A Simple Non-Invasive Method to Predict the Mitral Valve Geometric Orifice Area after Edge-to-Edge Repair

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Background and aim of the study: The edge-to-edge repair (EtER) technique consists of anchoring the free edge of the diseased leaflet of the mitral valve to the corresponding edge of the opposing leaflet. When the middle sections of the leaflets are sutured, a ‘double-orifice’ (DO) mitral valve is artificially created. The main consequence of this technique is that mitral valve geometric orifice area (MGOA) is sensibly reduced and a functional mitral stenosis might be created. The study aim was to determine, mathematically, the MGOA by using a simple non-invasive formula following an EtER, and to examine the influence of suture position on the resulting MGOA.

Methods: The Lemniscate (also called the Lemniscate of Bernoulli), which has a shape similar to the DO EtER, was used to determine the MGOA following an EtER.

Results: The reduction in MGOA following EtER was more dramatic for mitral valves with a small initial MGOA. For example, a centered suture reduced the MGOA by 54.9% for an initial MGOA of 6.41 cm²; this resulted in an increase in mean transmitral valve pressure gradient (TPG) of 340%, from 0.5 to 2.2 mmHg, corresponding to a mild mitral valve stenosis. In contrast, the reduction was up to 73.5% for an initial MGOA of 3.77 cm²; this resulted in an increase in TPG of 1,339%, from 1.3 to 18.7 mmHg, corresponding to a severe mitral valve stenosis.

Conclusion: Although the DO EtER technique appears to be effective for correcting mitral regurgitation, the significant reduction in mitral valve area may become problematic for the patient. However, this simple mathematical model may help clinicians to determine the reduction in MGOA following EtER.
ETER (DO-ETER). Consequently, in the present study the initial ellipse represented the MGOA before ETER, and the Lemniscate the MGOA after ETER (see Fig. 1).

The area demarcated by the Lemniscate is given by the following simple equation:

\[
\text{MGOA after DO-ETER} = \left(\frac{\text{Maximal MVOD before DO-ETER}}{2}\right)^2 + \left(\frac{\text{Maximal MVOD before DO-ETER}}{2} - \text{(Location of the suture)}\right)^2
\]

where MVOD is the mitral valve orifice diameter.

The location of the suture corresponds to the minimal distance between the position of the suture and the commissure (see Fig. 1). The maximal MVOD before ETER can be simply determined non-invasively using either two-dimensional (2D) or three-dimensional (3D) Doppler echocardiographic images (4).

For validation, the MGOA measured after ETER (obtained using the above formula) in two fresh ex-vivo bovine mitral valves excised from whole hearts purchased commercially, was compared with the area obtained using a standard validated image processing technique (level set method) (5,6). First, a picture of the mitral valve before ETER was taken and the MGOA was determined using this technique. The same process was then applied to the mitral valve after ETER (i.e., after the valve had been sutured).

This image processing technique has been used previously by Gaillard et al. (6) for post-processing medical images to automatically detect Doppler velocity contours. By determining the contour of the mitral orifice and knowing the real size of a pixel of the image, it was possible to calculate the MGOA.

Subsequently, in order to study the influence of the suture position on the resulting MGOA, the position of the suture was shifted from the center (50% of maximal mitral valve diameter) to the side (40% and 25% of maximal mitral valve diameter).

Table I: Mitral valve geometric orifice area (MGOA) before and after edge-to-edge repair (ETER) with a centered or shifted suture.

<table>
<thead>
<tr>
<th>Surgery/suture position</th>
<th>Bovine mitral valve 1</th>
<th>Bovine mitral valve 2</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Ex-vivo</td>
<td>Mathematical model (difference, %)</td>
</tr>
<tr>
<td>MGOA before ETER (cm²)</td>
<td>5.69</td>
<td>5.69</td>
</tr>
<tr>
<td>MGOA after ETER (cm²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centered sutures*</td>
<td>2.34</td>
<td>2.28 (2.6)</td>
</tr>
<tr>
<td>s = 50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shifted sutures*</td>
<td>2.48</td>
<td>2.37 (4.6)</td>
</tr>
<tr>
<td>s = 40%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.27</td>
<td>3.10 (5.3)</td>
</tr>
<tr>
<td>s = 25%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values in parentheses are percentages.

‘s’ is the position of the suture (as % of the maximal mitral valve orifice diameter) obtained ex-vivo in two bovine mitral valves compared to predicted values using the mathematical model.
The comparison between ex-vivo measurements and the predicted MGOA using the mathematical model was in very good agreement (see Table I), with the overall difference in terms of MGOA after EtER between the two methods being less than 6.5%.

The reduction in MGOA after EtER was more dramatic for mitral valves with a small initial MGOA (Table II). For example, a centered suture reduced an initial MGOA of 6.41 cm² by 54.9%; this in turn led to a 340% increase in the mean transmitral valve pressure gradient (TPG), as measured using the Gorlin formula (7), from 0.5 to 2.2 mmHg, which corresponded to a mild mitral valve stenosis. In contrast, reductions of up to 73.5% occurred for a small initial MGOA of 3.77 cm²; this resulted in a 1,339% increase in the TPG, from 1.3 to 18.7 mmHg, which corresponded to a severe mitral valve stenosis. For a shifted suture, the area reduction was less than for the centered suture, for a given initial MGOA (Table II). For example, in the case of the small initial MGOA of 3.77 cm², the area reduction for the shifted suture (25% of maximal mitral valve diameter) was 52%; this resulted in a 338% increase in the TPG, from 1.3 to 5.7 mmHg, which corresponded to a moderate mitral valve stenosis.

### Discussion

The significant reduction in MGOA following EtER may lead to an elevated transmitral valve pressure gradient (see Table II) and, consequently, to an increase in left atrial (LA) pressure and a greater risk of LA fibrillation. This high LA pressure can be transmitted to the pulmonary vasculature and cause pulmonary hypertension (8). The pulmonary capillary pressure at this level causes an imbalance between the hydrostatic pressure and the oncotic pressure, leading to the extravasation of fluid from the vascular tree and the pooling of fluid in the lungs (congestive heart failure, pulmonary edema) (9,10). In the case of LA fibrillation, there is a loss of the atrial contraction that plays an important role in the generation of an adequate LA pressure to maintain blood flow across the stenotic valve. Moreover, the lack of an organized atrial contraction may result in stagnant blood in the left atrium or left atrial appendage, which may lead to thromboembolism (11). Left atrial fibrillation has other deleterious effects, including an increase in the heart rate and, due to the reduction in diastolic duration, a decrease in the time available for filling of the left ventricle (12).
Study limitations

The present mathematical model had one minor limitation, namely that in the case of a healthy mitral valve with a normal annulus the mitral orifice can be considered as an ellipse, whereas in mitral valve disease the orifice and annulus are usually deformed, and the latter is no longer completely elliptical. In order to determine the influence of the approximation of the mitral orifice by an ellipse in the case of a diseased mitral valve, the difference in terms of the area between the ellipse and the deformed mitral annulus, was calculated based on 30 echocardiographic images recorded in patients with mitral regurgitation. Realization that the difference in area between the ellipse and the deformed mitral annulus was not more than 9% confirmed that any error in the mathematical formula, caused by approximating the mitral orifice before EtER by an ellipse in the case of a diseased mitral valve, would be limited.

In conclusion, the present study involved the introduction of a simple and non-invasive mathematical model to predict the resultant MGOA following EtER. It was shown that, even if the ‘double-orifice’ EtER technique seems effective for the correction of mitral regurgitation, the significant reduction in mitral valve area - and hence the occurrence of a mitral stenosis - may become problematic for the patient. In order to minimize the stenosis generated after EtER, it was preferable (when the valve lesions permitted) to shift the suture. Finally, this simple mathematical model may help clinicians to determine the extent of mitral valve area reduction after ‘double-orifice’ EtER, and thus to optimize the suture position for each patient.

References