A SIMPLE NON-INVASIVE METHOD TO PREDICT MITRAL VALVE GEOMETRIC ORIFICE AREA FOLLOWING AN EDGE TO EDGE REPAIR

Emmanuel Gaillard[a], Lyes Kadem[b], Louis-Gilles Durand[a]

[a] *Laboratory of Biomedical Engineering, Institut de Recherches Cliniques de Montréal (IRCM), University of Montreal, Montreal, Canada*
[b] *Laboratory of Cardiovascular Fluid Dynamics, Concordia University, Montreal, Canada*

INTRODUCTION

The edge to edge repair (EtER) technique has been introduced in 1991 to treat mitral[1] and tricuspid[2] regurgitation due to complex valvular lesions. The method consists of anchoring the free edge of the diseased leaflet to the corresponding edge of the opposing leaflet, just at the place of the regurgitant jet. When the middle sections of the leaflets are sutured, a "double-orifice" mitral valve is artificially created (Fig. 1b). This procedure is recommended in bileaflet prolapse (Barlow's disease), anterior leaflet prolapse, commissural prolapse and functional mitral regurgitation. The main consequence of the EtER technique is that mitral valve geometric orifice area (MGOA) is sensibly reduced and a functional mitral stenosis might be created. Predicting MGOA following an EtER is therefore important to limit left ventricular preload and avoid a mismatch between MGOA and patient's blood demand.

The purpose of this study was to determine mathematically the MGOA with a simple non-invasive formula following an EtER. This formula was validated by using *ex-vivo* bovine mitral valves.

MATERIALS AND METHODS

To determine the MGOA following an EtER, we have used the Lemniscate, also called the Lemniscate of Bernoulli. It was first described by the Swiss physician and mathematician Jacques Bernoulli in 1694 (article published in Acta Eruditorum) as a modification of an ellipse. The Lemniscate has a shape similar to the "double-orifice" EtER. So, in this study, the initial ellipse represents the MGOA before EtER and the Lemniscate the MGOA after EtER (see Fig. 1). The area demarcated by the Lemniscates is given by the following simple equation:

Mitral Valve Geometric Orifice Area following "Double-Orifice" EtER

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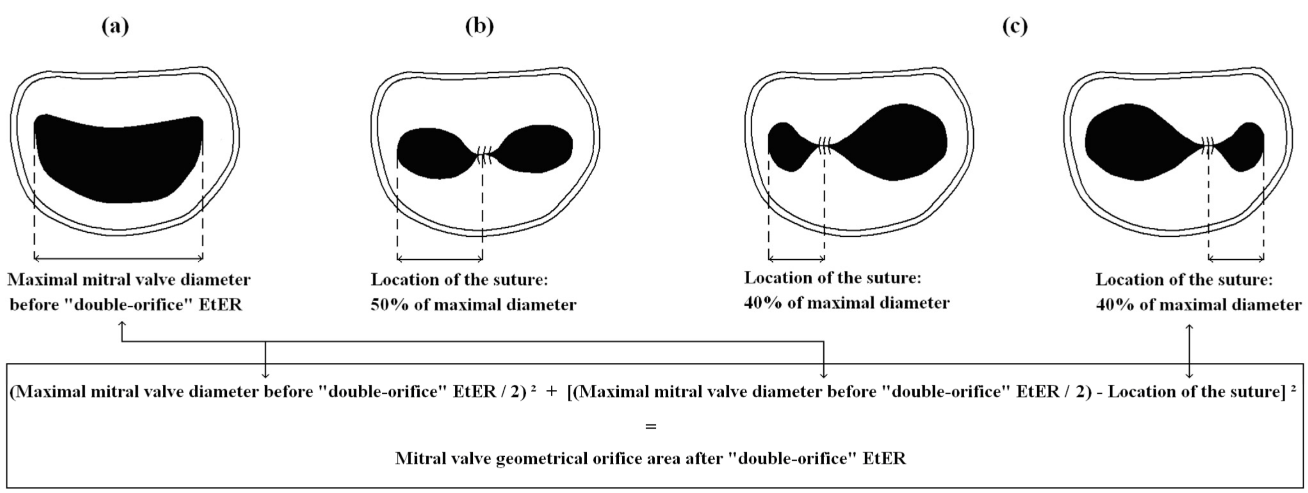

Figure 1: (a) Normal mitral valve (b) Centered "Double-orifice" edge to edge repair (EtER) technique (centered suture) (c) Shifted "Double-orifice" edge to edge repair (EtER) technique (shifted suture).

Table 1: Mitral valve geometric orifice area (MGOA) before edge to edge repair (EtER) and after EtER (with a centered or shifted suture (s is the position of the suture in % of maximal mitral valve diameter)) obtained from *ex-vivo* in two bovine mitral valves compared with the predicted values using the mathematical model.

	Bovine mitral valve 1			**Bovine mitral valve 2**	
	Ex-vivo	***Mathematical model (difference in %)***		***Ex-vivo***	***Mathematical model (difference in %)***
MGOA before EtER (cm²)	5.69	5.69		6.07	6.07
MGOA after EtER (cm²)					
Centered suture					
s = 50%	2.34	2.28 (*2.6%*)		2.71	2.59 (*4.5%*)
Shifted suture					
s = 40%	2.48	2.37 (*4.6%*)		2.83	2.68 (*5.5%*)
s = 25%	3.27	3.10 (*5.3%*)		3.63	3.40 (*6.5%*)

[Maximal Mitral Valve Diameter Before “Double-Orifice” EtER / 2]² + [(Maximal Mitral Valve Diameter Before “Double-Orifice” EtER / 2) – (Location of the Suture)]²

The location of the suture corresponds to the minimal distance between the position of the suture and the commissure (see Fig. 1b and 1c). The maximal mitral valve diameter before EtER can be simply determined non-invasively using 2D or 3D Doppler echocardiographic images.

For validation, we have compared the MGOA after an EtER obtained in two fresh *ex-vivo* bovine mitral valves excised from whole hearts bought in a commercial food store using the above formula with the area obtained using a standard validated image processing technique (level set method).[3,4] This method has already been used for post-processing medical images. Furthermore, in order to study the influence of the suture position on the resulting MGOA, we have shifted the position of the suture from the center (50% of maximal mitral valve diameter) to the side (40% and 25% of maximal mitral valve diameter).

RESULTS AND DISCUSSION

Comparison between *ex-vivo* measurements and the predicted MGOA using the mathematical model was in a very good agreement (see Table 1). The overall difference in terms of MGOA after EtER

Table 2: Effect of suture position on mitral valve geometric orifice area (MGOA) following edge to edge repair (EtER) for several initial MGOAs. The variations (in %) are the difference between the MGOA before EtER and after EtER divided by the MGOA before EtER. s is the position of the suture in % of maximal mitral valve diameter.

MGOA before EtER (cm²)	**6.41**	**6.03**	**5.65**	**5.28**	**4.90**	**4.52**	**4.15**	**3.77**
Centered suture								
s = 50%								
MGOA (cm²)	2.89	2.56	2.25	1.96	1.69	1.44	1.21	1.00
Variation	*54.9%*	*57.5%*	*60.2%*	*62.9%*	*65.5%*	*68.1%*	*70.8%*	*73.5%*
Shifted suture								
s = 40%								
MGOA (cm²)	2.98	2.65	2.34	2.05	1.78	1.53	1.30	1.09
Variation	*53.5%*	*56.1%*	*58.6%*	*61.2%*	*63.7%*	*66.2%*	*68.7%*	*71.1%*
s = 25%								
MGOA (cm²)	3.70	3.37	3.06	2.77	2.50	2.25	2.02	1.81
Variation	*42.3%*	*44.1%*	*45.8%*	*47.5%*	*49.0%*	*50.2%*	*51.3%*	*52.0%*

between the two methods was less than 6.5%.

Table 2 has shown that the reduction in MGOA following EtER was more dramatic for mitral valves with small initial geometric orifice area. For example, a centered suture reduced the MGOA by 54.9% for an initial mitral valve orifice area of 6.41 cm² whereas reduction reached up to 73.5% for the small initial mitral valve orifice area of 3.77 cm². For a shifted suture, the area reduction was less than in the case of the centered suture, for a given initial MGOA. For example, in the case of the small initial mitral valve initial orifice area of 3.77 cm², the area reduction for the shifted suture (25% of maximal mitral valve diameter) was 52% while for the centered suture, the area reduction was 73.5%. This significant reduction in MGOA following an EtER may lead to elevated transmitral valve pressure gradient and consequently to an increase in left atrial (LA) pressure and higher risks of LA fibrillation. This high LA pressure can be transmitted to the pulmonary vasculature and causes pulmonary hypertension.[5]

CONCLUSION

This study allowed us to introduce and validate a simple and non-invasive mathematical model to predict the resulting mitral geometric orifice area following an edge to edge repair. We have shown that, even if the "double-orifice" edge to edge repair technique seems to be an effective method to correct mitral regurgitation, the significant reduction of mitral valve area and so the occurrence of a mitral stenosis can become a problem for the patient. Finally, this simple mathematical model could be helpful for clinicians to determine the mitral valve area reduction after "double-orifice" EtER and to optimize the suture position for each patient.

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