Aortic valve sparing surgery and influence on end-systolic diameter

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ABBREVIATIONS

AV	aortic valve
AR	aortic regurgitation
AVRep	aortic valve repair
AVR	aortic valve replacement
BAV	bicuspid aortic valve
CABG	coronary artery bypass grafting
CH	coaptation height
ECG	electrocardiogram
EF	ejection fraction
EH	effective height
EuroSCORE	European System for Cardiac Operative Risk Evaluation
FAA	functional aortic annulus
LV	left ventricle
LVEF	left ventricular ejection fraction
LVEDD	left ventricular end-diastolic diameter
LVESD	left ventricular end-systolic diameter
LVOT	left ventricle outflow tract
MV	mitral valve
MVRep	mitral valve repair
NYHA	New York Heart Association
PTFE	polytetrafluoroethylene
STJ	sinotubular junction
TTE	transthoracic echocardiography
TEE	transoesophageal echocardiography
TG	transgastric
VAJ	ventriculo-aortic juction
VSD	ventricular septal defect

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SUMMARY

Title: Aortic valve sparing surgery and influence on end-systolic diameter
Author: Ema Liu
Keywords: aortic valve repair, aortic regurgitation, ventricular function

Aortic regurgitation, also known as aortic insufficiency is a condition due to incompetence of the aortic valve or any part of the aortic valve apparatus that causes diastolic flow of the blood into the left ventricle. When it becomes symptomatic, it presents similar to heart failure symptoms such as dyspnoea on exertion, orthopnoea, angina pectoris, palpitations and fatigue. Some of the causes of the aortic regurgitation are: rheumatic fever, endocarditis, bicuspid aortic valve which is an anatomical variation that occurs in 2% of the population and unicuspid or quadricuspid that occurs in less than 1%, respectively.

Patients diagnosed with aortic regurgitation have high mortality rate if left untreated. Surgical treatment such as aortic valve replacement and aortic valve repair, can significantly increase survival rate in those patients. Aortic valve repair is commonly used on BAV and has a good success rate. There are various types of procedures that might be performed like commissurotomy, valvuloplasty, reshaping, decalcification, repair of structural support or patching. Although aortic valve repair is a more complex technique compared to aortic valve replacement but it is used commonly since it avoids unnecessary risks of thromboembolism, endocarditis and bleeding due to long-term anticoagulation therapy needed after replacement of the valve with a mechanical or biologic prosthesis.

Echocardiography is used for preoperative and postoperative follow up of the patients to assess ventricular function by measuring the left ventricular ejection fraction, left ventricular end-diastolic diameter and left ventricular-systolic diameter.

SAŽETAK

Naslov: Kirurgija očuvanja aortnog zaliska i utjecaj na promjer lijeve klijetke na kraju sistole

Autor: Ema Liu

Ključne riječi: kirurgija očuvanja aortnog zaliska, aortna regurgitacija, ventrikularna funkcija

Aortna regurgitacija, također poznata kao aortna insuficijencija je stanje nastalo zbog nesposobnosti aortnog zaliska ili bilo kojeg dijela aparature aortnog zaliska koji uzrokuje dijastolički protok krvi u lijevu klijetku. Kada postane simptomatična, prikazuje se sličnim simptomima srčanog zatajenja kao što su dispneja pri naporu, ortopneja, angina pectoris, palpitacije i umor. Neki od uzroka aortne regurgitacije su: reumatska groznica, endocarditis, bikuspidalan aortni zalisak kao anatomska varijacija koja se pojavljuje u 2% populacije i unikuspidalan i kvadrikuspidalni zalisci koji se pojavljuju u manje od 1% populacije.

Pacijenti s dijagnozom aortne regurgitacije imaju visoku stopu smrtnosti ako se ne liječe. Kirurško liječenje poput zamjene aortnog zaliska ili očuvanja aortnog zaliska mogu značajno povećati stopu preživljavanja kod tih pacijenata. Kirurgija očuvanja aortnog zaliska se obično koristi kod pacijenata s bikuspidalnim aortnim zaliskom i ima visoku stopu uspješnosti. Postoje razne vrste postupaka koji se mogu izvoditi poput komisurotomije, valvuloplastije, preoblikovanje, dekalcifikacije, popravak potpornih struktura ili krpanje. Iako je popravak aortnog zaliska složenija tehnika u usporedbi sa zamjenom aortnog zaliska, koristi se često jer se time izbjegavaju nepotrebni rizici tromboembolije, endokarditisa I krvarenja zbog dugotrajne antikoagulacijske terapije potrebne nakon zamjene zaliska sa mehaničkom ili biološkom protezom.

Ultrazvuk se koristi kao preoperativno i postoperativno praćenje bolesnika za procjenu ventrikularne funkcije mjerenjem frakcije izbacivanja lijeve klijetke te promjera lijeve klijetke na kraju dijastole i sistole.

1. INTRODUCTION

1.1. AORTIC VALVE

The aortic valve (AV) serves as a gate between the left ventricle (LV) and the systemic circulation. The main function of the AV is to prevent blood reflux without any obstacle for the blood going forward. The AV is composed of three leaflets or cusps: left coronary cusp, right coronary cusp and non-coronary cusp that together form a crescent-like configuration which gives them a unique shape. However, around 2% of the population have a condition called bicuspid aortic valve (two leaflets) which is anatomical variation of the heart.

The leaflets or cusps form a hemodynamic junction between LV and aorta. All the structures that are located distally to them are subjected to arterial pressures while those that are proximal are subjected to ventricular pressures. This trileaflet structure of the AV is the optimal solution for a low resistance valve opening[1]. The AV must open and close with minimal pressure differences between the ventricle and the aorta. In order to prevent the backflow of blood during closure, the leaflets must be perfectly aligned and should have a homogenous coaptation line. The AV apparatus consists of three different annuli or rings: the circular basal ring (surgical ring), the crown-shape ring and the circular commissural ring[2].

The aortic root (*Figure 1*) is the part of aorta which is connected to the heart and it includes the AV. It forms the left ventricular outflow tract (LVOT) which further forms a bridge between the LV and the ascending aorta. The aortic root is composed of annulus, leaflets, leaflet attachments, aortic sinuses (sinuses of Valsava), interleaflet triangles and the sinotubular junction (STJ)[2].

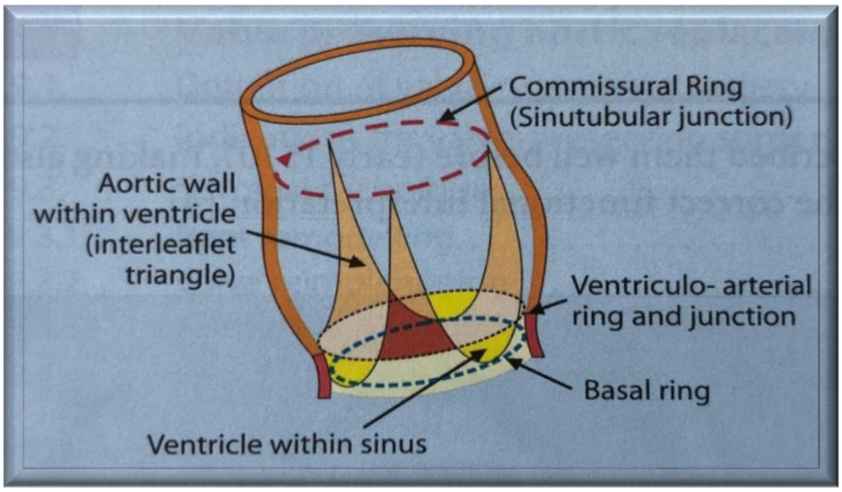


Figure 1: Diagram of the aortic root demonstrating the valve cusps attachments within the root; adapted from Hans-Joachim Schäfers[2]

During the ventricular systole, the semilunar leaflets open into aortic sinuses (sinuses of Valsava). Two of those sinuses give rise to the coronary arteries therefore naming the sinuses as the right and left coronary sinus and posterior sinus (non-coronary).

The attachments of two adjacent AV cusps meet in the area called commissures. Under each commissure lies one of the three interleaflet triangle which represent the extension of LVOT, and histologically they are made of thinned aortic wall[3]. These interleaflet triangles are the important part of proper valve function because through them, the systolic expansion of the aortic root maximizes ejection of LV and also reduces the shear stress on the cusps[4].

1.2. AORTIC REGURGITATION

Aortic regurgitation (AR), also known as aortic insufficiency (*Figure 2*) is a condition caused by incompetent aortic valves which as a result causes diastolic flow of the blood from the aorta to the LV. The pathophysiology of AR is that the pressure in the left ventricle is lower compared to the pressure in the aorta and therefore, AV cannot close completely which causes the backflow of the blood.

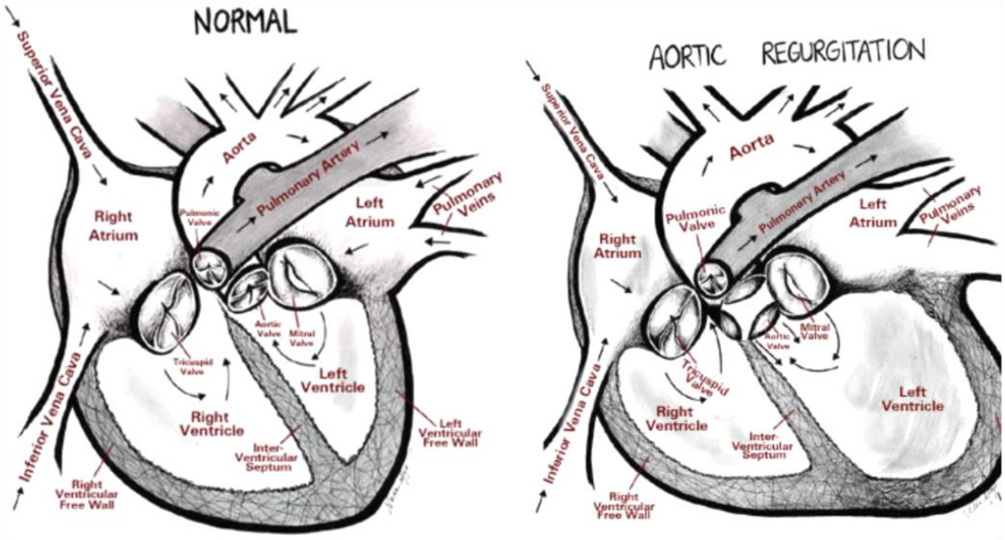


***Figure 2**:* Normal aortic valve vs. Aortic regurgitation; The Howard Gilman Institute for Heart Valve Disease [5].

AR can result from any disease that distorts the aortic leaflets or the aortic root which prevents their correct apposition. The most common causes of the AV abnormalities which result in AR are: degenerative AV calcifications, bicuspid aortic valve, infective endocarditis and rheumatic fever. The causes arising from the aorta that are linked to AR include idiopathic aortic root dilatation, Marfan's syndrome, aortic dissection and collagen vascular disease.

1.3. DIAGNOSIS AND CLASSIFICATION OF AORTIC REGURGITATION

In order to diagnose AR, transthoracic echocardiography (TTE) is used to provide the two-dimensional view of the regurgitant jet and also to measure velocity and volume of the jet. Not only that it can establish the presence of AR, but also can assess AR severity, evaluate hemodynamic consequences, delineate underlying mechanisms as well as to assess whether AV can be repaired or not [6]. However, TTE image quality is often insufficient to assess the mechanisms of AR and therefore transoesophageal echocardiography (TEE) is the method of choice. Due to the oblique orientation of the AV, it needs a multi-planar assessment to correctly align the AV plane with the ultrasonic beam. If using TTE, imaging from multiple echo windows is required. The preferred views for TTE are parasternal long and short-axis views. In case of TEE, the midoesophageal aortic valve short and long axis views, the transgastric (TG) and the deep transgastric long axis views should be combined in order to completely assess AV morphology and to analyse AR mechanism[6]. In pre-operative assessment of AR by using either TTE or TEE it is important to measure the size of aortic annulus, STJ, sinuses of Valsava, and first few centimetres of the ascending aorta (*Figure 3*). While obtaining these measurements, one can also measure the length of apposition of cusps and the effective height (EH) of the cusps. EH (*Figure 4*) is the difference in height between central free margins of leaflets and aortic insertion lines. Normal values in adult are 9-10mm and everything less than 6-7mm will indicate a degree of prolapse[7].

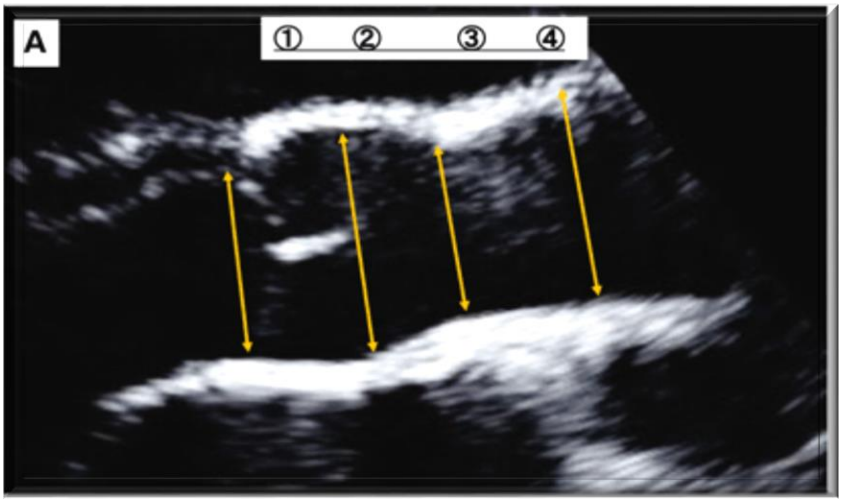


Figure 3: Image showing measurements of the aortic diameter. 1) aortic valve diameter, 2) sinuses of Valsava diameter, 3) STJ diameter, 4) ascending aorta diameter[8].

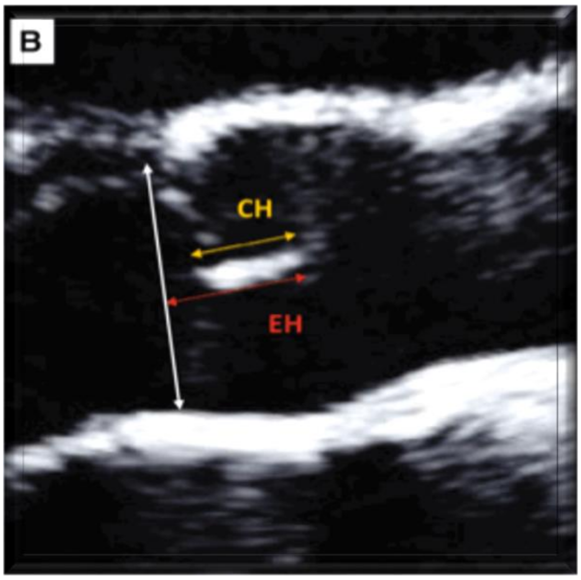


Figure 4: Coaptiation height (CH) and effective height (EH) of the aortic valve[8].

According to the American Heart Association guidelines, in order to diagnose AR it is necessary to have the following findings: colour jet width >65% of LVOT diameter, Doppler vena contracta width >0.6 cm, early termination of the mitral inflow, holodiastolic flow reversal in the descending aorta, regurgitant volume >60 ml, regurgitant fraction >50%, and increased LV size[9].

However, TTE is not the only method but also chest X-rays can assist in diagnosis of AR by showing left ventricular hypertrophy and aortic dilation together with electrocardiogram (ECG) showing left ventricular hypertrophy. In order to assess the severity of AR, cardiac catheterization is used.

Nevertheless, physical examination of the patient plays an important role in diagnosing AR. Primarily, an early diastolic murmur and the S3 heart sound (S3 gallop) can be heard in the third left intercostal space, and often radiates along the left sternal border.

AR can be classified as acute or chronic. Acute AR can be caused by infective endocarditis which causes acute perforation of the AV, and therefore a sudden increase in blood volume in the LV. Due to the volume overload, the filling pressure of the LV will increase causing the left atrial pressure to rise, too, which stimulates the development of the pulmonary oedema. This acute AR is considered a medical emergency due to its high mortality rate if left untreated. By heart auscultation, a short diastolic murmur and soft S1 can be heard. On the other hand, chronic AR develops if the patient survives the acute AR, due to the adaptation of the LV by eccentric hypertrophy and dilatation as a compensating mechanism for volume overload. Due to compensation, the filling pressures will also go back to normal. Because of all these changes, it is called a compensated phase. Patient with chronic AR can be totally asymptomatic with normal exercise tolerance. After a certain period, LV will enter a decompensated phase where the filling pressures increase again.

Treatment for both acute and chronic AR are either aortic valve replacement (AVR) or aortic valve repair (AVRep).

Carpentier wrote in 1983 that surgeons are not really concerned with the lesion but rather with the function of the valve and therefore the aim of valve reconstruction is to restore normal valve function and due to that he developed a functional approach for dealing with valve lesions in order to simplify pre-operative valve analysis. According to his classification, valves with normal leaflet motion are classified as type I, those with prolapsed leaflets as type II and restricted leaflet motion as type III[10]. This was the base for developing a functional classification of AR which is repair oriented with the aim to provide a framework for assessment of AV (*Figure 5*).

In order to understand the functional classification, one must know that aortic valve annulus is not a single structure but rather has two different components, ventriculo-aortic junction (VAJ) and sinotubular junction (STJ) and together they form what is called a functional aortic annulus (FAA).

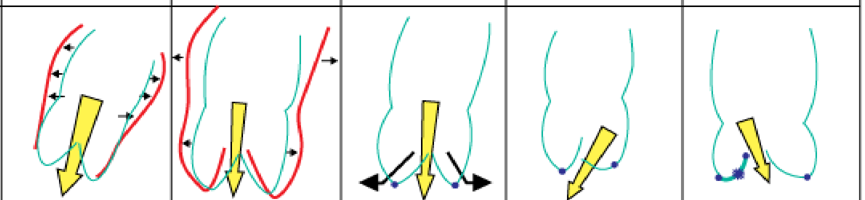
AI class	Type I Normal cusp motion with functional aortic annulus dilatation			Type II Cusp Prolapse	Type III Cusp Restriction
	Ia	Ib	Ic		
Mechanism					
Repair techniques (primary)	STJ remodeling *Ascending aortic graft*	Aortic Valve sparing: *Reimplantation* *or* *Remodeling with SCA*	SCA	Prolapse Repair • *Plication* • *Triangular resection* • *Free margin resuspension* • *Patch*	Leaflet Repair Raphé shaving Decalcification Patch
(Secondary)	SCA		STJ Annuloplasty	SCA	SCA

Figure 5: Repair-oriented functional classification of aortic regurgitation[11].

1.4. TREATMENT OF AORTIC REGURGITATION

AR treatment includes non-surgical and surgical options. Which one to choose depends on the severity of AR. Non-surgical treatment refers to various medications such as diuretics, anti-hypertensive medications, beta blockers, vasodilators as well as antibiotics and is mostly used for trivial (grade 1) to mild (grade 2) AR. On the other hand, surgical treatment is preferred for patients with moderate (grade 3) to severe (grade 4) AR. One of the most important measures used to decide whether to perform surgical treatment or not is called ejection fraction (EF). EF is a measure of the fraction of blood that the left ventricle of the heart is able to pump out to the rest of the body during one heartbeat. Surgical treatment is usually recommended when left ventricular ejection fraction (LVEF) falls below 60% or if the LV is larger than 50 mm, both of which can be determined by echocardiography[12].

For surgical treatment of AR there are two techniques: aortic valve repair (AVRep) or aortic valve replacement (AVR).

1.5. AORTIC VALVE SPARING SURGERY

Aortic valve repair (AVRep) is a surgical treatment for AV disease caused by AR without any component of stenosis. This surgical procedure helps to restore normal blood flow, reduce symptoms and therefore prolong patients' life. It is generally the first choice treatment for AV disease since it has lower risk of infection, minimize the need for anticoagulation therapy and most importantly it preserves the function and the strength of AV. In order to perform AVRep, AV cusps must be flexible and thin without calcifications. Most AVRep result in downsizing the effective orifice area with the aim to increase coaptation with the available AV cusp area[13]. The procedure itself is performed through the traditional open-heart surgery with sternotomy. Various types of repair can be involved such as: patching tears or holes in the cusps by inserting tissue, creating more support at the root or base of the AV, separation of the fused AV cusps (bicuspid, unicuspid), removing or reshaping tissue with the purpose of better valve closure and tightening the annulus by artificial ring implantation called annuloplasty.

One of the sole reason for AR is cusp perforation (*Figure 6*) which can be either iatrogenic, consequence of healed endocarditis or due to the resection of a papillary fibroelastoma. In order to correct this problem, surgeons use a simple patch of fresh or glutaraldehyde fixed autologous pericardium. This procedure is good for repairing small holes (<5 mm) and the patch should always be greater than the defect because of retraction during the healing process and after, continuous fine polypropylene suture is used for patching the defect[14].

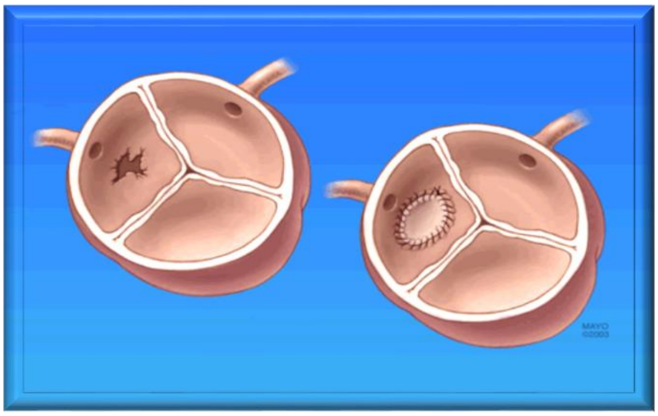


Figure 6: Illustration showing cusp perforation and subsequent patching[13].

Rheumatic disease and congenital heart disease can cause incompetent AV which can be repaired with cusp augmentation by using glutaraldehyde fixed bovine or autologous pericardium. On the other hand, prolapsed cusps with elongated free margin are repaired by plication technique along the nodule of Arantius. In order to know the degree of the shortening, other cusps and their level of coaptation should be examined[13].

Bicuspid aortic valve (BAV) can cause AR by prolapse or retraction of the conjoint cusps (*Figure 7*). The aim of the repair is to shorten the conjoint cusps and elevate the free margin of the cusp with the aim to increase coaptation with the other non-prolapsing cusp. The free margin is resected triangularly in the central fused raphe portion and the cut edges of the cusp are re-approximated with sutures in an interrupted fashion[13]. Therefore, bicuspid AVRep reshapes the AV leaflets making them open and close more completely and this would be an option for treatment of leaking valves without stenosis and narrowing[15].

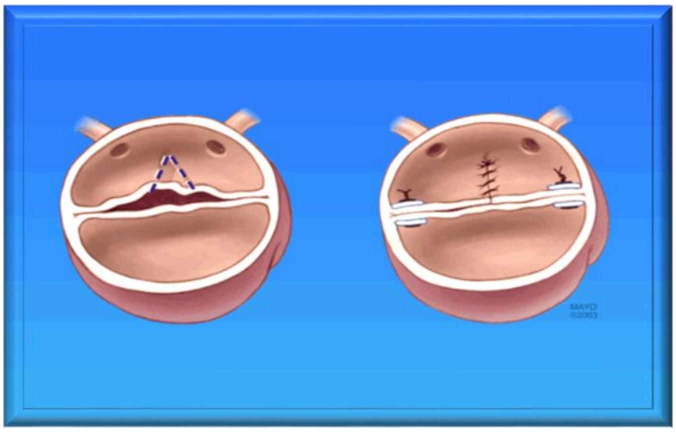


Figure 7: Illustration showing bicuspid valve with conjoint cusp prolapse and subsequent shortening [13].

Tricuspid AV prolapse is most commonly due to one or more cusp prolapse with or without fenestrations (*Figure 8*). Prolapse is usually a result of myxomatous degeneration, leading to elongation of cusp tissue in a horizontal dimension and also can be caused by pericommissural fenestrations[16,17]. These fenestrations do not cause AR directly because they are located in the coaptation zone of the cusps, but rather the thin strand that connects the free margin to the commissure may dilate or even rupture which will lead to deformation and cusp prolapse. The aim of tricuspid AVRep is to shorten the free margin in order to meet the other non-prolapsed cusps. Several ways exist for repairing this defect such as that the prolapsed cusp can be plicated near the commissure with fine polytetrafluoroethylene (PTFE) sutures [18], re-suspended with limited triangular resection with re-approximation of the cut edges with sutures or shortening of the free margin with suture by anchoring it to the commissure[13].

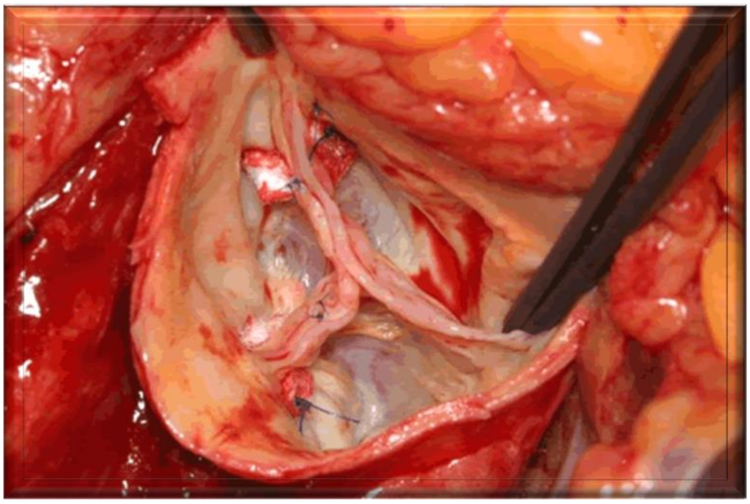


Figure 8: Intraoperative photograph illustrating complete repair of the prolapsed cusp of the tricuspid aortic valve[13].

Furthermore, most common failures with valve sparing surgical techniques are due to residual cusp prolapse which can either be primary unrecognized lesion or secondary prolapse induced by reconstruction of the aortic root[19,20]. Therefore, Schäfers et al. proposed to restore the EH of the cusps up to 8-10mm with a dedicated caliper[7]. Due to this, Lansac et al. suggested a standardized approach of AVRep which addresses both the valves and the aorta by physiological reconstruction of the aortic root with remodelling technique and resuspension of EH of the cusp together with an expansible subvalvular ring annuloplasty (CAVIAAR technique) [21].

First step of aortic cusp repair would be careful inspection of the AV. The geometric height of each cusp is measured with a ruler. Retracted cusp is one that has geometric height <17mm in tricuspid aortic valves and <20mm in BAV[14]. A polypropylene 6/0 stay suture is used to pass it through each noduli of Arantius, pulled outwards on the commissure and the two stitches at the level of noduli of Arantius are retracted in opposite direction (*Figure 9*) [22].

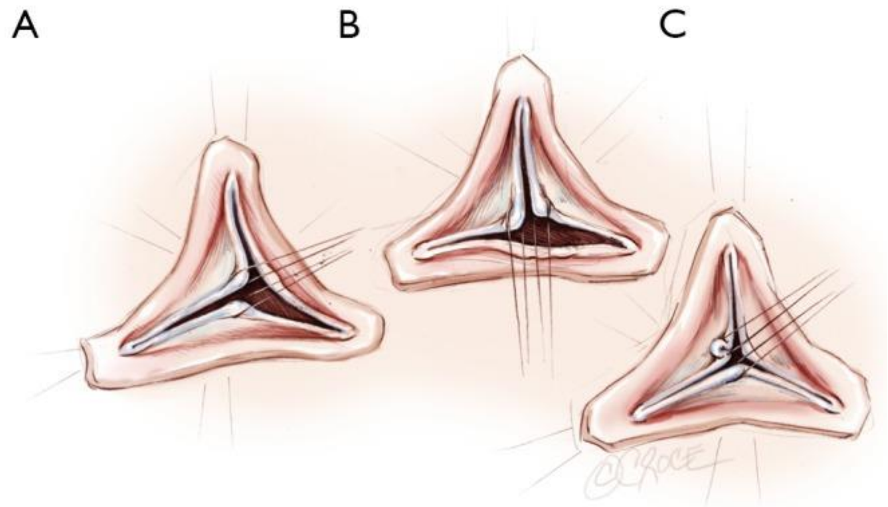


Figure 9: First step of aortic cusp repair: adjacent cusp free edges alignment[21].

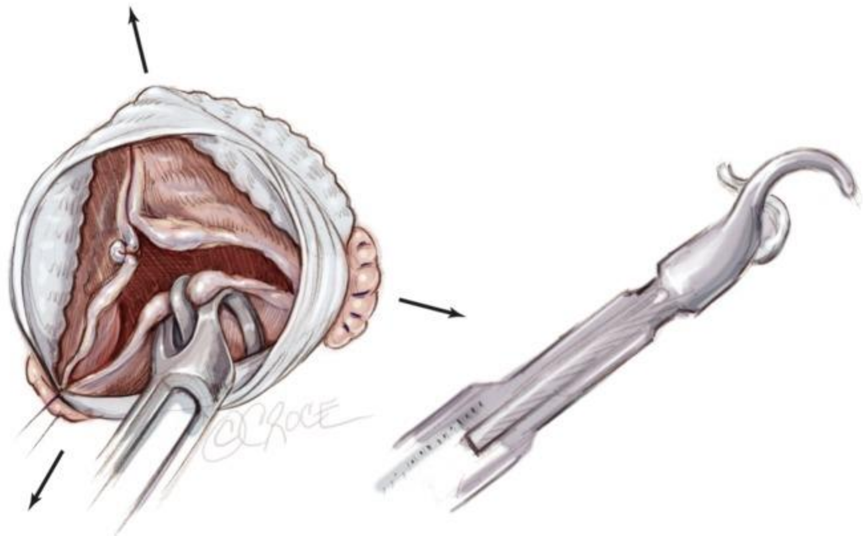


Figure 10: Second step for cusp repair: resuspension of effective height of the cusp using a caliper suggested by Schäfers et al. [21].

Furthermore, aortic root is remodelled and commissural traction sutures are placed to again measure EH of each cusp (*Figure 10*). A dedicated caliper is used for evaluation of any residual cusp prolapse and plicating stitches are added on the free margin of the leaflet until EF of the cusp is 9mm[21].

1.6. SELECTION OF PATIENTS FOR AORTIC VALVE REPAIR

Current guidelines indicate that a decision for early AVRep surgery is not yet justified without the known indicators of limited spontaneous prognosis (symptoms, LV dysfunction). However, AVRep would be an option for any type of AR with preserved cusp tissue, which means that AVRep would not be a good option for AV stenosis with an exception of congenital aortic stenosis with unicuspid AV. The presence of cusp calcifications or cusp retraction is associated with bad durability of AVRep and the AVR would be a better option. The definition of preserved cusp tissue best relies on measuring the intraoperative geometric height of the cusps[23]. *Figure 11* shows guidelines for management of AR and *Figure 12* demonstrates indications for surgery for severe AR.

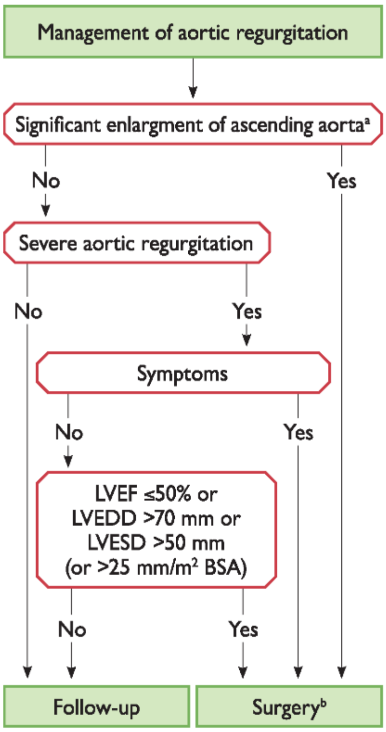


Figure 11: Management of aortic regurgitation[24].

AR: aortic regurgitation; BSA: body surface area; LVEDD: left ventricular end-diastolic diameter; LVESD: left ventricular end-systolic diameter; LVEF: left ventricular ejection fraction

Recommendations	Class	Level
A. Severe aortic regurgitation		
Surgery is indicated in symptomatic patients.	I	B
Surgery is indicated in asymptomatic patients with resting LVEF ≤50%.	I	B
Surgery is indicated in patients undergoing CABG or surgery of the ascending aorta or of another valve.	I	C
Heart Team discussion is recommended in selected patients* in whom aortic valve repair may be a feasible alternative to valve replacement.	I	C
Surgery should be considered in asymptomatic patients with resting ejection fraction >50% with severe LV dilatation: LVEDD >70 mm, or LVESD>50 mm (or LVESD >25 mm/m² BSA in patients with small body size).	IIa	B

Figure 12: Indications for surgery in severe aortic regurgitation[24].

*patients with pliable non-calcified tricuspid or bicuspid aortic valves who have type I (enlargement of aortic root with normal cusp motion) or type II (cusp prolapse)

2. AIM OF THE STUDY

Chronic AR stimulates many compensatory mechanisms in order to accommodate for pressure and volume overload caused by the regurgitating valve. In order for the LV to maintain normal left ventricular ejection fraction (LVEF), the LV hypertrophies (eccentric hypertrophy) and increases in dimension. These compensatory mechanisms allow for the disease to be asymptomatic for a period of time but when these mechanisms fail, the symptoms will appear. If not treated properly, patients with severe LV dilation and symptoms have a poor chance of survival.

For all symptomatic patients and asymptomatic patients with severely impaired LV function (LVEF≤50%, LVESD>50mm or LVEDD>70mm) a surgical intervention is recommended in the form of either aortic valve repair (AVRep) or aortic valve replacement (AVR) techniques.

The aim of this study is to evaluate changes in LV dimensions and function after AVRep and to compare the final results to AVR in order to show that AVRep is as good or even better choice than AVR in terms of left ventricular end-systolic diameter (LVESD).

3. PATIENTS AND METHODS

This is a retrospective review of patients who have had AVRep due to AR with or without aortic root aneurysm at the University Hospital Dubrava in Zagreb.

3.1. STUDY POPULATION

Between November 2014 and December 2018, 71 patients underwent AVRep surgery for treatment.

Study population characteristics were collected before the surgery and are summarized in Table 1.

The mean patient age was 52±13.9 years. There were 58 (82%) male patients and 13 (18%) female patients.

All together 32 (45%) patients had BAV and 2 patients have Marfan syndrome.

For the purposes of comparison, 27 patients were included who underwent AVR surgery as treatment in the period between December 2015 and November 2018.

Study population characteristics were collected pre-operatively and are also summarized in *Table 1*.

The mean patient age was 56±13.8 years. There were 24 (89%) male patients and 3 (11%) female patients. The number of patients with BAV was 8 (29%) and none of them have Marfan syndrome.

All together, 98 patients were included in this study.

Table 1: Study population characteristics

	AVRep (n=71)	**AVR** (n=27)	**P value**
Age	52 ± 13.9	56 ± 13.8	0.2053
Male	58 (82%)	24 (89%)	0.5448
NYHA functional class			
I	16 (23%)	6 (22%)	
II	49 (69%)	16 (59%)	
III	6 (8%)	5 (19%)	
IV	0	0	
Bicuspid aortic valve	32 (45%)	8 (29%)	0.1779
Marfan sydrome	2 (3%)	0	
Endocarditis	0 (0%)	3 (11%)	0.0192
EuroSCORE II	2,67 ± 2,01%	2,28 ± 1,76%	0.3775

All data are presented as mean or median ± standard deviation or as number (percentage).

AVRep: aortic valve repair; AVR: aortic valve replacement; NYHA: New York Heart Association; EuroSCORE: European System for Cardiac Operative Risk Evaluation

3.2. ECHOCARDIOGRAPHY

All patients underwent pre-operative transthoracic echocardiography (TTE) for the purposes of anatomic evaluation of the AV, the assessment of the diameters of aortic root (annulus, sinuses of Valsava, STJ and proximal ascending aorta), the function of the LV and its dimensions. M-mode and 2-dimensional echocardiography together with colour flow Doppler data were acquired.

Referent values for LVESD are 35-56 mm. Enlarged LVESD was defined for values >45mm.

Referent values for LVEF are 50-75%. Impaired LVEF was defined for all values that are <50%.

AR severity was assessed using the approach that includes measurement of the jet width relative to the LVOT width, magnitude of the diastolic flow reversal in descending aorta and vena contracta width (represents the smallest flow diameter at the level of AV in LVOT).

Colour-flow Doppler provides a semi-quantitative approach for assessing AR severity. The diameter and the cross-sectional area of the jet at its origin are another colour Doppler indices of the severity of AR[25]. The maximum colour jet width (diameter) is measured in diastole immediately below the aortic valve and the jet width is proportional to the size of the aortic valve defect[25].

Transesophageal echocardiography (TEE) was performed intraoperative (before and after) for both AVRep and AVR.

AR severity was classified as absent (grade 0), trivial (grade 1+), mild (grade 2+), moderate (grade 3+) and severe (grade 4+). AR grade $\geq$ 3 was considered significant. The pre-operative AR grades are summarized in *Table 2*.

Table 2: Pre-operative aortic regurgitation grades

Aortic regurgitation grade	**AVRep** (n=71)	**AVR** (n=27)	**P value**
Absent	3 (4%)	0	1
Trivial	4 (6%)	0	1
Mild	19 (27%)	1 (4%)	0.0110
Moderate	29 (41%)	19 (70%)	0.0125
Severe	16 (22%)	7 (26%)	0.7914

All data are presented as number (percentage).

AVRep: aortic valve repair; AVR: aortic valve replacement

3.3. SURGERY

All the patients were evaluated pre-operatively by the attending surgeon together with cardiologist to decide for the appropriate surgical treatment technique.

All together, 98 patients underwent aortic valve surgery, from which 71 had AVRep and 27 patients had AVR.

The most common technique used in patients with AVRep was valve sparing root replacement with Yacoub technique + valve repair combined with implantation of extra-aortic ring (Coroneo), which 40 (56%) patients underwent[26]. The second most common technique used was tubular aorta replacement + valve repair, which 18 (25%) patients had. 10 (14%) patients underwent isolated valve repair while only 1 (2%) patient had partial root replacement with valve repair.

Primary reason for AVRep after cusp analysis was prolapse of the aortic cusps solely which 20 (28%) patients had or prolapse in combination with other mechanism such as calcification or fenestration.

Therefore, the most common technique for cusp repair was by using central plicating stitches to correct the excess length[27].

68 (96%) patients had annuloplasty with external ring Extra aortic Coroneo ring.

Table 3 summarizes operative data for AVRep group while *Table 6* summarizes operative data for both AVRep and AVR groups.

Table 3: Aortic valve repair operative data

	AVRep (n=71)
Type of AVRep	
Valve sparing root replacement (Yacoub) + valve repair	40 (56%)
Valve sparing root replacement (AV re-implantation (David) repair) + valve repair	2 (3%)
Tubular aorta replacement + valve repair	18 (25%)
Isolated valve repair	10 (14%)
Partial root replacement (1-2 sinus) + valve repair	1 (2%)
Cusp analysis	
Prolapse	20 (28%)
Retraction	1 (2%)
Calcification	3 (4%)
Fenestration	7 (10%)
Normal	19 (27%)
Prolapse + calcification	11 (16%)
Prolapse + fenestration	5 (7%)
Fenestration + calcification	1 (2%)
Unknown	4 (6%)
Cusp repair	
Central placating stitches	44 (62%)
Decalcification	2 (3%)
Central placating suture + running suture	5 (7%)
Central placating suture + decalcification	8 (11%)
No repair	8 (11%)
Annuloplasty	68 (96%)
Additional procedures	14 (20%)

All data are presented as number and percentage.

AVRep: aortic valve repair

3.4. FOLLOW UP

Echocardiography was performed postoperatively (within 7 days from the surgery) by the cardiologists in University Hospital Dubrava and follow up every 6 months after surgery for 2 years by individually chosen cardiologists. LVESD and LVEF were measured and compared to the values obtained at the pre-operative and immediate post-operative echocardiographic evaluation.

None of the patients died during the surgery and all patients were still alive during the period when this paper was written.

3.5. STATISTICAL ANALYSIS

All continuous variables are presented as mean ± standard deviation or median. Categorical variables are presented as counts and percentages. Fisher's exact test and student t-tests were used for comparison of continuous variables when appropriate.

All statistical analyses were performed using Microsoft Excel version 15.11.2 software.

Values of $p<0.05$ were considered statistically significant, while values of $p<0.01$ highly significant[28].

4. RESULTS

4.1. PREOPERATIVE AND OPERATIVE DATA

Pre-operative clinical characteristics of patients undergoing either AVRep or AVR were comparable (*Table 1*). The mean age of patients at surgery was similar between the two groups (AVRep=52±13.9 vs AVR=56±13.8, p=0.2053) as well as the percentage of male patients (AVRep=82% vs AVR=89%, p=0.5448). There was higher percentage of patients with BAV in AVRep compared to AVR (AVRep=45% vs. AVR=29%, p=0.1779).

There was no significant difference comparing predictive operative mortality calculated by EuroSCORE II (EuroSCORE II: AVRep=2,67±2,01% vs AVR=2,28±1,76%, p=0.3775) scoring system. More patients with AR as a consequence of endocarditis were in AVR group (3 patients) compared to AVRep group (0 patients). 2 patients in AVRep group had AR as a consequence of Marfan syndrome compared to 0 patients in AVR group.

Tables 4 summarizes operative data for both AVRep and AVR groups. None of the patients died in the operative room during the surgery. AVRep was considered in 7 (26%) patients before they underwent AVR.

The difference between cross clamp time and pump times was significant between two groups (cross clamp time: AVRep=111,1±24,9 vs. AVR=80,7 ± 36,9, p<0.05; Pump time: AVRep=146,1±32,2 vs. AVR=116,9 ± 59,4, p<0.05).

7 (10%) patients who underwent AVRep had concomitant coronary artery bypass grafting (CABG), 4 (6%) patients had concomitant mitral valve (MV) repair and 5 (7%) patients had aortic hemi-arch replacement done in addition to AVRep while 2 (7%) patients had concomitant CABG, 3 (11%) patients had MVRep, 2 (7%) patients had hemi-arch replacement and 4 (15%) patients had ventricular septal defect (VDS) closure in AVR group.

Table 4: Operative data

	AVRep (n=71)	**AVR** (n=27)	**P value**
Cross clamp time (min)	111,1±24,9	80,7 ± 36,9	0.0005
Pump time (min)	146,1±32,2	116,9 ± 59,4	0.0024
Type of AVR			
Root + valve		14 (52%)	
Isolated valve		11 (41%)	
Tubular aorta + valve		2 (7%)	
Intention to repair		7 (26%)	
Additional surgical procedures			
CABG	7 (10%)	2 (7%)	1
Aortic hemiarch	5 (7%)	2 (7%)	1
VSD closure	0	4 (15%)	0.0049
MVRep	4 (6%)	3 (11%)	0.3902

All data are presented as number (percentage).

AVRep: Aortic valve repair; AVR: aortic valve replacement; CABG: coronary artery bypass grafting; VSD: ventricular septal defect; MVRep: mitral valve repair

4.2. ECHOCARDIOGRAPHY

Echocardiographic data were obtained in pre-operative, post-operative and follow up period. *Table 5* and *Table 6* summarizes post-operative and follow up AR severity grades, respectively. *Figure 12* demonstrates how severity grades of AR changed during the three periods mentioned above. AR severity grades were comparable among both groups regarding pre-operative grades 0 (absent), I (trivial) and IV (severe). However, there is a high significance ($p=0.01$ for both) between the two groups in pre-operative period regarding grades II (mild) and III (moderate). Regarding post-operative AR severity grades in both groups it was comparable for patients who had absent, mild, moderate (only 1 patient in AVR group) and severe AR. However, there is a statistical significance between the two groups for patients in post-operative period, meaning that 12 patients in AVRep group and none of the patients in AVR group had trivial AR ($p<0.05$). During follow up period, AR in AVRep group remained absent for 29 (41%) patients, trivial for 12 (17%) patients, mild for 5 (7%) patients, moderate for 1 patient and severe for one patient while in AVR group 13 (48%) patients doesn't have AR anymore and only 1 (4%) patient has trivial AR.

Table 7 summarizes echocardiographic parameters measured pre-operatively, post-operatively and at follow up appointments. Both pre-operative LVESD and LVEF were comparable between two groups. Mean pre-operative LVESD in AVRep was 41,3±9,4mm and in AVR group 39,9±7,1mm ($p=0.5$). In both groups we can notice a decrease in post-operative LVESD (AVRep=38,2±8,0mm vs AVR=39,8±8,0mm, $p=0.4$), which further decreased at follow-up in AVRep group (36,2±5,8mm) while it slightly increased in AVR group (40,5±8,9mm) and is considered significant ($p=0.0042$).

LVEF decreased significantly in both groups in immediate post-operative period due to the acute correction of volume overload. However, at follow-up, LVEF increased in both groups, but more in AVRep group (AVRep=61,5±7,6mm vs AVR=53,3±12,3mm, $p<0.01$).

Figure 13 and *Figure 14* illustrates how LVESD and LVEF changed over time in both groups, respectively.

Table 5: Post-operative aortic regurgitation grades

Aortic regurgitation grade	**AVRep** (n=71)	**AVR** (n=27)	**P value**
Absent	54 (76%)	24 (89%)	0.2609
Trivial	12 (17%)	0	0.0330
Mild	3 (4%)	0	0.5589
Moderate	0	1 (4%)	0.2755
Severe	0	0	1

All data are presented as number (percentage).

AVRep: Aortic valve repair; AVR: aortic valve replacement

Table 6: Follow up aortic regurgitation grades

Aortic regurgitation grade	**AVRep** (n=71)	**AVR** (n=27)	**P value**
Absent	29 (41%)	13 (48%)	0.6483
Trivial	12 (17%)	1 (4%)	0.1051
Mild	5 (7%)	0	0.3183
Moderate	1 (1%)	0	1
Severe	1 (1%)	0	1

All data are presented as number (percentage).

AVRep: Aortic valve repair; AVR: aortic valve replacement

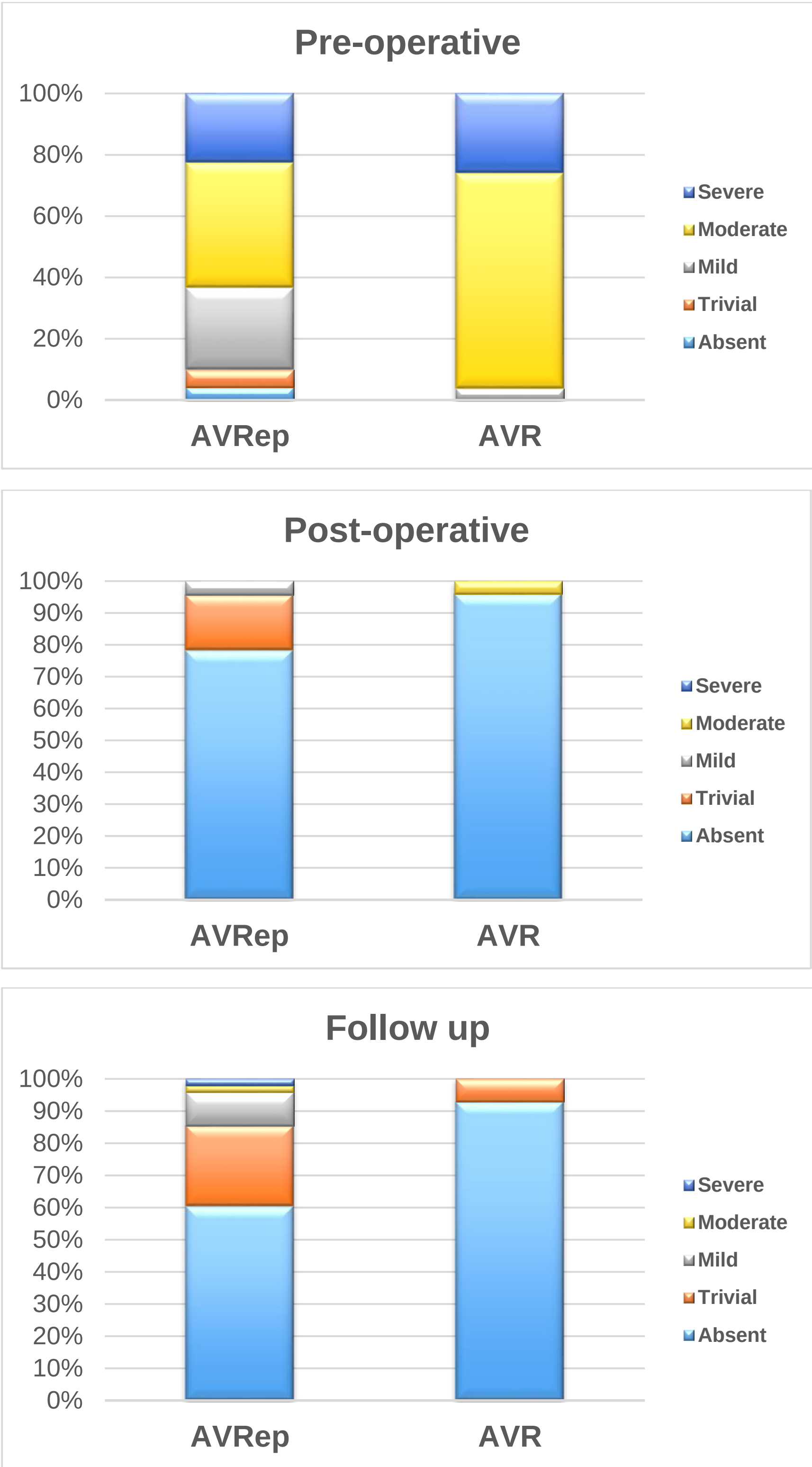


Figure 12: Aortic regurgitation severity grades pre-operative, post-operative and during follow up. Data are displayed as percentages per group. AVRep: aortic valve repair; AVR: aortic valve replacement

Table 7: Echocardiographic data for left ventricular end-systolic diameter and left ventricular ejection fraction

	AVRep (n=71)	AVR (n=32)	P value
LVESD (mm)			
Pre-operative	41,3±9,4	39,9±7,1	0.4546
Post-operative	38,2±8,0	39,8±8,0	0.3498
Follow up	36,2±5,8	40,5±8,9	0.0042
LVEF (%)			
Pre-operative	59,1±8,5	57,3±9,6	0.3419
Post-operative	56,0±8,8	51,8±8,9	0.0277
Follow up	61,5±7,6	53,3±12,3	0.0001

All data are presented as mean ± standard deviation.

AVRep: aortic valve repair; AVR: aortic valve replacement; LVESD: left ventricular end-systolic diameter; LVEF: left ventricular ejection fraction

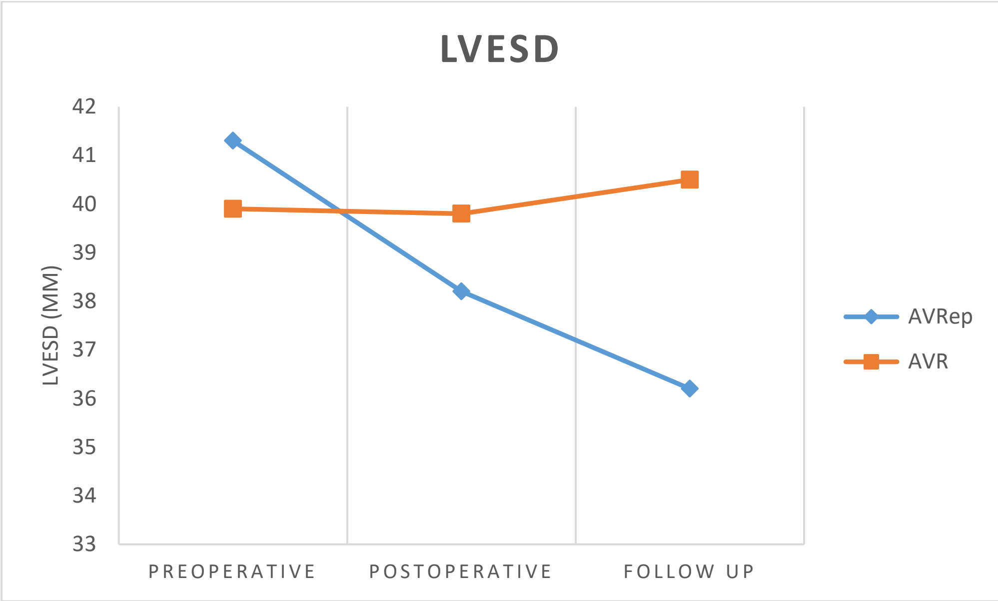


Figure 13: Left ventricular end-systolic diameter over time in aortic valve repair compared to aortic valve replacement. Data are displayed as estimated means. LVESD: left ventricular end-systolic diameter; AVRep: aortic valve repair; AVR: aortic valve replacement

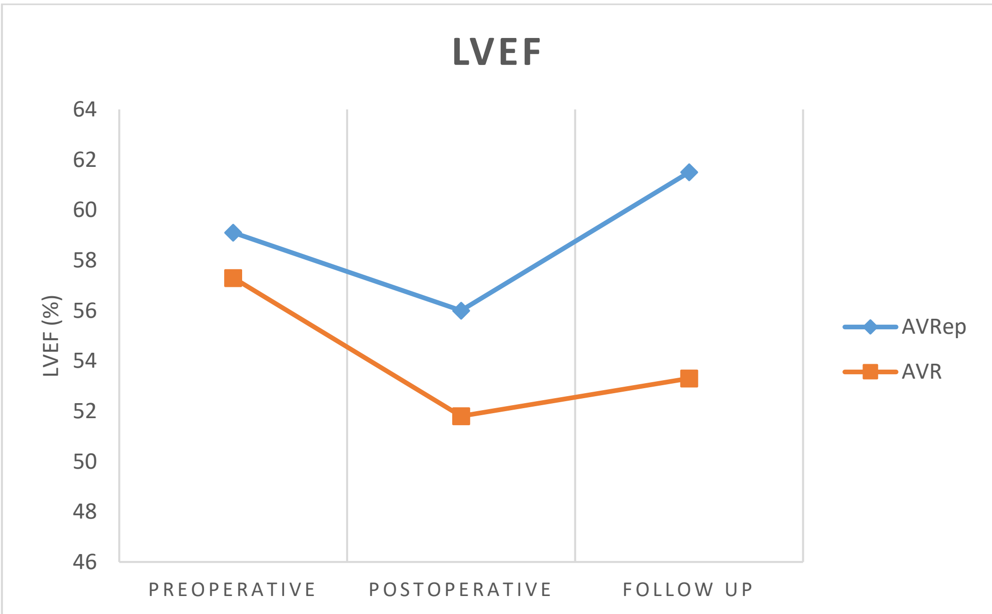


Figure 14: Left ventricular ejection fraction over time in aortic valve repair compared to aortic valve replacement. Data are displayed as estimated means. LVEF: left ventricular ejection fraction; AVRep: aortic valve repair; AVR: aortic valve replacement

5. DISCUSSION

The study was performed to see the effects of AVRep on LVESD post-operatively and at follow up and to compare it to AVR to see whether it is a better option for treatment of AR or not. Immediately post-operatively, significant decrease in LVESD and LVEF was noted in AVRep and AVR group. However, LVESD further increased at follow up in AVRep group while it significantly increased in AVR group. LVEF significantly increased at follow up more in AVRep group compared to AVR group.

According to the results, there is no doubt that AVRep surgical techniques are great alternatives to AVR in order to avoid unnecessary risks of prosthetic valves such as thromboembolism, infection, endocarditis and other haemorrhagic events caused by long-term therapy with anticoagulants.

However, when making a decision of sparing the AV leaflets that are damaged from long-term AR instead of simply replacing them with biologic or mechanical valves, there is always a risk of failing to restore their normal competence and therefore failing to remove LV volume overload.

Furthermore, not all AVs can be repaired and sometimes it is harder to do AVRep than AVR. In order to decide which surgical procedure to perform on the damaged AV, there are few things to consider such as: the severity of AV disease, the age of the patient and overall health and also whether patient needs more than one heart surgery for correction of another heart problem because in that case both conditions can be treated at once.

Like any surgical procedure, AVRep carries its own risk factors which include bleeding, infection, stroke, blood clots, heart rhythm abnormalities and even death. The risks depend on the overall health of the patient, the type of the procedure and the surgical team that performs the surgery.

AR causes left ventricular volume overload on the heart which causes LV to remodel in order to compensate. Chronic AR is usually relatively well compensated by LV remodelling and is asymptomatic for a significant amount of time. However, if chronic AR is left untreated, over time the compensating mechanism will fail and LVEF will decrease which will cause symptoms to appear. These patients have poor survival rate if they are not treated surgically.

In this study, I have made a further insight into functions of the LV by analysing LVESD and LVEF. AVR data were used to compare the data between two groups in order to show whether results after AVRep are comparable to results after AVR. As stated before, both groups had a decrease in LVESD and LVEF post-operatively due to acute correction of volume overload, but LVESD further decreased in AVRep group, while it increased in AVR group and LVEF increased in both groups at follow up, but more in AVRep group.

The limitations of this study should be noted. First, this is a retrospective and non-randomized study. Second, there was an insufficient number of AVR patients for comparison since AVRep was more commonly performed and it might have had some influence on calculated p values. Third, there was a big loss due to follow up since it was hard to obtain all the data because of lack of patients' participation since some of them did not show up for their appointments and therefore were not reachable.

6. CONCLUSION

It is important to decide whether to use a conservative approach to repair the regurgitant valve or to simply replace it with a mechanical or biologic prosthesis. There is a significant risk of failure in restoration of normal coaptation of the valve leaflets which would lead to potential reoperation. It is known that AVR is technically easier to perform and reproducible than AVRep techniques but carries its own risks.

Over the past 20 years there has been a great success in mitral valve repair (MVRep) which has greatly influenced the progression of AVRep techniques. Many risk factors for potential AVRep failure have been identified over the years and therefore, various techniques have been proposed to approach them. Aortic annuloplasty with resuspension of EH of the cusp are key steps for a reproducible AVRep[21].

By comparing AVRep with AVR techniques has led to a conclusion that survival rates are similar but AVRep is linked to much lower rates of complications such as thromboembolism, endocarditis and bleeding events[29,30].

This retrospective study showed that influence of AVRep on LVESD and LVEF is comparable and even better than AVR techniques especially after follow up of the patients. The presence of intact fenestration, BAV or limited calcification is not a contraindication for AVRep as many of the patients in this study had calcified cusps.

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9. BIOGRAPHY

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