight as being a normal imaging artifact of a correctly deployed device in the coronal imaging position on both transesophageal and transthoracic echocardiography. In the future, this could be used during follow-up to aid clinical practitioners in assessing device position and function. (J Am Soc Echocardiogr 2014;27:323-8.)

Keywords: Left atrial appendage closure, Echocardiography, Ultrasound physics

In recent years, percutaneous closure of the left atrial appendage (LAA) has emerged as a promising technique for the prevention of stroke in a selected group of patients with atrial fibrillation and a contraindication to anticoagulation therapy.[1,2] Two different devices are currently available in clinical practice: the WATCHMAN device (Atritech, Plymouth, MN)[3] and the Amplatzer Cardiac Plug (ACP; AGA, St Jude Medical, Minneapolis, MN).[4,5] The latter is a disk occluder device, developed on the basis of the Amplatzer double-disk septal occluders used for closure of atrial septal defects and patent foramen ovale, and is constructed of self-expandable nitinol wires woven into two disks. When expanded, the disks function as an occluder of the LAA and in addition stabilize the device relative to the surrounding structures. Echocardiography is increasingly important in the preprocedural anatomic assessment of the LAA, the real-time guidance of device deployment, and the long-term follow-up of device position and function.[6,7] The ACP device frequently presents on echocardiography as a figure-of-eight superimposed on the occluder device (Figure 1).

The aims of this study were (1) to clarify the figure-of-eight display while imaging an LAA closure device using mathematical modeling and in vitro data and (2) to assess the prevalence and clinical relevance of the figure-of-eight display during and after deployment of the ACP device in 24 consecutive patients from two referral centers.

METHODS

Mathematical Model

We hypothesized that the planar mesh structure of an expanded ACP device closely resembles an epitrochoid curve[8] (Supplemental

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This study is part of the Limburg Clinical Research Program UHasselt-ZOL-Jessa, supported by the foundation Limburg Sterk Merk, Hasselt University, Ziekenhuis Oost-Limburg and Jessa Hospital.

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0894-7317/$36.00

http://dx.doi.org/10.1016/j.echo.2013.11.001

Abbreviations

ACP = Amplatzer Cardiac Plug

LAA = Left atrial appendage

TEE = Transesophageal echocardiography

3D = Three-dimensional

TTE = Transthoracic echocardiography

2D = Two-dimensional

Figure 1; available at www.onlinejase.com). Ultrasound waves falling onto the device are deflected in many directions because of the heterogeneity of mesh fiber orientations. Only those waves reflected toward the probe constitute the ultrasound image. Therefore, mesh points at which the tangent vector of the mesh (i.e., the derivative in that point) is perpendicular to the direction of the ultrasound beam are expected to be very reflective and highlighted on the resulting image (Figure 2). This hypothesis was implemented in a custom-written MATLAB routine (The MathWorks, Natick, MA) used for plotting of the epitrochoid curve and calculation of the mesh points that are expected to be most reflective.

In Vitro Validation Setup

An ACP device (16 mm in diameter) was mounted into a custom-made in vitro setup consisting of a small water-filled tank and an LAA phantom used to insert the ACP device. Transducer position was externally controlled using a fixation arm. Two-dimensional (2D) and three-dimensional (3D) echocardiography was performed with a commercially available system (iE33; Philips Medical Systems, Andover, MA) using the X5-1 probe and the CX7-2t probe. Images were obtained from a "frontal" (sagittal or transversal) probe position and a "coronal" probe position, with the ultrasound plane being parallel with the surface of the disk. All images were stored in digital format for subsequent offline analysis, using the commercially available CardioView software (TomTec Imaging Systems, Unterschleissheim, Germany).

Patient Cohort

Between October 2009 and February 2013, a total of 24 patients underwent percutaneous LAA closure procedures using the ACP device at Ziekenhuis Oost-Limburg (Genk, Belgium) (n = 5) and University Hospital Gasthuisberg (Leuven, Belgium) (n = 19). Periprocedural transesophageal echocardiographic guidance was performed at both centers. After deployment of the ACP device, device position and function was assessed on transesophageal echocardiography (TEE) using Doppler of the LAA area. Before discharge, 2D and Doppler transthoracic echocardiography (TTE) was performed in all patients to exclude pericardial effusion, assess mitral valve function and left ventricular function, and confirm device positioning and function. Standard clinical follow-up with TTE and/or TEE at the discretion of the treating cardiologist was performed at 2 to 6 months at the referring center (n = 5) or the center of implantation (n = 19).

Images from periprocedural TEE, postprocedural TTE, and follow-up TTE and/or TEE were retrospectively analyzed in all 24 patients. In case of a figure-of-eight display, the respective imaging plane was noted.

RESULTS

Mathematical Model

The MATLAB output assumed for an ACP device of 16 mm in diameter is shown in Figure 3, with close resemblance to the nitinol mesh configuration of the real device. When emphasizing only those curve points with a tangent vector perpendicular to a vertical ultrasound beam, a symmetric figure-of-eight configuration is established, similar to the echocardiographic image.

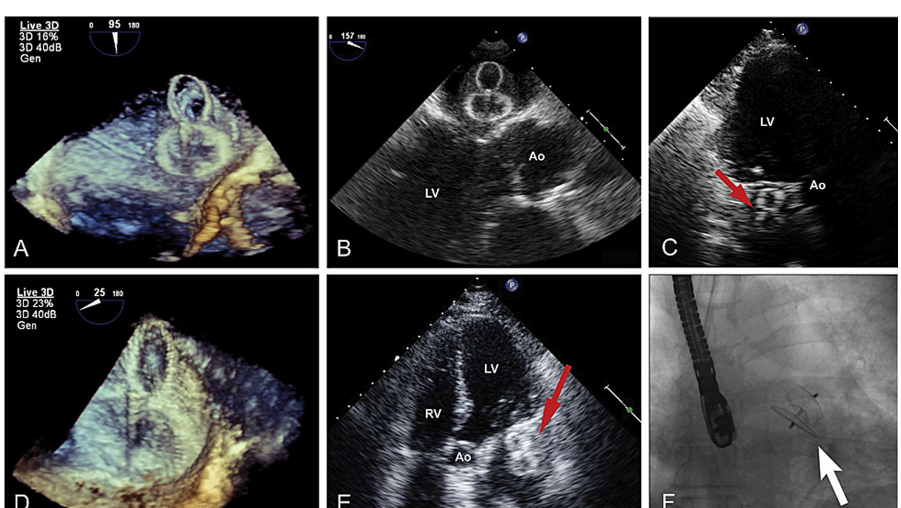

Figure 1 Percutaneous closure of the LAA using a disk occluder (ACP), with real-time transesophageal echocardiographic guidance in patient 1 **(A–C)** and patient 2 **(D–F)**. **(A)** After deployment of the ACP device, a figure-of-eight display is observed on real-time 3D TEE (see Video 1; available at www.onlinejase.com). **(B)** Two-dimensional TEE shows a morphologically identical figure-of-eight located in the left atrium in 157° midesophageal position (see Video 2; available at www.onlinejase.com). The aortic root and left ventricle are visualized below. **(C)** Two-dimensional TTE shortly after the procedure shows a figure-of-eight (*red arrow*) located in the lateral part of the left atrium, in the apical three-chamber view. **(D)** After deployment of the ACP device, a figure-of-eight configuration is observed on real-time 3D TEE. **(E)** Two-dimensional TTE 2 months after the procedure shows a figure-of-eight (*red arrow*) in the apical five-chamber view (see Video 3; available at www.onlinejase.com). **(F)** Fluoroscopic image immediately after deployment shows a normal device function and deployment (*white arrow*). Notice the coronal position of the transesophageal echocardiographic probe with respect to the device during LAA closure.

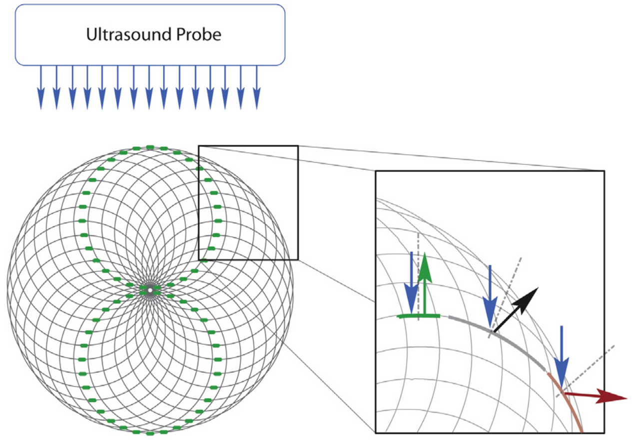

Figure 2 Interaction of ultrasound waves and device mesh fibers. Ultrasound waves falling onto a meshed device are expected to deflect in many directions because of the heterogeneity of mesh fiber orientations. In those mesh sections with tangent vector perpendicular to the incoming ultrasound wave, the ultrasound energy will be reflected toward the transducer (*green arrow*). Other mesh sections will refract the ultrasound waves sideward with only little ultrasound energy returning to the probe (*black arrow*), while other sections will completely deflect the ultrasound waves away from the probe (*red arrow*). The resulting image as observed by the ultrasound probe will mainly comprise those regions with highest ultrasound wave reflectivity (*green areas*).

In Vitro Validation Setup: Importance of Probe Position

In vitro 2D echocardiography of the ACP device using the transthoracic echocardiographic probe in the "frontal" and "coronal" position is shown in Figure 4. In the frontal position, cross-sectional images of the device are obtained. From a coronal imaging position, the figure-of-eight display is easily identified. Three-dimensional echocardiography obtained from the frontal imaging position shows a homogeneous disk structure and no figure-of-eight, regardless of the viewing angle. However, 3D echocardiography obtained from a coronal imaging position again shows the figure-of-eight in the reconstructed 3D image, seen in every viewing angle.

Patient Cohort

Table 1 summarizes the results of all analyzed echocardiographic images of the 24 patients who underwent percutaneous LAA closure with the ACP device. All procedures were successful, with correct device deployment as confirmed by fluoroscopy and correct device function as assessed on 2D and Doppler TEE. In one patient, a possible procedure-related stroke was noted. Clinical characteristics of the majority of the Leuven subgroup have been previously reported.[9] Follow-up occurred for five of 24 patients (21%) at the referring center and for 19 of 24 patients (79%) at the implanting center. After a mean follow-up period of 24 ± 10 months, no device-related complications occurred in the latter group. One patient died after 30 months of follow-up because of a subdural hematoma during prophylactic treatment with low–molecular weight heparin after a pelvic fracture.

Periprocedural 2D transesophageal echocardiographic images (available in 11 patients) revealed figures-of-eight in only two patients. Predischarge 2D TTE revealed figures-of-eight in 83% of patients

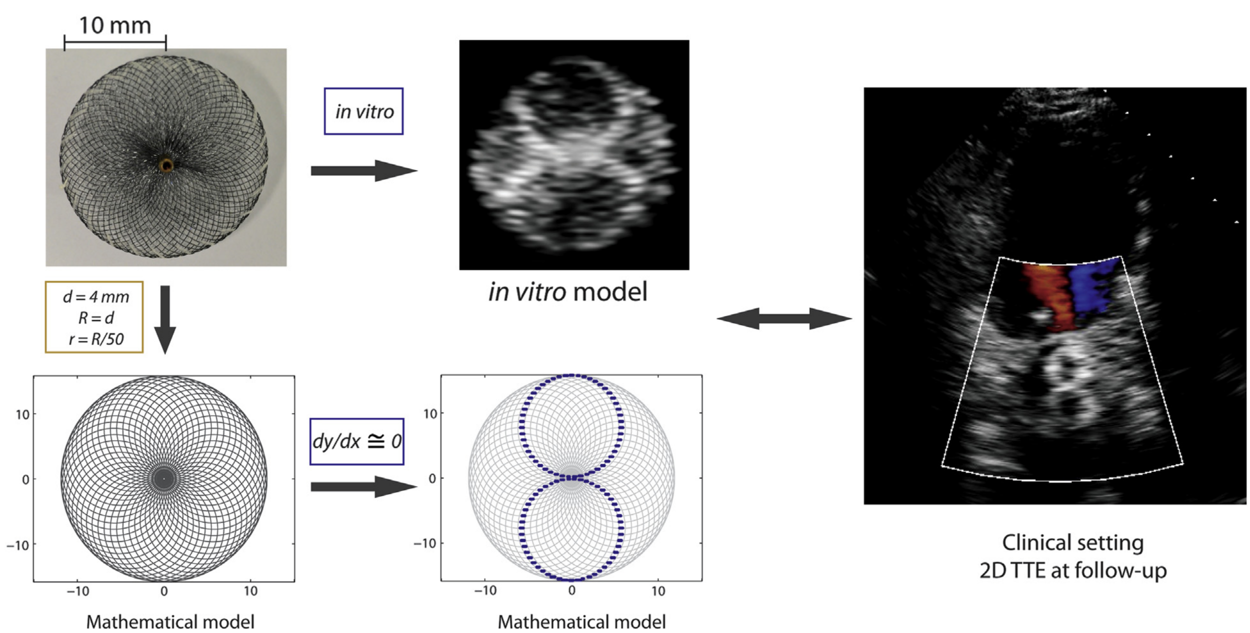

Figure 3 A mathematical and in vitro model for the figure-of-eight display. Nitinol mesh configuration of the ACP device (16 mm in diameter) (*upper left*) is compared with a graphical plot of an epitrochoid curve as simulated by the MATLAB-routine (*lower left*). When emphasizing the points with a tangent vector perpendicular to a vertical ultrasound beam (derivative $dy/dx \cong 0$), a symmetric figure-of-eight is evident (*lower middle*). This simulation closely resembles the image obtained in vitro, when visualizing the ACP device from a coronal probe position (*upper middle*). A similar image is found in the clinical setting during 2D TTE (in a slightly off-axis apical three-chamber view) of a patient who underwent LAA closure with the ACP device (*right*).

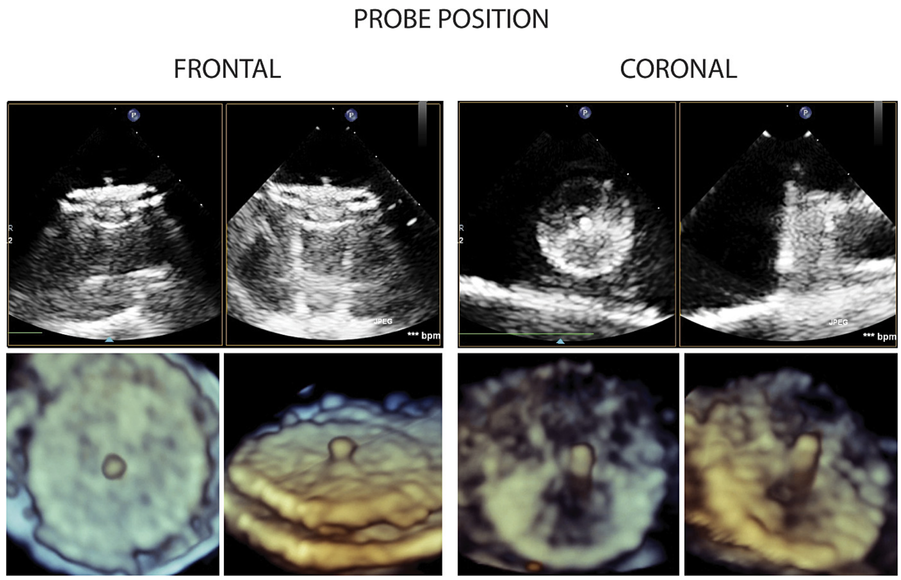

Figure 4 Importance of probe positioning for the figure-of-eight on echocardiography. Visualization of an ACP from the frontal as opposed to the coronal viewpoint on echocardiography, using an orthogonal X-plane view (*upper row*) versus 3D echocardiography (*lower row*). From a frontal point of view (*left*), there is no 2D or 3D figure-of-eight display. In contrast, in the coronal view (*right*), both 2D and 3D images reveal a figure-of-eight display. Furthermore, in the coronal imaging position, even if no figure-of-eight display is visualized in 2D, a figure-of-eight will still be obtained in 3D images.

Table 1 The figure-of-eight display in 24 patients who underwent LAA closure with the ACP device

		Periprocedural			Postprocedural		2-mo to 6-mo follow-up		Follow-up TEE		
Patient	Center	3D TEE	2D TEE	Viewing plane	2D TTE	Viewing plane	2D TTE	Viewing plane	3D TEE	2D TEE	Viewing plane
1	G	Y	Y	3Ch (157°)	Y	A5C+A3C	Y	A5C	NA	NA	—
2	G	Y	N	—	Y	A5C+A3C	Y	A5C	NA	NA	—
3	G	Y	N	—	Y	A5C	NA	—	NA	NA	—
4	G	Y	N	—	Y	A5C+A3C	NA	—	NA	NA	—
5	G	Y	N	—	Y	A5C	NA	—	NA	NA	—
6	L	NA	N	—	Y	A5C	Y	A5C	NA	NA	—
7	L	NA	NA	—	Y	A5C	Y	A5C	NA	NA	—
8	L	NA	NA	—	N	—	Y	A5C	NA	NA	—
9	L	NA	NA	—	Y	A5C	Y	A3C	NA	NA	—
10	L	NA	NA	—	N	—	NA	—	NA	NA	—
11	L	NA	N	—	Y	A5C	NA	—	Y	N	—
12	L	NA	NA	—	Y	A5C+PLAX	NA	—	NA	N	—
13	L	NA	NA	—	N	—	NA	—	NA	NA	—
14	L	NA	N	—	Y	A5C	Y	A5C	Y	Y	5C (0°)
15	L	NA	NA	—	Y	A5C	Y	A5C	Y	N	—
16	L	NA	NA	—	Y	A5C	Y	A5C	NA	NA	—
17	L	NA	N	—	Y	A5C	Y	A5C	NA	NA	—
18	L	NA	Y	3C (132°)	Y	A5C+PLAX	Y	A5C	NA	NA	—
19	L	NA	NA	—	Y	A5C+S5C	Y	A5C/A4C	Y	N	—
20	L	NA	NA	—	Y	A5C+A3C	NA	—	Y	N	—
21	L	NA	NA	—	Y	A2C+A5C	Y	PLAX	NA	N	—
22	L	NA	NA	—	Y	A5C+S5C	NA	—	NA	N	—
23	L	NA	N	—	Y	A5C	Y	A5C+A3C	NA	NA	—
24	L	NA	NA	—	N	—	N	—	Y	Y	3C (147°)
All		5/5	2/11		20/24		14/15		6/6	2/9	

A5C, Apical five-chamber view; *A3C*, apical three-chamber view; *5C*, five-chamber view; *G*, Genk; *L*, Leuven; *ME*, midesophageal; *N*, figure-of-eight display was not encountered; *NA*, not available; *S5C*, subcostal five-chamber view; *PLAX*, parasternal long-axis view; *3C*, three-chamber view; *Y*, figure-of-eight display was encountered.

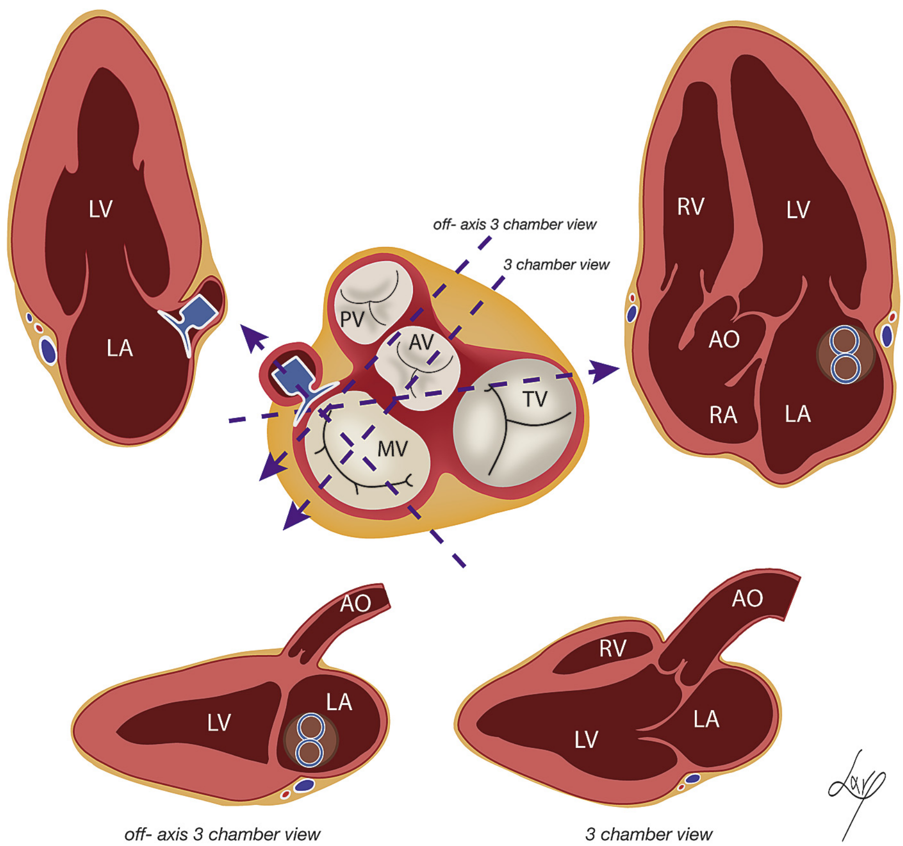

Figure 5 Standard echocardiographic imaging planes with respect to LAA and ACP device. A cross-sectional view of the basis of the heart (*center*) shows the position of the mitral valve (MV), aortic valve (AV), pulmonary valve (PV), tricuspid valve (TV), and ACP device (*blue*) in the LAA. Standard two-chamber view shows a cross-sectional view of the device (*left*), whereas standard five-chamber view offers a "near-coronal" view of the front of the ACP device (*right*). Standard three-chamber view, apical or parasternal (*bottom right*), is almost parallel with the front of the device, although the ACP device will not be visualized in a normal three-chamber imaging plane in which mitral valve leaflet are visible. Nevertheless, when tilting the imaging plane laterally toward the anterior commissure (off-axis three-chamber view, *bottom left*) one can expect a coronal view of the ACP device.

(20 of 24). Follow-up 2D TTE at 2 to 6 months revealed figures-of-eight in 93% of patients (14 of 15). Follow-up 2D TEE was performed in 9 patients and showed figures-of-eight in two patients.

In predischarge and follow-up transthoracic echocardiographic images, figure-of-eight displays were encountered in 34 of 39 of echocardiographic studies (Table 1). In these images, the figure-of-eight was most frequently encountered in the apical five-chamber view (32 of 34 [94%]). In a slightly off-axis three-chamber view, either apical or parasternal, the figure-of-eight was obtained in eight of 34 (24%).

During periprocedural real-time 3D transesophageal echocardiographic guidance (data available for retrospective analysis in only five patients), figure-of-eight displays were encountered in all patients. Follow-up 3D TEE (available in six other patients) also showed figures-of-eight in all patients, indicating a prevalence of the figure-of-eight display during 3D TEE of 100%.

DISCUSSION

Percutaneous closure of the LAA is gaining importance as a promising technique for the prevention of stroke in a selected group of patients with atrial fibrillation and contraindications to anticoagulation therapy. Echocardiography plays an important role to guide implantation procedures and during follow-up in these patients. A figure-of-eight display of the ACP is evident in the echocardiographic illustrations of some recently published articles on LAA closures.[1,7] However, until now, this finding has not been explained. In this study, we demonstrate that this particular imaging phenomenon on echocardiography is in fact an ultrasound-related artifact due to the orientation of nitinol fibers in the correctly unfolded ACP device and their interaction with ultrasound waves and should therefore not be interpreted as device malfunction or incorrect deployment. This figure-of-eight was seen in all patients who underwent 3D TEE during the procedure or at follow-up and in a vast majority of patients during standard postprocedural 2D TTE.

Current echocardiographic evaluation during follow-up of patients with LAA closure devices lacks good echocardiographic pointers of correct device position. This figure-of-eight finding could be an additional sign to look for during echocardiographic imaging of patients with implanted ACP devices, in particular during predischarge or follow-up studies. On the basis of the anatomic location of the LAA closure device with respect to the other cardiac structures and the different imaging planes (Figure 5), we can expect the figure-of-eight artifact to show up most likely in a five-chamber or a three-chamber view (apical or parasternal). This is supported by the data in our patient cohort, in which the figure-of-eight was most commonly noticed in a five-chamber view (94%) or a three-chamber view (24%) and never in the two-chamber view. To visualize the LAA device in the three-chamber view, slightly off-axis imaging is necessary (Figure 5), most likely explaining the lower incidence in this retrospective study. We would therefore suggest that practitioners performing postprocedural echocardiographic follow-up studies explicitly look for the figure-of-eight display in the five-chamber view or the off-axis three-chamber view, by tilting the imaging plane slightly laterally toward the anterior mitral commissure. This strategy might provide additional pointers to assess device position and function, in addition to the current evaluation.

Interestingly, as opposed to 2D TEE, a figure-of-eight morphology was obtained in all 3D transesophageal echocardiographic images of the ACP device. As demonstrated by the in vitro validation study, an imaging probe in the coronal position will result in a figure-of-eight display in the reconstructed 3D ultrasound image, irrespective of rotation or viewing angle. As such, the odds of observing a figure-of-eight are significantly higher on 3D TEE than on 2D TEE. This explains why the figure-of-eight was observed in all patients during real-time 3D periprocedural guidance, whereas in the same 2D transesophageal echocardiographic images, it occurred only when the imaging plane was specifically rotated into a three-chamber or five-chamber view. In our study, no 3D transthoracic echocardiographic images were obtained. With recent technological advances and improved image quality of transthoracic 3D images, its role in the assessment of an LAA closure device and the visualization of the figure-of-eight display needs further study.

This study had several limitations. Because of the retrospective study design, only standard echocardiographic images (i.e., without specifically aiming to visualize the figure-of-eight) were available for analysis. This may explain the low incidence of a figure-of-eight in 2D transesophageal echocardiographic images and 2D transthoracic echocardiographic long-axis views, as only standard cross-sectional views of the LAA device were recorded. Also, our results are applicable only to the ACP device, not the WATCHMAN LAA occluder. Finally, because no patient had device complications during clinical follow-up, the predictive value of the figure-of-eight could not be assessed. Larger prospective studies would be needed to assess the sensitivity and specificity of this figure-of-eight display for correct device positioning and/or uneventful device-related clinical follow-up.

CONCLUSIONS

A successfully deployed Amplatzer LAA closure device very often shows as a figure-of-eight on echocardiographic imaging as a result of the specific mesh geometry of the disk device and its interaction with ultrasound waves. It is most frequently seen in the transthoracic apical five-chamber view. It is important to recognize this figure-of-eight as being a normal imaging artifact. Furthermore this finding might aid practitioners in the assessment of device position and function, in addition to the current evaluation using 2D and Doppler echocardiography.

ACKNOWLEDGMENTS

We thank St Jude Medical for providing a sample of the ACP device for in vitro testing purposes. We also thank Christophe Smeets, MSc, for his technical assistance in setting up the in vitro model.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.echo.2013.11.001.

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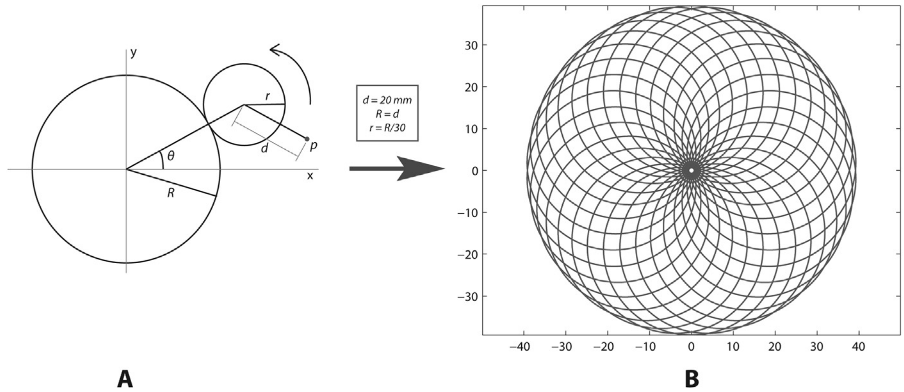

Supplemental Figure 1 Genesis of an epitrochoid curve. **(A)** Analytically, an epitrochoid is a curve traced by a point *p* attached to a circle of radius *r* rolling around the outside of a fixed circle of radius *R*, where the point *p* is a distance *d* from the center of the exterior circle. The parametric equation for an epitrochoid curve is $\begin{pmatrix} x(\theta) = (R+r)\cos\theta - d\cos\left(\frac{R+r}{r}\theta\right) \\ y(\theta) = (R+r)\sin\theta - d\sin\left(\frac{R+r}{r}\theta\right) \end{pmatrix}$, with parameter θ ranging from 0 to 2π. For a disk occluder of radius *S*, the parameters in the equation can be approximated as follows: $R = \frac{S}{2}; d \cong R; r << R$. **(B)** *N* samples of the parameter θ were generated and used for simulation and plotting of the epitrochoid curve in a custom-written MATLAB routine. This figure shows an example of the output when simulating an input radius *S* = 40 mm, sample size *n* = 10,000, and *r* = *R*/30. The value of *r* determines the density of the curve, with higher mesh densities for a smaller radius *r*.