

# The Carpentier-Edwards classic and physio annuloplasty rings in repair of degenerative mitral valve disease: A retrospective study

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## Research article

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# Abstract

## Background

Physio ring (SR) is considered an improved version of the Classic rigid ring (RR). Today, SR is more widely used in mitral valve (MV) repair. We sought to compare the long-term outcomes of repair with RR and SR in degenerative mitral valve disease.

## Methods

In a computerized registry of our institution, 306 patients had isolated MV repair with either RR (139 patients) or SR (167 patients) ring between 2005 and 2015. Fifteen of them had concomitant tricuspid valve repair. Ninety-two (30.1%) had Barlow's disease and 214 (69.9%) had fibroelastic deficiency. The patients had similar demographic and echocardiographic characteristics.

## Results

There were 4 (1.3%) operative mortalities. Mean follow-up time was  $107.4 \pm 13.2$  months. Left ventricular end diastolic and end systolic diameters significantly improved in both groups but not between groups. Survival at 10 years was 84.6% (93.1% in RR and 91.5% in SR;  $p = 0.177$ ) and 10-year freedom from recurrent  $MR \geq 2+$  was 74.5% (88.2% in RR and 86.3% in SR;  $p = 0.110$ ). Reoperations for repair failure were 8 in RR and 6 in SR. By Cox regression analysis, Barlow's disease, preoperative  $MR = 4+$  and chordal shortening were predictors of repair failure. Old age ( $\geq 70$  years), NYHA functional class IV and pulmonary artery systolic pressure ( $\geq 40$  mmHg) were predictors of poor survival by univariate analysis.

## Conclusion

Long-term outcomes of repair for degenerative MV disease with the Classic and Physio rings are comparable. Artificial chordal implantation should be used instead of chordal shortening for diseased chordae.

## Background

Mitral valve (MV) repair consists of valvuloplasty and annuloplasty with a rigid, semi-rigid or flexible ring. Annuloplasty rings reduce the mitral annulus (MA) size, prevent its further dilation and restoring proper leaflet coaptation.<sup>1</sup> The range of available annuloplasty rings is quite extensive and reflects the lack of consensus on the features of a durable and effective device. Moreover, there exist no clear principles that guide the choice of 1 type of ring over another in the clinical practice of most surgeons and so, ring selection is usually based on a surgeon's preference rather than evidence. For degenerative mitral valve disease (MVD), a balance needs to be struck between rigidity of design which aids in remodelling and flexibility which preserves the dynamic function of the MA<sup>2</sup>. In addition, the incidence of detrimental systolic anterior motion (SAM), adverse trans-mitral pressure gradient and the impact on left ventricular (LV) function must all be considered when choosing an annuloplasty device<sup>3</sup>.

Criticisms of the Carpentier-Edwards Classic rigid ring (RR) of causing SAM, left ventricular outflow tract obstruction (LVOTO) and impairment of LV function led to the development of the semi-rigid Physio ring (SR)<sup>2,4</sup>. Whilst there are so many studies that compared the short and long-term outcomes of different annuloplasty rings, to the best of our knowledge, only one randomized study compared the RR and SR<sup>5</sup>. This study aimed to compare the long-term outcomes of MV repair for degenerative MVD with a RR and SR.

## Methods

### Study Design

This is a retrospective, nonrandomized review of all patients who underwent valve reconstruction with either the annuloplasty RR or SR as the primary intervention for degenerative MVD at our institution. The study was approved by the internal Institutional Review Board with a waiver for patient consent.

### Patients

A computerized registry of patients at the Vishnevskiy 3RD Central Clinical Hospital was used to identify patients who underwent repair for degenerative MVD with/without tricuspid valve repair (TVR) between 2005 and 2015. Three hundred and six consecutive patients had repair with either RR (139) or SR (167). The degenerative MV was identified as either FED or Barlow's disease intraoperatively using the Carpentier guidelines.<sup>6</sup> Preoperative data collected included patient's age, sex, preoperative NYHA functional class, ejection fraction and degree of mitral regurgitation (MR), presence of preoperative atrial fibrillation, diabetes mellitus, and the form of degenerative MVD. Table 1.

Table 1  
Demographic data and mitral valve characteristics

Characteristics	Total	RR	SR
No. of patients (%)	306	139 (45.4%)	167 (54.6%)
Age, (mean y SD)	71.2 ± 9.2	72.8 ± 9.5	69.6 ± 8.8
Sex	233	109 (78.4%)	124 (74.3%)
Male	73	30 (21.6%)	43 (25.7%)
Female			
Atrial fibrillation	21 (6.9%)	9 (6.5%)	12 (7.2%)
MR grade	6 (2.0%)	1 (0.7%)	5 (3%)
2	147 (48.0%)	82 (59%)	65 (38.5%)
3	153 (50%)	56 (40.3%)	97 (57.4%)
4			
NYHA Functional Class	7 (2.3%)	4 (2.9%)	3 (1.8%)
I	130 (42.5%)	40 (28.8%)	90 (53.9%)
II	150 (49.0%)	84 (60.4%)	66 (39.5%)
III	19 (6.2%)	11 (7.9%)	8 (4.8%)
IV			
Diabetes mellitus	16 (5.2%)	7 (5.0%)	9 (5.4%)
PA systolic pressure ≥ 40 mm Hg	22 (7.2%)	8 (5.8%)	14 (8.3%)
Degenerative MVD (n,%)	92 (30.1%)	38 (27.3%)	54 (32.3%)
Barlow	214 (69.9%)	101 (72.7%)	113 (67.7%)
FED			
Leaflet involvement (n,%)	29 (9.5%)	7 (9.7%)	22 (13.1%)
Anterior	177 (57.8%)	104 (74.8%)	73 (43.7%)
Posterior	100 (32.7%)	28 (20.1%)	72 (43.1%)
Bi-leaflet			

RR, classic rigid ring; SR, physio semi-rigid ring; MR, mitral regurgitation; NYHA, New York Heart Association; PA, pulmonary artery; MVD, mitral valve disease; FED, fibroelastic deficiency.

<b>Characteristics</b>	<b>Total</b>	<b>RR</b>	<b>SR</b>
Leaflet condition (n,%)	275 (89.9%)	125 (89.9%)	150 (89.8%)
Prolapse	12 (3.9%)	5 (3.6%)	7 (4.2%)
Calcifications	19 (6.2%)	9 (6.5%)	10 (6.0%)
Normal			
Chordae (n,%)	184 (60.1%)	84 (60.4%)	100 (59.9%)
Rupture	70 (22.9%)	35 (25.2%)	35 (21.0%)
Elongations	52 (17.0%)	20 (14.4%)	32 (19.2%)
Normal			
Annulus (n,%)	290 (94.8%)	129 (92.8%)	161 (96.4%)
Dilated, not calcified	11 (3.6%)	7 (5.0%)	4 (2.4%)
Dilated, calcified	5 (1.6%)	3 (2.2%)	2 (1.2%)
Not dilated			
RR, classic rigid ring; SR, physio semi-rigid ring; MR, mitral regurgitation; NYHA, New York Heart Association; PA, pulmonary artery; MVD, mitral valve disease; FED, fibroelastic deficiency.			

Table 2  
Operative Data

Characteristics	Total	RR	SR	p value
Minimally invasive	36	15	21	0.122
CPB (mean min $\pm$ SD)	80.0 $\pm$ 27.1	84,9 $\pm$ 21,0	97,5 $\pm$ 31,0	0.063
Cross-clamp (mean min SD)	54.3 $\pm$ 18.0	61.1 $\pm$ 19.8	57.5 $\pm$ 12.9	0.072
Concomitant procedures	15	9	6	-
TVR	21	9	12	-
Radiofrequency ablation				
Valvuloplasty	290	133	157	-
Segmental resection leaflet	16	6	10	-
Other leaflet interventions (patch, plicature)				
Chordoplasty	70	35	35	-
Chordal shortening	13	7	6	-
Chordal transfer	57	27	30	-
Chordal replacement with PTFE sutures	52	20	32	-
Without chordoplasty				
Decalcification of the MA and leaflets	11	7	4	-
Mitral annulus reduction	215	93	122	-
-By sliding leaflet technique	10	0	10	-
- By annulus plication				
Ring size	189	92	97	-
Smaller than 34	117	45	72	-
34 or larger				
RR, classic rigid ring; SR, physio semi-rigid ring; CPB, cardio-pulmonary bypass; TVR, tricuspid valve repair; PTFE, polytetrafluoroethylene.				

## Surgical Techniques

Patients received isolated repair (with TVR in 15 cases) performed by 1 of 4 surgeons. Intraoperative echocardiography was performed in all patients before and after repair. All most all patients had median sternotomy. Moderate hypothermic ( $28 \pm 30$ C) cardiopulmonary bypass was instituted using bicaval and ascending aortic cannulation. Myocardial protection was by antegrade and/or retrograde cold blood

cardioplegia. After aortic cross-clamping, MV exposure was through an extended trans-septal incision or through a left atrial incision along Sondergaard's groove.

Prolapse of the posterior leaflet was preferentially corrected by quadrangular resection when the prolapsing segment was billowing with/without chordal rupture or elongation, to remove the diseased part of the valve as much as possible. When the remaining part of the posterior leaflet showed excess tissue (as in Barlow disease), the resection was combined with a sliding leaflet procedure including two triangular resections of the remnants of the non-prolapsing posterior leaflet. When there was no excess tissue in the remaining portion of the posterior leaflet (as in FED), a sliding procedure was performed, but without removal of tissue of the remaining posterior leaflet. Prolapse of the anterior leaflet was corrected by chordal transfer or artificial chordal implantation. Prolapse induced by chordal elongation was treated by chordal shortening. This was done by either chordal burying or papillary muscle repositioning.

A classic RR or a physio SR was then inserted for ring annuloplasty after measuring the inter-trigone distance and height of the anterior leaflet. (Fig. 1) The choice of ring was left to the discretion of the surgeon at the time of operation. After repair, the saline test and then a trans-esophageal echocardiography were performed to test for valve competence. Patients with regurgitant jet area  $> 2 \text{ cm}^2$  had a re-repair on a second pump-run. A concomitant radio-frequency ablation was performed for all patients with permanent or paroxysmal AF present for at least 6 months before surgery. There were instances of decalcification of the MA and leaflets, annulus plication and patching for perforated leaflets. The frequency with which these different techniques were used is listed in Table 2. Anticoagulation was stopped within 4 months if there was no indication for continuation.

## Follow-up

The patients were assessed at 4 weeks post-surgery in an MV clinic. Subsequent follow-up information was obtained annually either through direct clinic visits or telephone interviews. The clinic visits included a history and physical examination and electrocardiogram. Patients had echocardiography at 1, 6- and 12-months post-surgery. This was repeated every 1 to 3 years or when clinically indicated. The mean follow-up was  $107.4 \pm 13.2$  months. Valve and procedure related complications were defined and recorded according to established criteria<sup>7</sup>. Operative mortality was defined as death occurring within 30 days after surgery in or out of the hospital.

## Statistical Analysis

The Cox proportional hazards methods were used to analyse the data on recurrence of MR. For survival and follow-up of events, Kaplan–Meier techniques were used with log–rank testing. For recurrence of MR, a classic Kaplan–Meier technique was used with the first echocardiographic follow-up date demonstrating the recurrence of regurgitation as date of the event. Evaluation of multivariate relationships of potential predictive factors for late death, reoperation and  $\text{MR} \geq 2+$  was by multivariable Cox regression analysis. Variables with a univariate P value  $\leq 0.1$  or those of known biological significance but failing to meet the critical  $\alpha$  level were submitted for consideration to multivariable Cox

analysis. A stepwise technique was used to enter the selected variables in the analysis. Statistical analysis of the data was performed with IBM SPSS Statistics version 23.

## Results

### Survival and Reoperation Rate

Operative mortality was 1.3% out of which 1 patient died of sepsis with multiple organ failure, 2 died of complications of acute myocardial infarction and 1 death was associated with low cardiac output. Survival at 5 years was 94.1% and 84.6% at 10 years (Fig. 2A). It was identical in the 2 groups ( $p = 0.177$ ) and in patients with and without concomitant TVR ( $p = 0.082$ ). The causes of deaths were: heart failure (15), cardiac arrhythmias (7), chronic renal failure (5), cancer (3), stroke (4). The causes of 9 deaths were unknown. Freedom from reoperation at 5 years was 96.1% and 95.4% at 10 years (RR -97.4% and SR -98.0%;  $p = 0.167$ ). (Fig. 2B). Table 3.

Table 3  
Postoperative outcomes

n, (%)	Total	RR	SR	<i>p</i> value
Operative mortality	4 (1.3%)	1 (0.3%)	3 (1.0%)	0.085
Mortality at 5yrs	18 (5.9%)	7 (2.3%)	11 (3.6%)	0.301
Mortality at 10yrs	47 (15.4%)	21 (6.9%)	26 (8.5%)	0.177
Recurrent MR $\geq 2+$ at 5 yrs	39 (12.7%)	17 (5.6)	22 (7.1%)	0.071
Recurrent MR $\geq 2+$ at 10 yrs	78 (25.5%)	36 (11.8%)	42 (13.7%)	0.110
Reoperation at 5 yrs	12 (3.9%)	7 (3.3%)	5 (1.6%)	0.281
Reoperation at 10 yrs	14 (4.6%)	8 (2.6%)	6 (2.0%)	0.167
RR, classic rigid ring; SR, physio semi-rigid ring; MR, mitral regurgitation.				

### Immediate Surgical Result of Mitral Valve Repair

Operative success was assessed by the echocardiographic examination of MV function within the first postoperative month postoperatively. At 1 month postoperatively, 99.0% of all patients had no or trivial mitral regurgitation (RR-100%, SR-98.2%). No case of endocarditis was documented.

### Recurrence of Mitral Regurgitation

Freedom from recurrent MR  $\geq 2+$  was 99.0% at 1 month, 87.3% at 5 years, and 74.5% at 10 years (Fig. 3A). When the interval-censored Turnbull approach is used to calculate the freedom from recurrence of mitral incompetence, similar results are obtained. In all patients, freedom from failing repair was better in FED (87.4%) than in Barlow disease (55.4%) ( $p = 0.022$ ). Ten-year freedom from repair failure

(reoperation and recurrent MR  $\geq 2+$ ) from all major events (mortality, reoperation, recurrent MR  $\geq 2+$ ) were 69.9% and 54.6% respectively. (Fig. 3B).

## Clinical Outcome and Morbidity

The mean follow-up echocardiograms were 6.1 per patient, ranging from 4 to 13. During the latest postoperative follow-up period, NYHA class was recorded, 91.3% of the patients improved by at least one NYHA functional class: 72% in class I, 21% in class II, 7% in class III. Eleven patients had recurrent atrial fibrillation and 5 others received a pacemaker implantation. Freedom from thromboembolic events and/or major anticoagulant-related bleeding was 98.0% at 5 years and 96.1% at 10 years for all patients.

There were 2 cases of haemolytic anaemia in the SR group the cause of which was found to be paravalvular regurgitation at the anterolateral commissure and P2 segments of the annulus on postoperative trans-esophageal echocardiogram. Both patients had valve replacements and the anaemia resolved. Two patients had reoperation for early postoperative sternal re-wiring following fracture of the wires and sternal instability.

## Predictive Factors of Recurrent MR $\geq 2+$

Significant univariate predictors of recurrent MR  $\geq 2+$  and/or reoperation were Barlow's disease, preoperative MR = 4+ and use of chordal shortening. By multivariate analysis significant predictors of recurrent MR  $\geq 2+$  and/or reoperation were Barlow's disease, shortening chordoplasty, anterior/bileaflet involvement, leaflet and/or annular calcification. Old age ( $\geq 70$  years), NYHA functional class IV and high pulmonary artery systolic pressure ( $\geq 40$  mm Hg) were independent predictive factors for poor survival by univariate analysis. Table 4.

Table 4  
Univariate and Multivariate Cox analysis

<b>FOR REOPERATION AND MR ≥ 2+</b>			
Analysis	Hazard Ratio	CL 95%	<i>P</i> value
Univariate analysis	2.12	1.15–3.03	< 0.001
Barlow's disease	2.04	1.00-3.59	0.011
Preoperative MR = 4+	1.83	0.97–2.01	0.002
Chordal shortening			
Multivariate analysis	2.78	1.88–3.06	0.021
Barlow's disease	2.00	0.16–2.06	0.003
Chordal shortening	1.62	0.97–1.98	< 0.001
Anterior or bileaflet involvement, Leaflet and/or annular calcification.	1.43	0.10–2.01	0.012
<b>FOR SURVIVAL</b>			
Univariate analysis	1.59	1.06–2.12	< 0.010
NYHA functional class IV,	1.53	0.61-3.00	0.022
Old age (≥ 70 years) and Pulmonary artery systolic pressure (≥ 40 mm Hg)	1.78	1.08–2.18	0.002
MR, mitral regurgitation; NYHA, New York Heart Association			

## Changes in LV function

The results of this study indicated little difference in the influence on postoperative cardiac function between RR and SR. During the first week after surgery, noticeable changes that occurred in the LV were reduction in LVEF or LVEDD. These changes were considered to be related to the sudden elimination of MR, which led to afterload augmentation and volume load reduction. During the next 6 months and onwards, several gradual changes were noticed, such as recovery of LVEF and further reduction of LVEDD and LVESD. These changes may have been related to the LV remodelling process after correction of MR. Table 5.

Table 5  
Left ventricular changes.

	RR			SR		
	Preop	Postop	Last f/u	Preop	Postop	Last f/u
LVEF (%) *	59.5 ± 7.8	53.5 ± 8.5	58.1 ± 10.0	61.2 ± 9.9	57.3 ± 5.8	60.1 ± 11.0
LVESD (mm)*	47.3 ± 6.7	43.8 ± 8.8	38.5 ± 9.6	46.3 ± 9.9	42.0 ± 4.5	39.3 ± 6.1
LVEDD (mm)*	59.7 ± 10.1	47.7 ± 7.6	47.0 ± 8.2	58.6 ± 9.7	49.9 ± 10.0	49.0 ± 6.6
LAD (mm)	53.1 ± 5.2	45.0 ± 2.6	44.5 ± 6.2	52.6 ± 9.2	44.6 ± 4.4	44.9 ± 7.2

RR, classic rigid ring; SR, physio semi-rigid ring; Preop, Preoperative; Postop, postoperative (immediate); Last f/u, last follow-up; LVEF, left ventricular ejection fraction; LVESD, left ventricular end-systolic dimension; LVEDD, left ventricular end-diastolic dimension; LAD, left atrial dimension. \*All parameters were changed significantly (p< .001) between postoperative and last follow-up at serial examination by means of echocardiography. There were no significant differences between the 2 rings in each parameter (repeated-measures analysis of variance).

## Discussion

The RR is intended to remodel MA deformity, stabilize repair by reducing the tension on reconstructed valvular portions, to enhance leaflet coaptation by reducing the mitral surface area and to prevent further annular dilatation. However, it reported to reduce the dynamic annular motion affecting transvalvular blood flow in the diastole, altering ventricular/valvular interaction and impairing LV function<sup>4,8,9</sup>. It also changes the physiological saddle shape of the MA to a planar configuration. reportedly causing LVOTO by exacerbating mitral-leaflet SAM, or by narrow wing the intersection angle between the aortic and the mitral-valvular planes<sup>10</sup>.

The aforementioned drawbacks of the RR pave the way for the construction of the SR eventhough it was subsequently demonstrated that RR itself was not responsible for these complications and that the LV performance actually improved after remodelling.<sup>2,11,12</sup> Excess posterior-leaflet tissue and inadequate ring sizing (resulting in too small a ring for a too large anterior-leaflet) were identified as the culprits of LVOTO which nonetheless resolves in most cases with volume loading or by the use of beta blockers<sup>13,14</sup>.

Whilst the RR is made of titanium alloy covered by a layer of silicone rubber and polyester knit fabric, the Physio SR is constructed of Elgiloy bands separated by polyester film strips, which provide high-strength fatigue resistance and excellent spring efficiency. The latter comes in a saddle shape to conform to the bulging of the aortic root whereas the former has a kidney shape.

The SR combines remodelling by selective rigidity (a feature of the RR) at the anterior section and selective flexibility (a feature of flexible rings) at the posterior section to give a significant reduction of stress on sutures while maintaining the annulus remodelling effect<sup>15</sup>. It conforms to the configuration of the normal MA during systole, with the characteristic 3:4 ratio between the anteroposterior and the

transverse diameters. It is also reported to maintain normal trans-mitral gradient pressure with excellent mid-term results<sup>16,17</sup>. After Carpentier et al report in 1995 that the SR reduces LV end systolic and end diastolic diameters whilst improving LV function, it gained popularity among MV surgeons<sup>18</sup>. Nevertheless, there is an understanding that its decreased ability to geometrically remodel especially the posterior annulus can have a detrimental effect on late repair durability. Despite its perceived superiority, several studies reported no difference in the general outcome between rigid, semi-rigid and flexible annuloplasty rings<sup>19</sup>.

Green et al.<sup>20</sup> reported similar effects of flexible and semi-rigid rings on LV function in an animal randomized study. Manabe et al in a retrospective, propensity score matched study also demonstrated no significant difference in LVEF, LVEDD and LVESD between these two rings.<sup>21</sup> A comparison of pericardial and SR annuloplasty also reported similar clinical and echocardiographic outcomes.<sup>1</sup>

David et al. including many others reported comparable clinical and echocardiographical outcomes in flexible and rigid rings.<sup>4,9,22</sup> Shahin et al. in a randomized study reported similar morbidity, mortality and LV function in the RR and SR at 5 years of follow-up.<sup>5</sup>

Our results confirm available clinical reports of good survival, freedom from recurrent significant MR and freedom from reoperation in repair for degenerative MVD.<sup>23,24,25</sup> We recorded a low 10-year mortality (15.4%; 6.9% in RR and 8.5% in SR,  $p = 0.177$ ). Our 10-year recurrent MR  $\geq 2+$  was also 25.5% (11.8% in RR and 13.7% in SR,  $p = 0.110$ ) and so was reoperation at just 4.6% (2.6% in RR and 2.0% in SR,  $p = 0.167$ ). We associated the worse clinical outcomes (though not significant) in the SR group with the larger number of patients with Barlow's disease in this group. We also noticed a slightly higher trans-mitral pressure gradient ( $6.8 \pm 1.93$  mmHg) in the RR group than the SR group on early postoperative echocardiography which normalised on the next echocardiography.

This study in accordance with other studies indicates that recurrent MR on echocardiographic studies is more frequent than the reoperation rate indicates implying that reoperation rate is not the best parameter to estimate durability of MV repair<sup>26</sup>. A 20-year study of repair for MV prolapse concluded that the therapeutic consequences of recurrent MR may be delayed for several years after onset of recurrent regurgitation<sup>27</sup>.

At early postoperative echocardiography all patients in the RR group and 98.2% of those in SR group had no or trivial MR. Nevertheless, recurrent MR occurred at a constant rate during the following years. Similar to other studies, factors that predicted recurrent MR or reoperation were Barlow's disease, a preoperative MR = 4+ and the use of chordal shortening<sup>28</sup>. Because degenerative process progresses even after repair, to mitigate recurrence of MR, generous resection of diseased portions of the posterior leaflet is required. Furthermore, chordae with degenerative changes should be managed by artificial chordal implantation or resection with transfer.

Following Flameng and co-workers report that when recurrent MR be it minor, moderate, or severe, is considered, only about 50% of patients remain free from more than trivial MR at 7 years after repair<sup>29</sup>, valve re-repair or replacement on a CPB rerun was routinely performed when residual MR greater than trivial was noticed on intra-operative echocardiography. In cases of significant recurrent MR after hospital discharge, the institution's policy was valve replacement.

More than 40% of the patients showing significant recurrent MR have a new leaflet prolapse (mainly from the anterior leaflet) which is associated with continuing valve degeneration, retraction of repaired posterior leaflet, or even due to chordal rupture or elongation<sup>30</sup>. The MV undergoes these changes irrespective of the type of ring implanted. In the 14 cases of reoperation for repair failure in this study, there were 9 cases of rupture of initially shortened chordae, 3 cases of progressive anterior leaflet degeneration and 2 instances of annuloplasty suture dehiscence. Despite the substantial number of cases of Barlow's disease, we did not find any case of LVOTO most probably because large rings (sizes > 34 mm) were used for patients with extensive leaflet enlargement and annular widening. More patients in SR than in RR received larger rings due to higher number of cases of Barlow's disease.

When patients bearing the surgical risk (i.e., use of chordal shortening) are excluded from the analysis, our recurrence rate drops from 2.6% per year to 1.7% per year. This residual rate of 1.7% per year can be attributed to the phenomenon of valve degeneration. Recurrence rate in Barlow's disease is 6.0% per year and 2.6% per year in FED. However, the impact of surgical risk factors (like chordal shortening, inadequate leaflet resection) is so high that after correction for these techniques, the residual recurrence rate decreases to almost that of FED (2.9 vs 2.6% per year).

**Limitations.** In addition to the general limitations inherent in retrospective series, the choice of classic RR or physio SR, which was left to the surgeon may represent a bias in the distribution of baseline characteristics between groups. Preoperative and postoperative data, such as annular size, tenting height, or tenting area, were available only in a small subset of patients, precluding a meaningful conclusion. The postoperative echocardiographic examinations were not performed at a similar interval of time from surgery. However, it is unlikely that this difference had an impact on MV hemodynamic performance. Finally, the results of our study cannot be automatically applied to other annuloplasty devices.

## Conclusion

We conclude that the long-term clinical and echocardiographic outcomes of repair for degenerative MVD with the Classic and Physio rings are comparable. We advocate the use of artificial chordal implantation instead of chordal shortening for chordae with degenerative changes. We also reiterate the importance of large size annuloplasty rings for Barlow's disease to avoid the incidence left ventricular outflow obstruction.

## Abbreviations

FED- Fibroelastic deficiency

LV- Left ventricle

LVOTO- Left ventricular outflow tract obstruction

MA- Mitral annulus

MR- Mitral regurgitation

MV- Mitral valve

MVD- Mitral valve disease

RR- Carpentier-Edwards Classic rigid ring

SAM- systolic anterior motion of anterior leaflet

SR- Carpentier-Edwards Physio semi-rigid ring

TVR- Tricuspid valve replacement

## Declarations

**Ethics Approval and consent to participate:** The study was approved by the internal Institutional Review Board with a waiver for patient consent.

**Funding:** Not applicable.

**Consent for publication:** Not applicable.

**Availability of data and materials:** The datasets during and/or analysed during the current study are available from the corresponding author on reasonable request.

**Competing interests:** The authors declare that they have no competing interests.

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**Authorship:** Sidiki AI- interpretation of data, designed and substantively revised the study; Faybushevich AG- design and analysis of work; Lishchuk AN- design of the work; Koltunov AN- design of the work.

## References

1. Sidiki AI, Faybushevich AG, Lishchuk AN. A second look at autopericardial mitral annuloplasty. *Cor Vasa*. 2020;62:37–43.

2. Kreindel MS, Schiavone WA, Lever JM, Cosgrove D. Systolic anterior motion of the mitral valve after Carpentier ring valvuloplasty for mitral valve prolapse. *Am J Cardiol*. 1986;57:408–12.
3. Carpentier AF, Lessana A, Relland JY, Belli E, Mihaileanu S, Berrebi AJ, Palsky E, Loulmet DF. The “Physio-Ring”: an advanced concept in mitral valve annuloplasty. *Ann Thorac Surg*. 1995;60:1177–986.
4. David TE, Komeda M, Pollick C, Burns RJ. Mitral valve annuloplasty: the effect of the type on left ventricular function. *Ann Thorac Surg*. 1989;47:524–8.
5. Shahin GM, van der Heijden GJ, Bots ML, Cramer MJ, Jaarsma W, Gadellaa JC, de la Riviere AB, van Swieten HA. The Carpentier-Edwards Classic and Physio mitral annuloplasty rings: a randomized trial. *Heart Surg Forum*. 2005;8:E389–94.
6. Adams DH, Anyanwu AC, Rahmanian PB, Abascal V, Salzberg SP, Filsoufi F. Large annuloplasty rings facilitate mitral valve repair in Barlow’s disease. *Ann Thorac Surg*. 2006;82:2096–101.
7. Akins CW, Miller DC, Turina MI, Kouchoukos NT, Blackstone EH, Grunkemeier GL, et al. Guidelines for reporting mortality and morbidity after cardiac valve interventions. *J Thorac Cardiovasc Surg*. 2008;135:732–8.
8. Van Rijk-Zwikker GL, Mast F, Schipperheyn JJ, Huysmans HA, Brusckhe AVG. Comparison of rigid and flexible rings for annuloplasty of the porcine mitral valve. *Circulation* 1990;82(Suppl IV):58 ± 64.
9. Okada Y, Shomura T, Yamaura Y, Yoshikawa J. Comparison of the Carpentier and Duran prosthetic rings used in mitral valve reconstruction. *Ann Thorac Surg*. 1995;59:658 ± 663.
10. Schiavone WA, Cosgrove DM, Lever HM, Stewart WJ, Salcedo EE. Long-term follow-up of patients with left ventricular outflow tract obstruction after Carpentier ring mitral annuloplasty. *Circulation* 1988;78(Suppl I):60 ± 65.
11. Wan S, Lee AP, Jin CN, Wong RH, Chan HH, Ng CS, et al. The choice of mitral annuloplastic ring—beyond “surgeon’s preference”. *Ann Cardiothorac Surg*. 2015;4:261–5.
12. Bonchek LI, Olinger GN, Siegel R, Tresch DD, Keelan MH Jr. Left ventricular performance after mitral reconstruction for mitral regurgitation. *J Thorac Cardiovasc Surg*. 1984;88:122–7.
13. Mihaileanu S, Marino JP, Chauvaud S, et al. Left ventricular outflow obstruction after mitral valve repair (Carpentier’s technique). Proposed mechanisms of disease *Circulation*. 1988;78(Suppl 1):78–84.
14. Carpentier A. The SAM issue. *Le Club Mitrale Newsletter*. 1989;1:5.
15. Carpentier AF, Lessana A, Relland JY, Belli E, Mihaileanu S, Berrebi AJ, et al. The “physio-ring”: an advanced concept in mitral valve annuloplasty. *Ann Thorac Surg*. 1995;60:1177–85. Discussion 1185-6.
16. Raffoul R, Uva MS, Rescigno G, Belli E, Scorsin M, Pouillart F, et al. Clinical evaluation of the Physio annuloplasty ring. *Chest*. 1998;113:1296–301.
17. Accola KD, Scott ML, Thompson PA, Palmer GJ, Sand ME, Ebra G. Midterm outcomes using the physio ring in mitral valve reconstruction: experience in 492 patients. *Ann Thorac Surg*.

- 2005;79:1276–83. discussion 1276-83.
18. Daniel TL, Chan, Clement SW, Chiu L-C, Cheng, Timmy WK. Au. Mitral Valve Annuloplasty With CarpentierEdwards Physio Ring: Mid-term Results. *Asian Cardiovasc Thorac Ann.* 2006;14:382–6.
  19. Khamooshian A, Buijsrogge MP, de Heer F, Gru¨ndeman PF. Mitral valve annuloplasty rings: review of literature and comparison of functional outcome and ventricular dimensions. *Innovations (Phila).* 2014;9:399–415.
  20. Green GR, Dagum P, Glasson JR, Daughters GT, Bolger AF, Foppiano LE, et al. Semirigid or flexible mitral annuloplasty rings do not affect global or basal regional left ventricular systolic function. *Circulation.* 1998;98:II128–35. discussion II135-6.
  21. Manabe S, Kasegawa H, Fukui T, Tabata M, Shinozaki T, Shimokawa T, et al. Do semi-rigid prosthetic rings affect left ventricular function after mitral valve repair? *Circ J.* 2013;77:2038–42.
  22. Chung CH, Kim JB, Choo SJ, Kim KS, Song H, Song MG, Song JK, Kang DH, Lee JW. Long-term outcomes after mitral ring annuloplasty for degenerative mitral regurgitation: Duran ring versus CarpentierEdwards ring. *J Heart Valve Dis.* 2007;16:536–44.
  23. Enriquez-Sarano M, Schaff HV, Orszulak TA, Tajik AJ, Bailey KR, Frye RL. Valve repair improves the outcome of surgery for mitral regurgitation: a multivariate analysis. *Circulation.* 1995;91:1022–8.
  24. David TE, Ivanov J, Armstrong S, Christie D, Rakowski H. A comparison of outcomes of mitral valve repair for degenerative disease with posterior, anterior, and bileaflet prolapse. *J Thorac Cardiovasc Surg.* 2005;130:1242–9.
  25. Vergnat M, Jassar AS, Jackson BM, Ryan LP, Eperjesi TJ, Pouch AM, et al. Ischemic mitral regurgitation: a quantitative three-dimensional echocardiographic analysis. *Ann Thorac Surg.* 2011;91:157–64.
  26. Flameng W, Herijgers P, Bogaerts K. Recurrence of mitral valve regurgitation after mitral valve repair in degenerative valve disease. *Circulation.* 2003;107:1609–13.
  27. Mohty D, Orszulak TA, Schaff HV, Avierinos JF, Tajik JA, EnriquezSarano M. Surgery for valvular heart disease: very long-term survival and durability of mitral valve repair for mitral valve prolapse. *Circulation.* 2001;104(suppl I):I1–7.
  28. David TE, Omran A, Armstrong S, Sun Z, Ivanov J. Long-term results of mitral valve repair for myxomatous disease with and without chordal replacement with expanded polytetrafluoroethylene sutures. *J Thorac Cardiovasc Surg.* 1998;115:1279–86.
  29. Unger-Graeber B, Lee RT, Sutton MS, Plappert M, Collins JJ, Cohn LH. Doppler echocardiographic comparison of the Carpentier and Duran anuloplasty rings versus no ring after mitral valve repair for mitral regurgitation. *Am J Cardiol.* 1991;67:517–9.
  30. Adams DH, Anyanwu AC, Rahmanian PB, Abascal V, Salzberg SP, Filsoufi F. Large annuloplasty rings facilitate mitral valve repair in Barlow’s disease. *Ann Thorac Surg.* 2006;82:2096–101.

## Figures

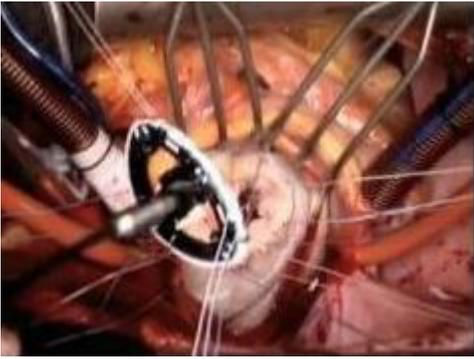


Figure 1

Insertion of a Carpentier-Edwards Physio Ring.

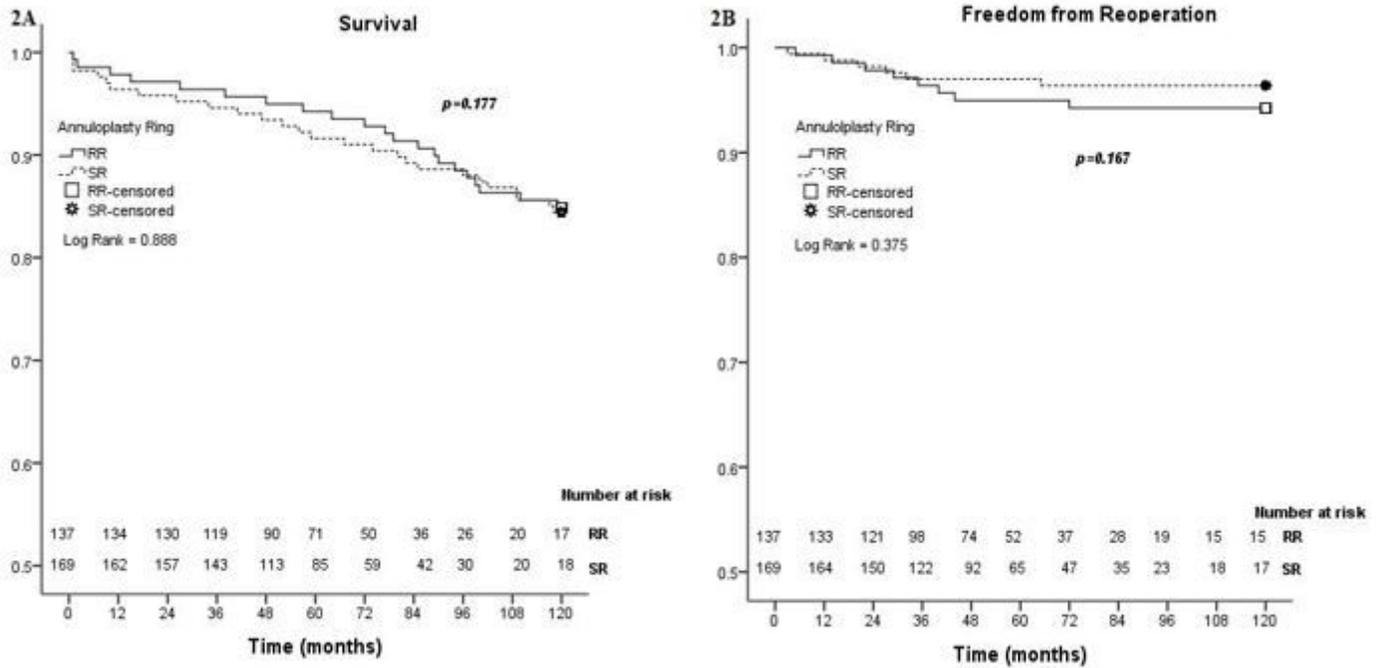
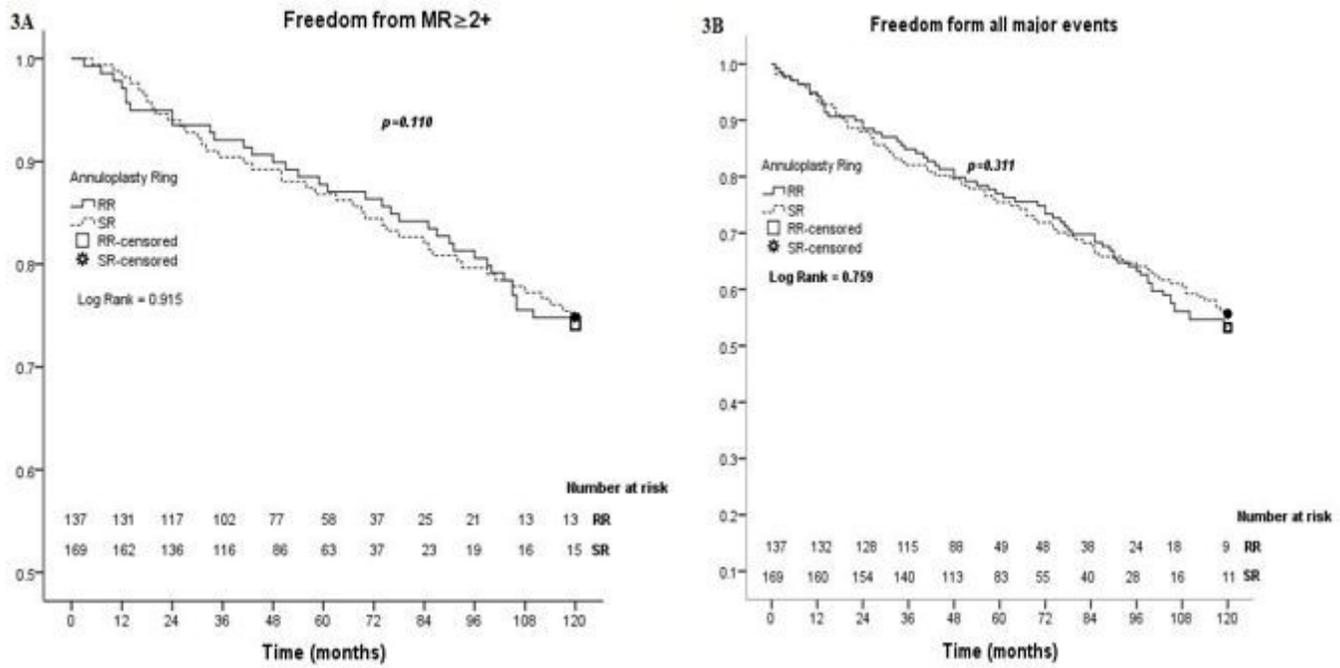


Figure 2

A- Cumulative survival at 10 years ( $p=0.177$ ); B- 10-year freedom from reoperation ( $p=0.167$ ).



**Figure 3**

A- 10-year freedom from recurrent MR $\geq$ 2+ ( $p=0.110$ ); B- Postoperative freedom from all major events such as death, reoperation or recurrent MR $\geq$ 2+ ( $p= 0.311$ ).