# Defects in the Oval Fossa: Morphologic Variations and Impact on Transcatheter Closure

Joseph J. Vettukattil, FRCPCH, Zaheer Ahmed, MD, Anthony P. Salmon, FRCP, Tomothy Mohun, PhD, and Robert H. Anderson, FRCPath, *Southampton, London, and Newcastle Upon Tyne, United Kingdom*

*Background:* Incomplete formation of the partition between the two atrial chambers in the region of the oval fossa results in a range of defects, which extend from patent foramen ovale to large secundum atrial septal defects (ASDs). There is wide variation in the morphology of the latter lesions. The spatial orientation of the margins of ASDs relative to the persisting flap valve is not easily definable with standard echocardiographic imaging. Careful evaluation of the morphology is essential in optimizing successful transcatheter closure to minimize complications. The advent of three-dimensional transesophageal echocardiography has changed the understanding of the morphology of these defects and facilitated successful percutaneous closure.

*Methods:* Since 2007, over a 4-year period, transcatheter closure of ASDs was performed in 105 patients.

*Results:* During the study period, there were two instances of embolization of the device. The morphology of the defects in the patients with embolization was evaluated carefully, and an unusual spiral configuration of the flap valve relative to the rims of the oval fossa was noted. These findings were then found in four additional patients and serve as the focus of this report. To facilitate understanding of the unusual morphology, the clinical findings were compared with images showing the mechanism of development of the atrial septum in the mouse, revealing a striking similarity.

*Conclusions:* Although uncommon, spiral spatial orientation of the margins of ASDs predisposes to embolization of devices used for percutaneous closure. Standard cross-sectional techniques have limited use in identifying this variation. Understanding of the development of the atrial septum in the mouse heart may help explain the morphogenesis of the defect and the mechanism predisposing to embolization. (J Am Soc Echocardiogr 2013;26:192-9.)

*Keywords:* ASD, Device closure, Oval fossa defects, Device embolization, Complications

Incomplete formation or failure of fusion, of the components of the partition between the atrial chambers in the region of the oval fossa results in a range of defects, which extend from patency of the oval foramen to large holes in the floor of the oval fossa, so-called secundum atrial septal defects (ASDs). It is well accepted that there is wide variation in the morphology of the latter lesions with respect to size, shape, number, position, distance from vital structures, firmness of the margins, and, perhaps most important, the spatial orientation of the margins of the defect relative to the persisting flap valve.[1] Careful evaluation of the morphology is essential in optimizing successful transcatheter closure. Appropriate assessment can potentially reduce procedural times and radiation dose and hopefully minimize complications.

In recent years, the advent of advanced techniques for imaging, such as three-dimensional (3D) transesophageal echocardiography, has changed our understanding of the morphology of these defects and facilitated successful percutaneous implantation of devices for closure.[2] During our own experience with interventional closure, we have encountered an anatomic variant that is unusually challenging for interventionists, which we have termed the spiral septum. Thus far, to the best of our knowledge, the arrangement we have visualized has not previously been described in terms of the spiraling septum, although the features we have observed might account for the arrangement termed "double atrial septum."[3,4] They could certainly be described in terms of malalignment of the primary atrial septum,[5] although the latter entity is seen typically in the setting of hypoplastic left heart syndrome.[6] In this work, we focus on the limitations of standard cross-sectional techniques (two-dimensional transesophageal echocardiography) in revealing the true morphology of these unusual cases we have encountered. We then show how an understanding of atrial septal development may help explain the mechanism predisposing to early embolization.

From University Hospital Southampton, Southampton, United Kingdom (J.J.V., Z.A., A.P.S.); the MRC National Institute for Medical Research, London, United Kingdom (T.M.); and the Institute of Genetic Medicine, Newcastle University, Newcastle upon Tyne, United Kingdom (R.H.A.).

Reprint requests: Joseph J. Vettukattil, FRCPCH, Congenital Cardiac Centre, Southampton University NHS Trust, Tremona Road, Southampton SO16 6YD, United Kingdom (E-mail: *joseph.vettukattil@uhs.nhs.uk*).

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| Abbreviations |
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| **ASD** = Atrial septal defect |
| **E** = Embryonic day |
| **3D** = Three-dimensional |

## METHODS

The 3D option for transesophageal imaging has been available for the assessment of holes within the oval fossa since 2007. During this period, we have attempted percutaneous closure in 105 patients, using routine cross-sectional echocardiographic interrogation. During this experience, we have encountered three significant complications, specifically two embolizations of the device and one pericardial effusion needing device explantation and subsequent surgical closure. Our interventions are all conducted using a standard protocol, with two experienced operators having direct access to imaging and interventional expertise. Factors that might lead to instability of the device are carefully excluded in all cases before the deployment of the device. This includes a thorough standard cross-sectional two-dimensional transesophageal echocardiographic assessment of the margins of the defect, assessment of the distance of the margins from vital structures, and assessment of the shape, size, number, and nature of the defects. During the period of study, we routinely used fluoroscopy, and two-dimensional transesophageal echocardiography, for balloon sizing of the defects. As all our echocardiographic equipment used for cardiac imaging provides the facility for 3D interrogation, and we use the standard 3D transesophageal probe for both cross-sectional and 3D imaging, 3D interrogation was performed in most cases without the need for additional expertise fully to evaluate its potential role. We provided formal 3D assessments, however, only when specifically requested, this occurring in 13 cases. Retrospective analysis of the obtained 3D data sets was performed, on request, in two cases. In our current series, the 3D data sets obtained from the first patient in whom we experienced embolization of a device were acquired at the time of deployment of the device but were not analyzed until after the embolization. In the second patient, even though we identified a spiral formation of the septal components at the time of deployment of the device, we had not recognized the association between this morphologic feature and embolization. On the basis of the cross-sectional findings in this particular patient, the unexpected findings did not stand out as a matter of concern, despite the fact that the embolization occurred the day after deployment. Using 3D transesophageal echocardiography, we subsequently evaluated the morphology of the defects in the patients with embolization and then appreciated the potential significance of an unusual spiral configuration of the flap valve relative to the rims of the oval fossa. We then observed similar findings in additional patients, and it is the analysis of these investigations that serves as the focus of this report. The characteristics of the patients are summarized in Table 1. Because we hypothesized that we might gain insights into the findings from knowledge of the development of the atrial septum, we also analyzed high-resolution episcopic data sets from a series of mouse embryos. All data sets were prepared following our standard technique, as previously described.[1] In all, we studied two data sets from embryos at embryonic day (E) 10.5, 14 at E11.5, 15 at E12.5, 14 at E13.5, six at E14.5, six at E15.5, five at E16.5, and five at E18.5. The data sets can be cut in the three orthogonal planes to demonstrate the salient anatomy.

## RESULTS

### 3D Transesophageal Echocardiographic Study

It is usually considered that so-called secundum defects, which represent deficiency of the flap valve of the fossa, itself derived from the embryonic primary atrial septum, are single or multiple holes occupying a variable area of the floor of the oval fossa. In keeping with this impression, and subsequent to standard cross-sectional interrogation, we found that most of our patients had solitary circular defects, all with the anticipated arrangement of the components of atrial septum. Careful evaluation in some patients, nonetheless, revealed an unusual spiral configuration of the margin of the rims of the fossa formed by the infolded atrial walls inferior to the superior caval vein (Figure 1). Three-dimensional transesophageal echocardiographic evaluation of these patients revealed wide separation between the left atrial and right atrial margins of the defects, with wide variation in the potential space between the two margins (Figures 2 and 3). Three-dimensional imaging confirmed the spiraling configuration of the defect, which was particularly extensive in the two patients in whom there had been embolization of the device inserted for interventional closure (Figures 4 and 5). Subsequent to the realization that the spiraling configuration might be related to the embolizations, we directly referred the additional patients noted to have this marked spiral morphology of the margins of the oval fossa, as shown in Figures 2, 3 and 6, for surgery, opting not to make any attempt at device closure. We have, however, achieved successful closure in two patients with spiraling morphology. The first patient had undergone attempted closure at another center. The attempt failed, and the patient was referred for 3D transesophageal echocardiography. We found a small fenestration in the central aspect of the fossa, which was closed successfully using a 35-mm Amplatzer patent foramen ovale device (St. Jude Medical, St. Paul, MN). The margins of the fossa, nonetheless, showed the unusual spiral configuration. In the second patient, we closed the defect by choosing an oversized device that covered the full extent of the spiraling margins. There was wide separation of the right and left atrial discs subsequent to closure but in the absence of any residual shunting.

### Developmental Study

It is striking that in the developing mouse embryo heart, a similar space is initially found between the flap valve and the muscular rims of the oval fossa, producing an arrangement similar to the malalignment of the primary septum seen in some of our patients with incomplete atrial septation. Just before term in the mouse (E18.5), it is an easy matter to recognize the right atrial rims of the oval fossa (Figure 7). Images taken to replicate the four-chamber view show that the floor of the fossa is formed by the primary atrial septum. This has become the flap valve of the oval foramen and is anchored to the atrioventricular cushions through its attachment to the left side of the anteroinferior buttress. In contrast, the superior rim of the oval fossa is formed by the secondary atrial septum, which at this stage is a muscular bulge in the atrial roof lying well to the left of the attachment of the left venous valve and centrally above the anteroinferior buttress (Figure 8). There is marked malalignment between the secondary septum and the flap valve, reminiscent of the spiral arrangement we detected in some of our patients showing incomplete atrial septation. More dorsally, however, the rim of the fossa is an infolding between the dorsal wall of the right atrium and the wall of the pulmonary vein, the pulmonary veins opening to the left atrium of the mouse through a solitary orifice (Figure 9).

The origins of this arrangement can be traced from comparable analysis of hearts obtained from earlier stages of mouse embryo development. As early as midgestation (E10.5), when the heart remains a simple looped tube, the systemic venous tributaries have already changed their junction with the common atrial chamber from being initially symmetric to draining exclusively to the right side. This process brings the left sinus horn into the left atrioventricular groove as