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Mitral Valve Repair Strategies: Comparison Between Transcatheter and Surgical Approaches

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1. Introduction

Mitral regurgitation (MR) is one of the most prevalent valvular diseases worldwide, causing a backflow of blood during systolic closure (Nkomo et al., 2006). For patients at high surgical risk, Transcatheter Edge-to-Edge Repair (TEER) has become the most popular percutaneous treatment, offering reduced post-intervention complications compared to open-heart surgery (Harky et al., 2021). TEER is based on the Alfieri stitch surgical procedure and involves suture-like clipping of the two leaflet segments using dedicated devices. MitraClip (Abbott, USA) and Pascal (Edward LifeSciences, USA) are the only commercially available options. Despite its widespread adoption, the long-term biomechanical consequences of TEER devices, as well as their impact on diastolic ventricular efficiency, remain largely unknown. This study aims to provide a comprehensive comparison of the effect of TEER devices and the Alfieri stitch on a healthy valve leaflet function and consequences induced in ventricular diastolic filling efficiency.

2. Methods

2.1 Mitral valve development

The silicon mitral valve (MV) development and validation has been described in our previous study (Delanoë et al., 2025). Briefly, anatomical characteristics of silicon MVs were based on Lifelike MV (Lifelike BioTissue., CA) that was imaged with desktop micro-CT scanner (NanoScan PET-CT, Mediso). 3DSlicer was used to segment the MV and a 3D negative mold was created using Meshmixer (Autodesk Inc., USA) which was then 3D printed (Lulzbot Inc., USA). Two silicons (EcoFlex00-50 and DragonSkin10, Smooth-On Inc., USA) were then poured layer by layer in the 3D-printed mold mimicking mitral leaflet layers with a final thickness of 1.5 mm. Mitral chordae were inserted between two silicon layers using 10 de-braided polyester strings per valve (Gütterman GmbH, Germany) ensuring 20 tension application points covering the leaflet surface. TEER devices (MitraClip NT and Pascal Ace Implant) and Alfieri stitch were placed in A2P2 configuration and compared to a control valve (Figure 1a).

2.2 Hemodynamic testing

Silicon MVs were tested in double activation left heart duplicator system (Tanné, Bertrand, Kadem, Pibarot, & Rieu, 2010) under following physiological conditions (Stroke Volume=70 mL, Heart Rate=70 bpm, Mean Aortic Pressure=100mmHg). Blood viscosity was reproduced using a saline glycerol solution fixed at 3.9cP. Hemodynamical responses were analyzed using Continuous Wave Doppler collected by transthoracic echocardiography (iE33, Philipps Healthcare, USA). The analysis of ventricular diastolic filling patterns was done through vector flow mapping (ITEcho, Cardiac Flow Design, Japan) and by quantifying the fluid centro-rotatif vorticity length, width and area.

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2.3 Biomechanical quantification

MVs' leaflet motion was captured using two high-speed video cameras (FASTCAM Mini AX50, Photron Inc., USA). 3D digital image correlation was used to conduct strain measurements (VIC-3D, Correlated Solutions, Inc., USA). To guarantee accuracy, a double calibration was done prior to each computation. Lagrangian strains were determined across the entire leaflet surface based on the 3D dataset. The displacement of individual leaflet segments (A1, A2, A3, P1, P2, P3)(Figure1a) during systole was analyzed to assess mitral prolapse.

3. Results and discussion

3.1 Hemodynamical consequences

When compared to the control, mitral valve repair strategies led to altered hemodynamic function with higher gradients and lower orifice areas ($p<0.001$). Surgical repair techniques resulted in the lowest gradients, largest orifice areas, and lowest energy loss when compared to other repair methods (Table 1) ($p<0.001$). When analyzing ventricular flow streamlines at early and end-diastole (Figure 1), vorticity was induced by all the configurations, with the Alfieri stitch being the one inducing the greatest vorticity. The ventricular efficiency after MV repair, regardless of the approach, seemed to be significantly impacted, resulting in a greater energy loss.

3.2 Biomechanical consequences

The Alfieri stitch displayed a more homogeneous distribution of major principal strain (E1) (Figure 1, Table 1), which was comparable to the control strain distribution. On the other hand, the MitraClip and Pascal devices induced more localized strain along the coaptation line with the MitraClip associated with a significant increase in E1 ($p<0.001$). Finally, leaflet displacement in the Z direction (towards left atrium) was significantly reduced in the Pascal configuration compared to the other repair strategies ($p<0.001$).

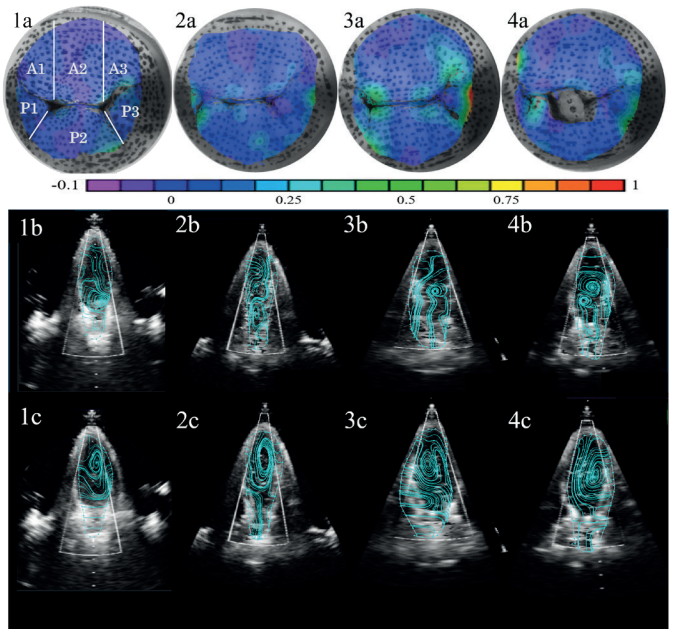

Figure 1. E1 (a) and early-diastole (b) and late-diastole flow patterns (c) induced by (1) Control Valve, (2) Alfieri approach, (3) MitraClip and (4) Pascal Device

4. Conclusions

The purpose of this study is to evaluate the efficacy of current mitral valve repair techniques by comparing their biomechanical and hemodynamic consequences to a control condition i.e on a healthy valve to eliminate possible consequences specific to mitral pathological conditions. The results suggest that the Alfieri stitch may preserve better ventricular filling and ejection efficiency while exerting less systolic strain on the leaflet surface compared to transcatheter TEER devices. Although both TEER devices demonstrated similar hemodynamic behavior, MitraClip produced the highest major principal strain (E1). Furthermore, biomechanical analysis of the leaflets showed that TEER devices generated higher strain fields, particularly along their lateral edges, whereas the Alfieri stitch resulted in a more uniform strain distribution.

Table 1. Hemodynamical and biomechanic parameters induced by the different mitral valve repair.

	MPG (mmHg)	EOA (cm^2)	GOA (cm^2)	EL (mW/m)	Z (mm)	E2	E1	C1 (mm_{-1})
Control	2.79 ± 0.17	2.71 ± 0.13	2.02 ± 0.02	0.5	0.44 ± 0.30	-0.01 ± 0.02	0.06 ± 0.04	0.09 ± 0.05
Alfieri	4.13 ± 0.19	2.15 ± 0.09	1.42 ± 0.02	4.7	0.92 ± 0.36	-0.03 ± 0.01	0.05 ± 0.02	0.14 ± 0.01
MitraClip	6.87 ± 0.21	1.63 ± 0.09	1.96 ± 0.02	7.1	0.93 ± 0.26	-0.02 ± 0.00	0.09 ± 0.03	0.13 ± 0.01
Pascal	6.29 ± 0.22	1.74 ± 0.08	1.23 ± 0.02	6.5	0.83 ± 0.31	-0.02 ± 0.00	0.06 ± 0.02	0.13 ± 0.00

Conflict of Interest Statement

Pr. Philippe Pibarot reports research grants from Edwards Lifesciences, Medtronic, and Pi-Cardia.

All other authors have no conflict of interest to disclose.

Contributor Roles

KD: Conceptualization, Methodology, Writing original draft; VS: Conceptualization, Methodology, Validation, Supervision, Writing-review & editing; PP: Funding acquisition, Validation, Supervision, Writing-review & editing; ES, LT, RR: Validation, Writing-review & editing.

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