Medizinische Fakulität

der

Universität Duisburg-Essen

Aus der Abteilung für Thorax- und Kardiovasuläre Chirurgie

COMPARISON OF MID-TERM HEMODYNAMIC PERFORMANCE BETWEEN THE BIOVALSALVA AND THE BIOINTEGRAL VALVED CONDUITS AFTER AORTIC ROOT REPLACEMENT

I n a u g u r a l - D i s s e r t a t i o n
zur
Erlangung des Doktorgrades der Medizin
durch die Medizinische Fakultät
der Universität Duisburg-Essen

vorgelegt von

Ayman Abdul Wahab Abdullah Raweh

aus Sanaa, Jemen

2020

DOI: 10.17185/duepublico/75289
URN: urn:nbn:de:hbz:465-20220224-090012-7

Dekan: Herr Univ.-Prof. Dr. med. J. Buer

1. Gutachter: Herr Prof. Dr. med. D. Wendt

2. Gutachter: Herr Prof. Dr. med. H. Eggebrecht

3. Gutachter: Herr Prof. Dr. med. A. Böning

Tag der mündlichen Prüfung: 27. Oktober 2020

PUBLICATIONS

- Presented at the 29th Annual Meeting of European Association for Cardio-Thoracic Surgery, October 3-7, 2015, Amsterdam, The Netherlands.

- Published in the journal of 'Interactive Cardiovascular and Thoracic Surgery' in July 2016.

  Wendt, D., Raweh, A., Knipp, S., El Gabry, M., Eißmann, M., Tsagakis, K., Thielmann, M., Jakob, H., Benedik, J. (2016): Comparison of mid-term haemodynamic performance between the BioValsalva and the BioIntegral valved conduits after aortic root replacement. Interact Cardiovasc Thorac Surg. 23(1), 112-7.

  https://www.ncbi.nlm.nih.gov/pubmed/27048273

  http://icvts.oxfordjournals.org/content/23/1/112.long

Contents

	Page
1. INTRODUCTION	**06**
1.1. Anatomy	07
1.2. Aim of the study	10
2. MATERIALS AND METHODS	**11**
2.1. Study protocol	11
2.2. Conduit characteristics	13
2.2.1. BioValsalva™	13
2.2.2. BioIntegral™	14
2.3. Operative technique	15
2.4. Echocardiography	16
2.5. Statistics	16
3. RESULTS	**18**
3.1. Patient population	18
3.2. Outcomes at 30 days	21
3.3. Follow-up outcomes and survival	22
3.4. Echocardiographic outcomes	24
4. DISCUSSION	**27**
5. LIMITATIONS	**32**
6. CONCLUSION	**34**
7. REFERENCES	**35**
8. APPENDIX	**41**
8.1. List of Figures	41
8.2. List of Photos	41

8.3. List of Tables 41
8.4. List of abbreviations 42

9. ACKNOWLEDGMENT 43
10. CURRICULUM VITAI 44

1. INTRODUCTION

Aortic valve disease is the third most common cardiac disease after hypertension and coronary artery disease and is currently the most common valve disease in the advanced age. Aortic valve diseases include stenosis and insufficiency. If the aortic root is dilated from a chronic aneurysm or acute dissection, then both the aortic valve and the ascending aorta should be replaced. This operation, which involves a composite graft to replace the aortic valve, aortic root and ascending aorta, with re-implantation of the coronary arteries into the graft is called the Bentall procedure (Freeman et al., 2004; Baumgartner, 2003; Zehr et al., 2004; Vahanian et al., 2012; Sievers and Misfeld, 2010). This procedure was originally described by Hugh Bentall and Antony De Bono in 1968 and used a mechanical valve. The modified Bentall procedure has become the gold standard in treating patients with pathology in the ascending aorta/aortic root combined with the aortic valve if valve-sparing procedures are not possible (Di Bartolomeo et al., 2008; Etz et al., 2007; Oka et al., 20211; Bentall and De Bono, 1968).

The most important drawback of using a mechanical valve is the need for permanent anticoagulation therapy, which has well known complications such as the risk of bleeding in a trauma or an emergency operation. Due to these complications, there was a need to develop biological valved conduits, particularly for the elderly and very young active patients. The benefit of biological valved conduits is avoiding permanent anticoagulation therapy; the patient is given an anticoagulation therapy for a specific period of time and after that only antiplatelet

therapy is needed. The main disadvantage of biological valved conduits is the uncertainty about their long-term function. As a result of the slow degenerative changes that cause calcification of the biological cusps, the conduits can lose their proper function, leading to structural valve deterioration. Moreover, significant changes in the biological valved conduits with clinically relevant dysfunction necessitate a reoperation (Dominik and Zacek, 2010; Brown et al., 2009; Chaikof, 2007; Nishimura et al., 2014; McClure et al., 2010; Slaughter and Jweied, 2007).

1.1. Anatomy

The aortic valve separates the left ventricle outflow tract from the aorta. It consists of three semilunar cusps (left, right and noncoronary), thus it is normally tricuspid. These cusps are attached to three aortic bulges called the sinuses of Valsalva, named after the Italian anatomist Antonio Valsalva (Figure 1). The coronary arteries originate from two of these three sinuses and therefore, they are named the left coronary sinus, the right coronary sinus and the noncoronary sinus (Figure 2). At the base of the sinuses of Valsalva, the ventricular muscle is partly incorporated. The sinus wall is made up of the aortic wall even though it is thinner than the native aortic wall. The areas that consist of the two cusps attached together are called commissures. The area between the left and right coronary cusps is the intercoronary commissure; the area between the right coronary cusp and the noncoronary cusp is the anterior commissure and the area between the noncoronary cusp and the left coronary cusp is the posterior commissure. The

membranous septum is just below the anterior commissure and there lies the bundle of His. The subaortic extension of calcification of the aortic valve may involve this area and it may cause a heart block. The aortic valve opens and closes in a passive way with minimum differences in pressure between the aorta and the left ventricle. When the aortic valve closes, this passive mechanism prevents the backflow of blood from the aorta to the left ventricle by perfectly aligning the cusps (Charitos and Sievers, 2013; Mihaljevic et al., 2008; Baumgartner, 2003).

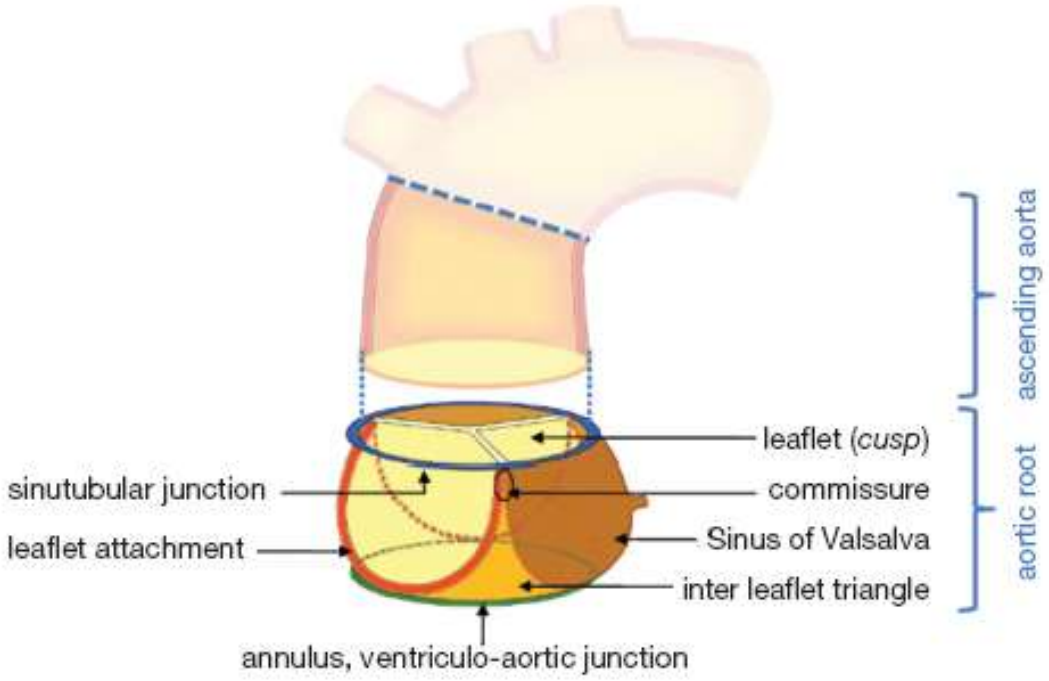

Figure 1. Proposed nomenclature for the aortic root components (adapted from Sievers HH, Schmidtke C. A classification system for the bicuspid aortic valve from 304 surgical specimens. J Thorac Cardiovasc Surg 2007;133:1226-33.)

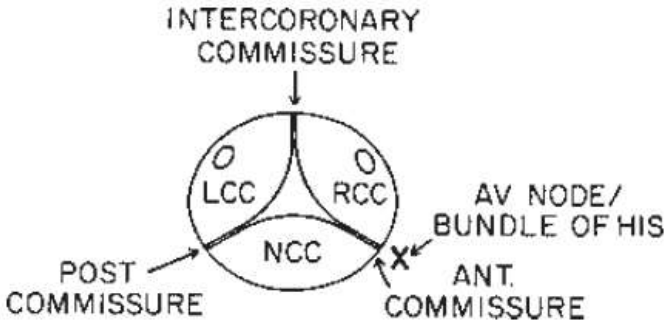

Figure 2. Aortic valve anatomy. (Baumgartner F. Valvular Heart Disease. Cardiothoracic surgery. 3rd Ed., Landes Biosciences, 2003: 6: S. 89-122)

The distal part of the sinuses of Valsalva, together with the commissures, form a tubular structure called the "sinotubular junction", which separates the aortic root from the aorta (Figure 1). Although the word annulus indicates the presence of a circular structure, there is no anatomical or a histological evidence of the presence of an annulus. The circular structure indicated by the nadirs of the leaflets is difficult to define as an annulus because of the absence of anatomical or histological evidence. Nevertheless, the popularity of the term "annulus" may originate from the fact that this is the area with the smallest diameter in the course of blood flow from the left ventricle to the aorta and is the area where the prosthetic valve sizer fits and defines the size of the prosthesis (Charitos and Sievers, 2013; Mihaljevic et al., 2008).

1.2. Aim of the Study

Currently, many biological valved conduits exist in the market and most have been evaluated. One of the biological valved conduits is the BioValsalva™ graft (BV) (Vascutek, Terumo, Inchinnanm, Scotland, UK). It has existed in the market for many years and it combines a porcine aortic valve with a bilaminate polyester graft. Another biological valved conduit is the BioIntegral™ (BI) conduit (BioIntegral Surgical Inc., Mississauga, Canada, formerly manufactured by Shelhigh). This conduit was introduced in the market more recently and is made of a porcine aortic valve and a graft from the bovine pericardium.

Most of the biological conduits have been compared only for their technical and clinical outcomes. Both of the BV and BI conduits have structural specifications different from each other. For that reason, there was a need to take a deeper look if these specifications have a significant effect in the mid-term follow-up on the hemodynamic performance of both conduits in the aortic root position. This is the first study to compare the hemodynamic performance of these two conduits. In addition, the early postoperative outcomes within 30-days were compared. Finally, this study compared the survival in the mid-term follow-up period.

2. MATERIALS AND METHODS

2.1. Study Protocol

This is a retrospective observational study that included 55 consecutive patients who underwent aortic root replacement at the West-German Heart and Vascular Center Essen. The 55 patients were divided into two groups: the first group received BV conduits and the second group received BI conduits, then we compared the BV conduits that were used in 27 Patients (n = 27) with the BI conduits that were used in 28 patients (n = 28). The BV conduits were implanted between July 2008 and May 2014 whereas the BI conduits were implanted between May 2013 and May 2014. The BI conduit was introduced more recently in the market and therefore, we started implanting it in May 2013 in our center. The choice of the conduit depended on the surgeon's preference. Also included in this study were patients with aortic valve and aortic root pathologies where valve sparing procedures were not possible. We also included the patients who needed further operative therapies like coronary artery bypass surgery, other valve surgery, or surgery for the aortic arch and descending aorta. All elective, urgent and emergency operations were included in this study. Institutional Review Board (die Ethik-Kommission der Medizinischen Fakultät der Universität Duisburg-Essen) approval was obtained according to the Declaration of Helsinki on June 1, 2021. The approval number is 21-10112-BO.

The primary study endpoints were hemodynamic data during follow-up (six months to 12 years), which included the maximum pressure gradient (Pmax),

maximum velocity (Vmax), mean pressure gradient (MPG), effective orifice area (EOA), and aortic regurgitation (AR) beside measuring the ejection fraction (EF). Secondary study endpoints were early postoperative outcomes within 30-days and survival. The data collected about the patients included demographic data, risk factors, comorbidities and the patients' current cardiac situation. Data collected on the operation itself included arterial cannulation site, body temperature, the use of intra-aortic balloon pump, the parameters of the cardiopulmonary bypass, the extent of the aortic replacement, concomitant operation and prosthesis size. In addition, data about postoperative complications and 30-day mortality were also recorded. At the mid-term follow-up, the patients were invited to our hospital for a physical check-up and an echocardiography. If this was not possible, the cardiologist of the patient was contacted to get the last echocardiography. If a patient could not be reached, their family doctor was asked about the patient's survival. If that was not successful, we contacted the citizens' registration office "Bürgeramt" in the city where that patient lived and asked if the patient was alive or not.

Echocardiographic data were stored in an institutional parallel workflow platform (Horizon Cardiology™, Medcon/McKESSON, San Francisco, CA, USA).

2.2. Conduit characteristics

2.2.1. BioValsalva™

The BV biological valved conduit consists of a biological porcine aortic valve (Elan™ stentless valve, Vascutek, Terumo, Inchinnanm, Scotland, UK) and a graft made of a two-layer material called Biplex™. The graft layers from inside out include the following: inner woven polyester and outer self-sealing elastomer. A third layer of ePTFE is not used anymore like in the older Triplex™ graft and therefore, a cautery can be used to cut in the graft for the coronary buttons. The entire conduit is preserved in a glutaraldehyde solution. The graft itself recreates the sinuses of Valsalva, which reduces the tension of coronary buttons. The main body length ranges between 11.9 and 12.4 cm and the conduit is available in 21, 23, 25, and 27 mm sizes (Vascutek, 2010).

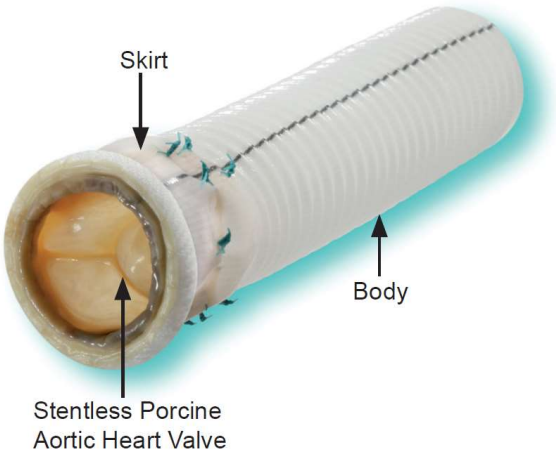

Photo 1. BioValsalva conduit. It shows the porcine valve, the sewing ring and the body. (Photo by Vascutek, Terumo)

2.2.2. BioIntegral™

The stentless and all-biological BI No-React® BioConduit™ is composed of a porcine valve and a single layer of bovine pericardium (BioIntegral Surgical Inc., Mississauga, Canada, formerly manufactured by Shelhigh). The usable main body length is 15 cm and the conduit is available in 21, 23, 25, 27, and 29 mm sizes (BioIntegral, 2020; Galiñanes et al. 2011).

Photo 2. BioIntegral conduit made of a porcine valve and a single layer of bovine pericardium. (Photo by BioIntegral Surgical)

2.3. Operative technique

After a standard median sternotomy, the cardiopulmonary bypass (CPB) was initiated through an arterial cannulation of the ascending aorta, aortic arch or the right axillary artery. A single venous cannula was inserted in the right atrial appendage or a bicaval cannulation was used depending on the concomitant procedure. Mild (28-32 °C) or moderate (25-28 °C) hypothermia was used depending on the concomitant procedure. Cardiac arrest was achieved with an antegrade and optional retrograde crystalloid cardioplegia (Custodiol®, Dr. F. Köhler Chemie, Bensheim, Germany) and additional topic cooling. After transection of the ascending aorta, the aortic valve was completely resected and subsequent debridement of the native annulus and aortic root was performed. The coronary buttons were mobilized. After that, graft sizing was achieved by using an industry-labelled sizer. Pledget re-inforced horizontal mattress sutures (Ethibond 2-0, V5 needle, Ethicon, Norderstedt, Germany) were placed circumferentially under the aortic valve annulus from inside to out and across an appropriately sized graft. If the BI conduit was used, the suture line of the prefabricated pericardial tube was placed in the middle of the non-coronary cusp. Holes for both coronary ostia were made by a N° 11 blade in the BV group or with the use of a 5.2 mm aortic punch (PP Medic, Düsseldorf, Germany) in the BI group. Both coronary ostia were reimplanted in an anatomic fashion by a running suture (Prolene 5-0, cc needle, Ethicon, Norderstedt, Germany).

2.4. Echocardiography

Patients in both groups underwent 2D echocardiographic (TTE) assessment during the follow-up. Echocardiographic measurements were acquired according to the current recommendations (Zoghbi, 2009). Transthoracic 2D echocardiographic (TTE) standard views were obtained using a standard ultrasound system with a 1-5 MHz (S5-1) probe (iE33, Philips Medical Systems, Andover, MA, USA). The effective orifice area (EOA) was calculated by using the continuity equation. Aortic regurgitation (AR) was evaluated and classified to (none/trace, mild, moderate and severe) according to the current recommendations.

2.5. Statistics

Continuous data were reported as mean ± standard deviation or median (25th to 75th percentiles) depending on the normality of distribution. Continuous variables were tested for normality of distribution using the Shapiro-Wilk test and Levene's Test was used to test the homogeneity of variances across groups. If the variables are normally distributed and variances are equal among groups, then independent-samples t-test was used to compare the means. If the groups were not equal, then an alternative statistic, called the Welch t Test statistic was used to compare the means. Cohen's d Test was used to compute the effect size to indicate the standardised difference between two means. If the variables were not normally distributed, then the the nonparametric Mann-Whitney U Test was used to compare the means. Categorical variables were summarized as counts

(percentages) and compared using Fisher's exact test if the sample size was small, whereas Pearson’s chi-squared test was used if the sample size was large. A P-value less than 0.05 was considered to indicate statistical significance. Survival curves were generated using the Kaplan-Meier method. All statistical analyses were performed using the SPSS® software package, version 27.0 (IBM Corp., Armonk, NY, USA) (IBM Corp., 2021).

3. RESULTS

3.1. Patient population

In this study, 55 patients were enrolled. Baseline patient characteristics of both groups are reported in Table 1. No significant differences were observed between both groups. The indication for surgery was aneurysm of the aortic root in 42 patients (76.3%), acute type A aortic dissection in 11 patients (20%) and aortic valve endocarditis with abscess in 2 patients (3.6%). There were no patients with Marfan syndrome.

Operative characteristics are reported in Table 2. A significant difference was observed between both groups; in particular, the prosthesis sizes were bigger in the BI group. Ten patients in the BI group received a 29 mm valve, but no patient in the BV group received a 29 mm valve since the BV conduit is not available in size 29 mm. The concomitant procedures were high in both groups (59.3% vs. 71.4%, P = 0.344). Concomitant procedures included coronary artery bypass grafting (CABG), mitral valve replacement/repair or the combination of procedures. Other concomitant procedures included the Maze procedure, the closure of a patent foramen oval and tricuspid valve repair. Endovascular stent grafting was performed in one patient with aortic dissection spreading into the abdominal aorta. Another patient received percutaneous stenting of the right iliac and left renal arteries. Ascending aorta surgery with hemiarch replacement was performed in 5 patients in the BV group vs. 2 patients in the BI group, and total aortic arch replacement was performed only in 1 patient in the BV group. A more

extensive replacement with a frozen elephant trunk procedure was performed in 1 patient in the BV group vs. 5 patients in the BI group.

Table 1. Baseline patient characteristics

VARIABLE	***BV*** *(N = 27)*	***BI*** *(N = 28)*	***P-Value****	***Effect Size***
Demographics				
Age, years	*71.0 (66.0 – 74.5)*	*66.0 (62.0 – 71.8)*	*0.149[2]*	*0.228*
Gender, male	*19 (70.4)*	*24 (85.7)*	*0.205[6]*	
BMI, kg/m²	*27.6 ± 3.1*	*28.5 ± 4.9*	*0.405[1]*	*-0.229[3]*
BMI > 30kg/m²	*6 (22.2)*	*10 (35.7)*	*0.310[6]*	
BSA, m²	*2.0 (1.9-2.2)*	*2.1 (1.9-2.2)*	*0.324[2]*	*0.158*
Risk factors & comorbidities				
Systemic hypertension	*24 (92.3)*	*23 (82.1)*	*0.423[6]*	
Diabetes mellitus	*3 (11.5)*	*4 (14.3)*	*0.764[4]*	
Coronary artery disease	*9 (34.6)*	*12 (42.9)*	*0.586[6]*	
PVD	*2 (7.4)*	*1 (3.6)*	*0.611[6]*	
Atrial fibrillation	*5 (18.5)*	*10 (35.7)*	*0.227[6]*	
COPD	*4 (15.4)*	*1 (3.6)*	*0.184[6]*	
Renal disease (serum creatinine >200 µmol/L)	*1 (3.8)*	*3 (10.7)*	*0.612[6]*	
Dyslipidemia	*14 (53.8)*	*10 (35.7)*	*0.273[6]*	
Smoking	*4 (15.4)*	*7 (25.0)*	*0.505[6]*	
Emergency	*5 (18.5)*	*6 (21.4)*	*0.790[6]*	
Cardiac				
Aneurysm ≥ 45mm	*25 (92.6)*	*26 (92.9)*	*0.970[6]*	
Aneurysm diameter, mm	*51.5 (48.3-60.0)*	*54.5 (50.0-60.0)*	*0.413[2]*	*0.136*
Aortic dissection	*4 (14.8)*	*7 (25.0)*	*0.503[6]*	
Aortic endocarditis	*2 (7.4)*	*0 (0)*	*0.236[6]*	
Aortic stenosis	*8 (29.6)*	*7 (25.0)*	*0.768[6]*	
Aortic regurgitation	*22 (81.5)*	*25 (89.3)*	*0.469[6]*	
Bicuspid aortic valve	*10 (37.0)*	*5 (17.9)*	*0.138[6]*	
Previous cardiac surgery	*3 (11.5)*	*3 (10.7)*	*0.923[4]*	
Risk Scores				

EuroSCORE-II, %	*3.8 (2.5-7.8)*	*5.3 (2.6-10.8)*	*0.389[2]*	*0.138*

Data are presented as mean ± SD, median (25th to 75th percentiles) or number (%); BMI, Body mass index; BSA, Body surface area; PVD, Peripheral vascular disease; COPD, Chronic obstructive pulmonary disease; EuroSCORE, European System for Cardiac Operative Risk Evaluation.

[1] Student's t Test, [2]Mann-Whitney U Test, [3] Cohen's d Test, [4] χ^2 Test, [5]Welch's t Test, [6]Fisher's exact Test

Table 2. Operative characteristics

VARIABLE	***BV*** *(N = 27)*	***BI*** *(N = 28)*	***P-Value****	***Effect Size***
Arterial cannulation site			*0.565[4]*	
Ascending aorta	*23 (85.2)*	*24 (85.7)*		
Axillary artery	*3 (11.1)*	*4 (14.3)*		
Femoral & axillary artery	*1 (3.7)*	*0 (0)*		
DHCA (<25°C)	*0*	*0*	.	
MHCA (25–28°C)	*8 (29.6)*	*7 (25.0)*	*0.770[6]*	
ASCP	*5 (18.5)*	*6 (21.4)*	*0.787[4]*	
IABP	*1 (3.7)*	*0 (0)*	*0.491[6]*	
CPB (min)	*154.5 (118.0–203.3)*	*146.5 (108.0–227.0)*	*0.634[2]*	*0.076*
Cross-clamp time (min)	*105.0 (74.0–140.5)*	*102.5 (80.0–135.0)*	*0.824[2]*	*0.037*
Reperfusion time (min)	*33.5 (24.0–65.8)*	*50.0 (25.0–71.8)*	*0.546[2]*	*0.125*
ASCP Time (min)	*47.3 ± 38*	*46 ± 24*	*0.939[1]*	*0.053*
Visceral ischemia time (min)	*39.5 ± 30.4*	*39.2 ± 21.4*	*0.988[1]*	*0.012*
Extent of aortic replacement			***0.176[4]***	
Ascending aorta	*20 (74.1)*	*21 (75)*		
Ascending aorta and partial arch	*5 (18.5)*	*2 (7.1)*		
Ascending aorta and total arch	*1 (3.7)*	*0 (0)*		
Ascending aorta, total arch and ET	*1 (3.7)*	*5 (17.9)*		
Concomitant Operation	*16 (59.3)*	*20 (71.4)*	*0.344[4]*	
CABG	*7 (25.9)*	*8 (28.6)*		
MVR	*1 (3.7)*	*4 (14.3)*		
Combined CABG and MVR	*2 (7.4)*	*2 (7.1)*		
Other	*6 (22.2)*	*6 (21.4)*		
Prosthesis size			*0.008[2]*	
23 mm	*1 (3.7)*	*1 (3.6)*		
25 mm	*13 (48.1)*	*8 (28.6)*		

27 mm	*13 (48.1)*	*9 (32.1)*
29 mm	*0 (0)*	*10 (35.7)*

Data are presented as mean ± SD, median (25th to 75th percentiles) or number (%); CABG, Coronary artery bypass grafting; MVR, Mitral valve replacement or repair; DHCA, Deep hypothermic circulatory arrest; MHCA, Moderate hypothermic circulatory arrest; CPB, Cardiopulmonary bypass; ASCP, Antegrade selective cerebral perfusion; IABP, Intra-aortic balloon pump; ET, Elephant frozen trunk.

[1] Student's t Test, [2]Mann-Whitney U Test, [3] Cohen's d Test, [4] χ^2 Test, [5]Welch's t Test, [6]Fisher's exact Test

3.2. Outcomes at 30 days

Outcomes at 30 days are reported in Table 3. Significant differences between both groups were not observed. 30-day mortality was 11.1% in the BV group versus 3.6 % in the BI group (P = 0.474). Postoperative stroke occurred in one patient in each group. Postoperative ventilation time greater than 48 hours was needed in 7 patients in the BV group and 8 patients in the BI group. Dialysis was needed in 5 vs. 8 patients (BV vs. BI group). Postoperative new-onset of atrial fibrillation was present in 5 patients in the BV group and 7 patients in the BI group. Patients who died within 30 days had a median EuroScore-II of 16.3% in the BV group and 26.0% in the BI group.

Table 3. 30-day outcomes

VARIABLE	*BV* (N = 27)	*BI* (N = 28)	*P-Value*[*]	*Effect Size*
Reoperation for bleeding	*2 (7.7)*	*2 (7.1)*	*0.939*[4]	
Sepsis	*0 (0)*	*3 (10.7)*	*0.237*[6]	
Stroke	*1 (3.8)*	*1 (3.6)*	*0.957*[4]	
Ventilation >48 hours	*7 (26.9)*	*8 (28.6)*	*0.893*[4]	

Pulmonary embolism	*0 (0)*	*0 (0)*	.	
Pneumonia	*4 (15.4)*	*5 (17.9)*	*0.808*[4]	
Dialysis-dependent renal failure	*5 (19.2)*	*8 (28.6)*	*0.530*[6]	
Tracheotomy	*4 (15.4)*	*2 (7.1)*	*0.413*[4]	
Implantation of pacemaker	*1 (3.8)*	*2 (7.1)*	*0.597*[6]	
Recurrent Laryngeal Nerve Injury	*0 (0)*	*0 (0)*	.	
New-onset Atrial fibrillation	*5 (18.5)*	*7 (25)*	*0.499*[4]	
ICU LOS (days)	*2.0 (1.0–6.3)*	*2.5 (1.0–6.0)*	*0.737*[2]	*0.052*
30-day mortality	*3 (11.1)*	*1 (3.6)*	*0.474*[4]	
Intraoperative	*1 (3.7)*	*0 (0)*		
Postoperative	*2 (7.4)*	*1 (3.6)*		
Cause of 30-day mortality			*0.540*[4]	
Cardiogenic shock	*1 (3.7)*	*0 (0)*		
Multiple organ failure	*1 (3.7)*	*1 (3.6)*		
Renal failure	*0 (0)*	*0 (0)*		
EuroScore-II for 30-day mortalities, %	*median 16.3 (n = 3)*	*26.0 (n = 1)*	*1.00*[2]	

Data are presented as mean ±SD, median (25th to 75th percentiles) or number (%); ICU, Intensive care unit; LOS, Length of stay.

[1] Student's t Test, [2]Mann-Whitney U Test, [3] Cohen's d Test, [4] χ^2 Test, [5]Welch's t Test, [6]Fisher's exact Test

3.3. Follow-up outcomes and survival

Follow-up outcomes are listed in Table 4. In follow-up, two patients in each group needed reoperation on the aortic root. The cause of reoperations was pseudoaneurysm in those four patients. Reoperation for structural valve dysfunction was not needed in both groups. Endocarditis did not happen in both groups. Overall survival rates in the BV group at 1, 2, 5 and 8 years were 82%, 78%, 74%, and 59% respectively. Overall survival rates in the BI group at 1, 2, 5 and 8 years were 89%, 86%, 86%, and 79% respectively. Ninety-six months postoperatively, both groups showed no difference in survival (p = 0.24).

Nonetheless, we see the tendency that the survival in the BI group is better. Survival is presented in Figure 3.

Table 4. Follow-up outcomes

VARIABLE	***BV*** *(N = 24)*	***BI*** *(N = 27)*	***P-Value****	***Effect Size***
Follow-up months	*106.0 (67.4-123.9)*	*85.0 (72.0-87.9)*	*0.012*[2]	*0.410*[3]
Range (months)	*(1.1-144.5)*	*(1.8-93.2)*		
Reoperation on the aortic root	*2 (8.3)*	*2 (7.4)*	*0.867*[4]	
Endocarditis	*0 (0)*	*0 (0)*	.	
Mortality during follow-up	*8 (33.3)*	*5 (18.5)*	*0.336*[6]	
Cause of death				
Mediastinitis	*1 (4.2)*	*1 (3.7)*		
Ischemic cardiac failure	*1 (4.2)*	*0 (0)*		
Arrhythmia	*0 (0)*	*1 (3.7)*		
Non cardiac	*4 (16.7)*	*2 (7.4)*		
Not clear	*2 (8.3)*	*1 (3.7)*		

Data are presented as mean ± SD, median (25th to 75th percentiles) or number (%).

[1] Student's t Test, [2]Mann-Whitney U Test, [3] Cohen's d Test, [4] χ^2 Test, [5]Welch's t Test, [6]Fisher's exact Test

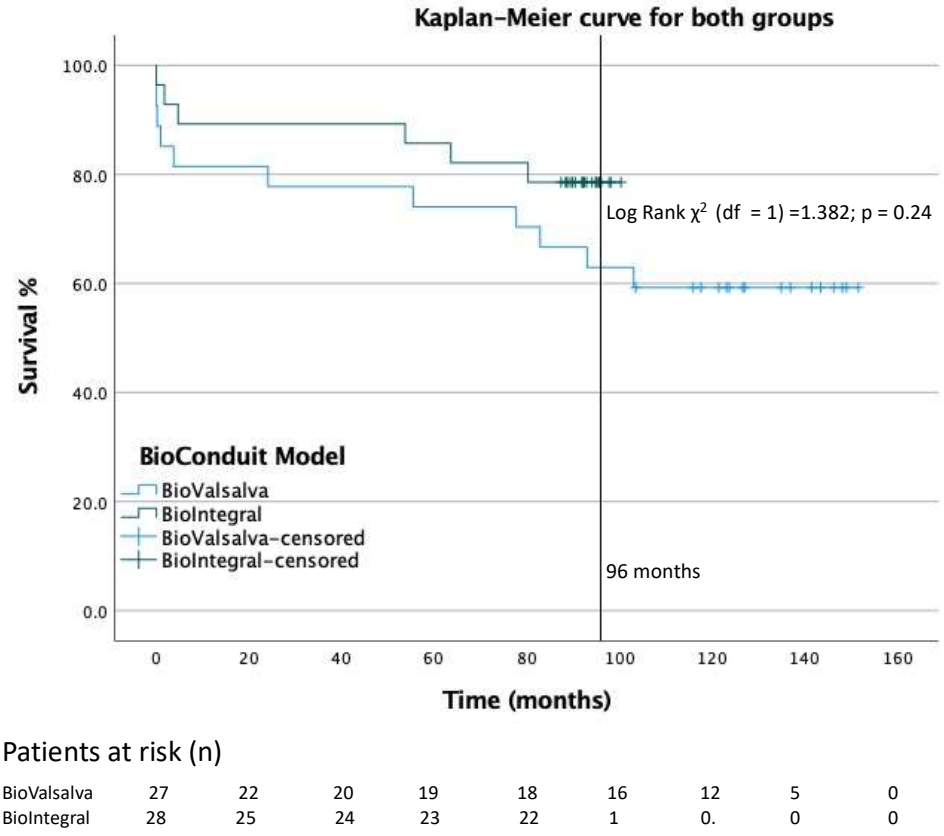

Figure 3. Kaplan-Meier curve for both groups (BV, blue; BI, green)

3.4. Echocardiographic outcomes

Echocardiographic evaluations during the follow-up are presented in Table 5. Mean pressure gradients (MPG) did not differ significantly between both groups at follow-up (11.9 mmHg in the BV vs. 9.5 mmHg in the BI group, P = 0.066) for all implanted sizes. The effective orifice areas (EOA) did not significantly differ between both groups (1.85 cm² in the BV group vs. 1.81 cm² in the BI group, P = 0.723). There was no significant difference in terms of ejection fraction (EF) (53.6% in the BV vs. 54.0% in the BI group, P = 0.881). Aortic regurgitation (AR) was not significantly different between both groups (P = 0.670). The none/trace

(85.7% vs. 80.0%) or mild (14.3% vs. 20.0%) AR did not differ in most patients. Moderate or severe AR was not observed. The MPGs for both groups for all valve sizes are shown in Figure 4 on the left. The details of MPGs for the valve sizes 25 und 27 mm are also shown in Figure 4 on the right. Figure 5 shows the study flow chart: allocation, 30-day, mortality, mortality in the follow-up, and echocardiographic follow-up.

Table 5. Echocardiographic follow-up

VARIABLE	***BV***	***BI***	***P-Value****	***Effect Size***
	(N = 15)	*(N = 21)*		
Follow-up months	*107.0 (90.7 – 115.0)*	*78.5 (60.1 – 85.6)*	*0.002[2]*	*0.616*
Range (months)	*(19-125)*	*(12-93)*		
EF (%)	*53.6 ± 6.4*	*54.0 ± 8.6*	*0.881[1]*	*0.052[3]*
Pmax (mmHg)	*19.2 ± 6.5*	*15.6 ± 5.7*	*0.114[1]*	*0.585[3]*
25 mm Valve	*18.2 ± 6.0*	*13.5 ± 7.6*	*0.306[1]*	*0.705[3]*
27 mm Valve	*20.8 ± 7.5*	*17.3 ± 3.4*	*0.335[5]*	*0.598[3]*
Vmax (m/s)	*2.15 ± 0.5*	*2.03 ± 0.3*	*0.413[1]*	*0.305[3]*
25 mm Valve	*2.16 ± 7.5*	*2.07 ± 0.3*	*0.819[1]*	*0.168[3]*
27 mm Valve	*2.18 ± 0.4*	*2.08 ± 0.2*	*0.681[5]*	*0.247[3]*
MPG (mmHg)	*11.9 ± 3.7*	*9.5 ± 3.6*	*0.066[1]*	*0.664[3]*
25 mm Valve	*11.2 ± 3.5*	*8.5 ± 3.9*	*0.289[1]*	*0.733[3]*
27 mm Valve	*12.1 ± 4.2*	*10.0 ± 1.92*	*0.251[5]*	*0.659[3]*
EOA (cm²)	*1.85 ± 0.4*	*1.81 ± 0.3*	*0.723[1]*	*0.132[3]*
25 mm Valve	*1.79 ± 0.4*	*1.78 ± 0.1*	*0.976[1]*	*0.022[3]*
27 mm Valve	*1.90 ± 0.4*	*1.86 ± 0.3*	*0.803[1]*	*0.142[3]*
Aortic regurgitation	*n = 14*	*n = 20*	*0.670[4]*	
None/trace	*12 (85.7)*	*16 (80.0)*		
Mild	*2 (14.3)*	*4 (20.0)*		
Moderate (0)	-	-		
Severe (0)	-	-		

Data are presented as mean ± SD, median (25th to 75th percentiles) or number (%); EF, Ejection fraction; Pmax, Peak pressure gradient; Vmax, Peak aortic jet velocity; MPG, Mean pressure gradient; EOA, Effective orifice area.

[1] Student's t Test, [2]Mann-Whitney U Test, [3] Cohen's d Test, [4] χ^2 Test, [5]Welch's t Test

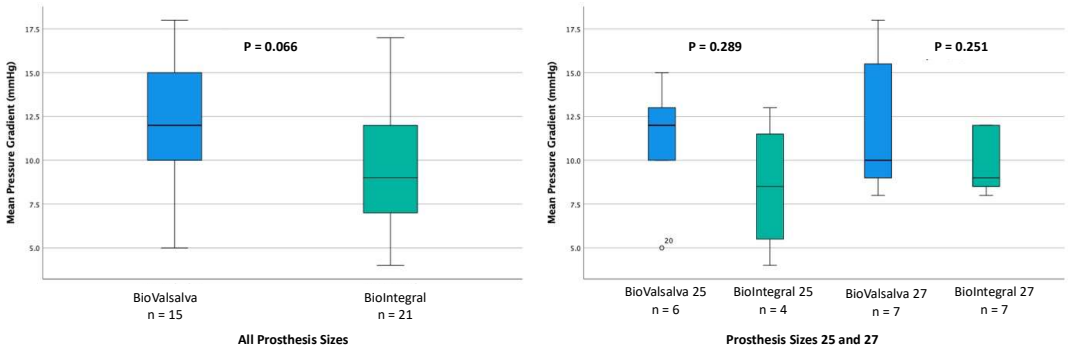

Figure 4. Box-Plot shows the mean pressure gradient for the BV and BI conduit (Left: all prosthesis sizes, right: for the sizes 25 and 27). Box-Plots indicate medians, 25th and 75th percentiles (boxes), and minimum and maximum values (whiskers).

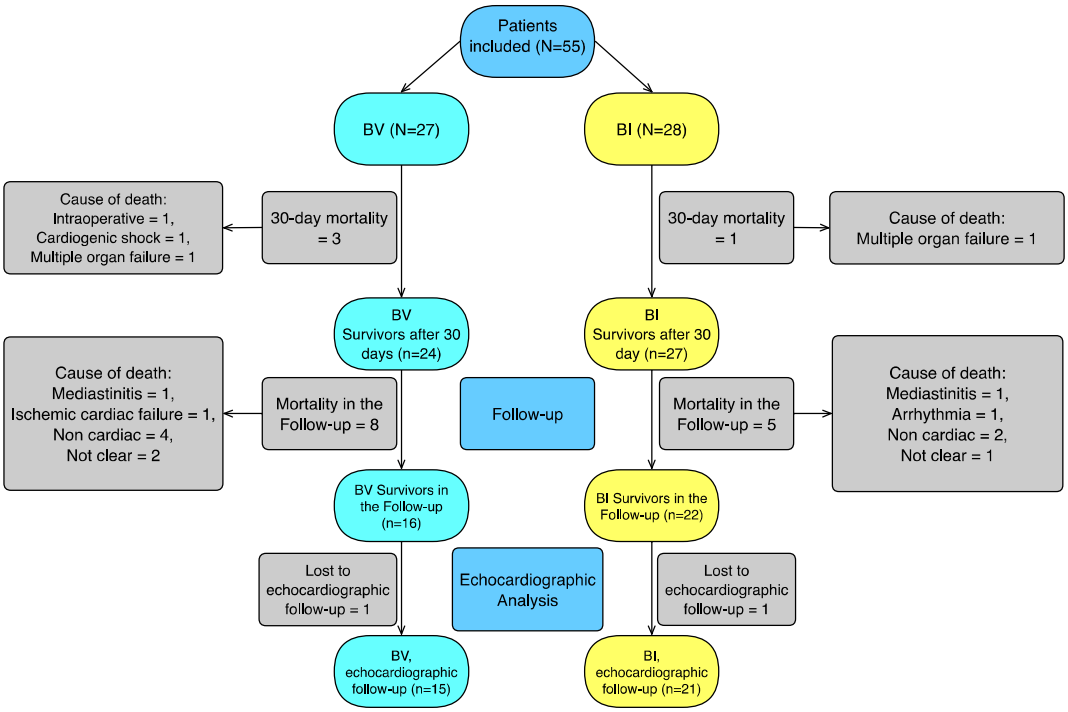

Figure 5. Study flow chart. Allocation, Mortality, Follow-up, Echocardiographic follow-up (BV, blue; BI, yellow)

4. DISCUSSION

Replacement of the aortic root and the ascending aorta is a challenging procedure. The technical innovation in aortic root surgery advances as we understand the aortic root pathologies more (Woldendorp, 2014). The results of this study were interesting: first, the average MPG in the follow-up of both conduits was 10.7 mmHg, which shows an excellent hemodynamic performance in both groups. Second, both conduits showed a low rate of AR in the follow-up. Third, there was no significant difference in survival between both groups. Forth, endocarditis did not happen in both groups.

This is the first study, as far as we know, that compares the hemodynamic performance of the BioValsalva™ and BioIntegral™ aortic valve conduits in a detailed manner. To our knowledge, both conduits have not been compared in their current version.

In the original Bentall procedure, a mechanical aortic valve was implanted (Bentall and De Bono, 1969). Biological aortic conduits were later implanted and one of those conduits was the Shelhigh ('Shelhigh BioConduit stentless valve') biological aortic-valved conduit (Shelhigh, Inc., Union, NJ, United States). This conduit had issues with sterility and safety and was withdrawn from the market by the FDA in 2007 (U.S. Food and Drug Administration, 2007). Even though the

original Shelhigh was flawed, a study group in Berlin published in an excellent 11-year study using the original Shellhigh conduit in 2013 (Musci et al., 2013).

Recently this company moved to Mississauga, Canada renaming itself BioIntegral Surgical Inc., and introduced a new modified product called BioIntegral BioConduit™. As a consequence of the encouraging results by Musci et al. (Musci et al., 2013), we started implanting the BI conduit in our center in 2013. At the same time, the BioValsalva™ aortic-valved conduit was the main biological conduit implanted in our center. Until now, most of the studies compared the biological conduits in terms of clinical and operative outcomes; however, there was lack of data on the hemodynamic performance and echocardiographic outcomes of those conduits. As a consequence, the goal of our study was to perform a echocardiographic follow-up of the patients. In addition, regardless of the type of prosthesis, hemodynamic data should be obtained at least 6 months postoperatively in order to limit the bias of hemodynamic instability in the immediate postoperative course. For this reason, we decided to analyse the performance of the conduits at least 6 months postoperatively.

It should mention that because of the later availability of the BI conduit in our center, the follow-up periods of both conduits differed significantly (106.0 vs. 85.0 months, P 0.012). In the follow-up, we did not observe a significant difference between MPGs for all valve sizes between both groups (BV, 11.9 ± 3.7 mmHg vs. BI, 9.5 ± 3.6 mmHg, P = 0.066). In addition, we did not observe any significant difference between both groups in term of EOAs (BV, 1.85 ± 0.4 cm^2 vs. BI, 1.81

± 0.3 cm², P = 0.723). Furthermore, we did not observe a significant difference in AR between both groups in the follow-up (None/trace AR in (12/14) 85.7% in BV group vs. (16/20) 80.0% in BI group, P = 0.670.

Moreover, Baraki et al. reported good hemodynamic results for the BV conduit in the follow-up of 25 patients showing no AR and mean pressure gradients of 13 ± 5 mmHg six months postoperatively, which supports our findings (Baraki et al., 2010). In addition, our findings are supported by Carrel et al. who reported good hemodynamic data for the original Shelhigh conduit for 30 patients after 6 months (MPGs of 8.5 ± 5.1 mmHg (range: 6-14 mmHg)) (Carrel et al., 2003).

In our study, the 30-day mortality was 7.3%, which is relatively high. A similar mortality rate (6.1%) among 147 patients who received biological conduits was reported by Woldendorp et al. (Woldendorp et al., 2014). The mortality rate reported in this study is also in accordance with the rate reported by Etz and colleagues in a series of 275 hand-sewn biological conduits (Etz et al., 2007). Moreover, the mean age of the patients in our study was 70 years, which represents the aging population undergoing cardiac operations. However, our study included a high percentage of complex procedures that include emergency indication (20.0%), acute type-A aortic dissections (20.0%) and infective endocarditis (3.6%), and this can cause the relative increase in mortality. Other studies reported similar high in-hospital mortality rates (>10%) among patients undergoing aortic

root replacement because of infective endocarditis or aortic dissection (Oka et al., 2011; Woldendorp et al., 2014; Halstead et al., 2005; Ergin et al. 1996).

In the follow-up, two patients died in each group because of cardiac causes that included mediastinitis, ischemic cardiac failure, and arrythmia. It is important to mention that in the follow up, two patients in each group needed reoperations on the aortic root. Those four patients had pseudoaneurysms. In the BV group, the patients had covered perforations that formed the pseudoaneurysms, whereas in the BI group the patients had pseudoaneurysms of both coronary ostia. One patient in each group died postoperatively because of mediastinitis.

From a structural point of view, both conduits use stentless biological valves. Nevertheless, the BV and BI stand in contrast with each other in two main things: first, the graft of the BV conduit is made of polyester, whereas the graft of the BI conduit is made of bovine pericardium. Therefore, the BI conduit is a complete biological conduit, which might be as good as aortic root homografts in resisting infections (Musci et al., 2013; Carrel et al., 2003; Galiñanes et al., 2011; Siniawski et al., 2003). Second, the BI conduit contains a straight pericardial graft with an incorporated stentless valve with no extra sewing ring, whereas the BV conduit has an extra sewing ring that adds 4 mm to the diameter of the valve, and this might decrease the effective orifice area.

From a design point of view, the BV conduit has two advantages over the BI conduit: first the BV graft is made of polyester, which might resist calcification in the long term. Second, the design of the BV conduit recreates the sinuses of

Valsalva, which reduces the distance between the coronary ostia and the graft itself and minimizes tension on the coronary anastomoses (Weltert, 2009), and moreover, preserves aortic root dynamics, due to the flexibility and distensibility of the incorporated sinuses.

From a surgical point of view, the BI conduit is easier to implant because of the flexibility and elasticity of the pericardium itself in contrast to the rigid sewing ring of the BV conduit. However, the BI conduit has no sewing ring; therefore, distortion of the conduit must be avoided to prevent incorrect valve closure and AR.

5. LIMITATIONS

Our study was limited by many factors. First, the number of patients included in this study was very small due to the rarity of the disease and because the study was performed in a single tertiary care medical center. Over 6 years, only 55 patients were suitable to be included in this study. Second, the data collection of the patients was retrospective with no randomization, which limited the design of this study and selection bias could not be excluded. Third, the reintroduction of the BI conduits in 2013 played an important role in limiting the follow of the patients with BI conduits, and it must be mentioned that both conduits were implanted in totally different time periods. The median clinical follow-up for the BV group was 106.0 months vs. 85.0 months in the BI group and median echocardiographic follow-up in the BV group was 107.0 months vs. 78.5 months in the BI group. These two medians were significantly longer in the BV group. Therefore, the follow-up of the patients with BI conduits was relatively shorter compared to the patients with the BV conduits, which could have impacted the outcome of the BI group when compared to the BV group.

The small sample size, the design of the study as a retrospective study and the different follow-up periods of both conduits limited the strength of the statistical analysis of this study. Because of the three factors mentioned above, this study could not reach its goal which is the detection of difference in the hemodynamic performance between both groups. These three factors could have negatively affected clinical outcome of those two biological conduits.

However, even though the BV and BI groups were studied in different time periods, both groups did not differ significantly in terms of demographic and intraoperative data. In addition, the relatively high mortality rate observed in our study should be seen because of the high rate of concomitant procedures. This study helps in generating further hypotheses about the two conduits, such as observing the development of pseudoaneurysms in the aortic root and the degeneration of the aortic valves in these two biological conduits.

6. CONCLUSION

This study compared the hemodynamic performance of both the BioValsalva™ and BioIntegral™ conduits. At the present time, medical companies advertise and market the unique features of their products and we have to independently test their claims. In this study, we report the outstanding mean pressure gradients, effective orifice areas and low rates of aortic regurgitation for all implanted conduits during the follow-up with no significant difference between both groups. The BioIntegral™ conduit is a new modified product which can rightfully compete with other well-established aortic-valved biological conduits. Before suggesting a specific aortic-valved biological conduit, more randomized studies with detailed echocardiographic data are needed to evaluate the long-term durability, performance and valve-related morbidity of these innovative aortic-valved biological conduits.

7. REFERENCES

1. Baraki, H., Al Ahmad, A., Sarikouch, S., Koigeldiev, N., Khaladj, N., Hagl, C., Pichlmaier, M., Haverich, A., Shrestha, M. (2010):

   The first fifty consecutive Bentall operations with a prefabricated tissue-valved aortic conduit: a single-center experience.

   J. Heart Valve Dis.19(3), 286-91.

2. Baumgartner, F. (2003):

   Cardiothoracic Surgery. 3. Ed.

   Austin: Landes Biosciences; S.89-122.

3. Bentall, H., De Bono, A. (1968):

   A technique for complete replacement of the ascending aorta.

   Thorax. 23, 338-9.

4. BioIntegral Surgical. BioConduit. (2020):

   Online Publication; http://www.biointegral-surgical.com/#!bioconduit/c1k

5. Brown, J.M., O'Brien, S.M., Wu, C., Sikora, J.A., Griffith, B.P., Gammie, J.S. (2009):

   Isolated aortic valve replacement in North America comprising 108, 687 patients in 10 years: changes in risks, valve types, and outcomes in the Society of Thoracic Surgeons National Database.

   J. Thorac. Cardiovasc. Surg. 137(1), 82-90.

6. Carrel, T.P., Berdat, P., Englberger, L., Eckstein, F., Immer, F., Seiler, C., Kipfer, B., Schmidli, J. (2003):

   Aortic root replacement with a new stentless aortic valve xenograft conduit: preliminary hemodynamic and clinical results.

   J. Heart Valve Dis. 12(6), 752-7.

7. Chaikof, E. (2007):

The Development of Prosthetic Heart Valves — Lessons in Form and Function.

N. Engl. J. Med. 357, 1368-1371.

8. Charitos, E.I., Sievers, H.H. (2013):

Anatomy of the aortic root: implications for valve-sparing surgery.

Ann. Cardiothorac. Surg. 2(1), 53-56.

9. Di Bartolomeo, R., Botta, L., Leone, A., Pilato, E., Martin-Suarez, S., Bacchini, M., Pacini, D. (2008):

Bio-Valsalva prosthesis: 'new' conduit for 'old' patients.

Interact. Cardiovasc. Thorac. Surg. 7, 1062-6.

10. Dominik, J., Zacek, P. (2010):

Heart Valve Surgery, An Illustrated Guide. 1. Ed.

Berlin: Springer-Verl.; 82-83.

11. Ergin, M.A., McCullough, J., Galla, J.D., Lansman, S.L., Griepp, R.B. (1996):

Radical replacement of the aortic root in acute type A dissection: indications and outcome.

Eur. J. Cardiothorac. Surg. 10(10), 840-4.

12. Etz, C.D., Homann, T.M., Rane, N., Bodian, C.A., Di Luozzo, G., Plestis, K.A., Spielvogel, D., Griepp, R.B. (2007):

Aortic root reconstruction with a bioprosthetic valved conduit: a consecutive series of 275 procedures.

J. Thorac. Cardiovasc. Surg. 133, 1455-63.

13. Freeman, R.V., Crittenden, G., Otto, C. (2004):

Acquired aortic stenosis.

Expert. Rev. Cardiovasc. Ther. 2(1), 107-16.

14. Galiñanes, M., Meduoye, A., Ferreira, I., Sosnowski, A. (2011):

Totally Biological Composite Aortic Stentless Valved Conduit for Aortic Root Replacement: 10-Year Experience.

J. Cardiothorac. Surg. 6, 86.

15. Halstead, J.C., Spielvogel, D., Meier, D.M., Rinke, S., Bodian, C., Malekan, R., Ergin, M.A., Griepp, R.B. (2005):

Composite aortic root replacement in acute type A dissection: time to rethink the indications?

Eur. J. Cardiothorac. Surg. 27(4), 632-3.

16. IBM Corp. (2021): IBM SPSS Statistics for Macintosh, Version 27.0. Armonk, New York.

17. McClure, R.S., Narayanasamy, N., Wiegerinck, E., Lipsitz, S., Maloney, A., Byrne, J.G., Aranki, S.F., Couper, G.S., Cohn, L.H. (2010):

Late outcomes for aortic valve replacement with the Carpentier- Edwards pericardial bioprosthesis: up to 17-year follow-up in 1,000 patients.

Ann. Thorac. Surg. 89(5), 1410–6.

18. Mihaljevic, T., Sayeed, M.R., Stamou, S.C., Paul, S. (2008): Pathophysiology of Aortic Valve Disease.

In: Cohn, L.H. Cardiac surgery in the adult.

3. Ed. S825-40. New York: The McGraw-Hill Companies

19. Musci, M., Amiri, A., Siniawski, H., Stein, J., Weng, Y., Hetzer, R. (2013):

Further experience with the "no-react" bioprosthesis in patients with active infective endocarditis: 11-year single center results in 402 patients.

Thorac. Cardiovasc. Surg. 61(5), 398-408.

20. Nishimura, R.A., Otto, C.M., Bonow, R.O., Carabello, B.A., Erwin, J.P. 3rd., Guyton, R.A., O'Gara, P.T., Ruiz, C.E., Skubas, N.J., Sorajja, P., Sundt, T.M. 3rd., Thomas, J.D. (2014):

2014 AHA/ ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines.

J. Thorac. Cardiovasc. Surg. 148(1), 1-132.

21. Oka, T., Okita, Y., Matsumori, M., Okada, K., Minami, H., Munakata, H., Inoue, T., Tanaka, A., Sakamoto, T., Omura, A., Nomura, T. (2011):

Aortic regurgitation after valve-sparing aortic root replacement: modes of failure.

Ann. Thorac. Surg. 92, 1639–44.

22. Sievers, H.H., Misfeld, M. (2010): Erworbene Vitien der Aortenklappe.

In: Haverich, A., Ziemer, G.: Herzchirurgie.

3. Ed.; S601-34, Berlin: Springer-Verlag GmbH

23. Siniawski, H., Lehmkuhl, H., Weng, Y., Pasic, M., Yankah, C., Hoffmann, M., Behnke, I., Hetzer, R. (2003):

Stentless aortic valves as an alternative to homografts for valve replacement in active infective endocarditis complicated by ring abscess.

Ann. Thorac. Surg. 75(3), 803-8.

24. Slaughter, M.S., Jweied, E. (2007):

Managing mechanical valves with reduced anticoagulation.

Expert Rev, Cardiovasc, Ther. 5(6), 1073–85.

25. U.S. Food and Drug Administration: May 2, 2007 FDA Requested Recall. 2007,

Online Publication; https://www.fda.gov/ucm/groups/fdagov-public/@fdagov-afda-orgs/documents/document/ucm056164.pdf

26. Vahanian, A., Alfieri, O., Andreotti, F., Antunes, M.J., Barón-Esquivias, G., Baumgartner, H., Borger, M.A., Carrel, T.P., De Bonis, M., Evangelista, A., Falk, V., Iung, B., Lancellotti, P., Pierard, L., Price, S., Schäfers, H.J., Schuler, G., Stepinska, J., Swedberg, K., Takkenberg, J., Von Oppell, U.O., Windecker, S., Zamorano, J.L., Zembala, M. (2012):

Guidelines on the management of valvular heart disease (version 2012): the Joint Task Force on the Management of Valvular Heart Disease of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS).

European Heart Journal. 33(19), 2451–96.

27. Vascutek. Stentless BioValsalva. (2010):

Online Publication; http://www.vascutek.de/downloads/Stentless_BioValsalva_brochure-4page_B276_1E_Aug%2010.pdf

28. Weltert, L., De Paulis, R., Scaffa, R., Maselli, D., Bellisario, A., D'Alessandro, S. (2009)

Re-Creation of a Sinus Like Graft Expansion in Bentall Procedure Reduces Stress at the Coronary Button Anastomoses: A Finite Element Study.

J. Thorac. Cardiovasc. Surg. 137(5), 1082-7.

29. Woldendorp, K., Starra, E., Seco, M., Hendel, P.N., Jeremy, R.W., Wilson, M.K., Vallely, M.P., Bannon, P.G. (2014):

Replacement of the aortic root with a composite valve-graft conduit: risk factor analysis in 246 consecutive patients.

Heart Lung Circ. 23(12), 1187-93.

30. Zehr, K.J., Orszulak, T.A., Mullany, C.J., Matloobi, A., Daly, R.C., Dearani, J.A., Sundt, T.M. 3rd., Puga, F.J., Danielson, G.K., Schaff, H.V. (2004):

Surgery for aneurysms of the aortic root: a 30-year experience.

Circulation. 110(11), 1364-71.

31. Zoghbi, W.A., Chambers, J.B., Dumesnil, J.G., Foster, E., Gottdiener, J.S., Grayburn, P.A., Khandheria, B.K., Levine, R.A., Marx, G.R., Miller, F.A. Jr., Nakatani, S., Quiñones, M.A., Rakowski, H., Rodriguez, L.L., Swaminathan, M., Waggoner, A.D., Weissman, N.J., Zabalgoitia, M. (2009):

Recommendations for evaluation of prosthetic valves with echocardiography and doppler ultrasound: a report From the American Society of Echocardiography's Guidelines and Standards Committee and the Task Force on Prosthetic Valves.

J Am Soc Echocardiogr. 22, 975–1014.

8. Appendix

8.1. List of Figures

	Page
Figure 1. Proposed nomenclature for the aortic root components	08
Figure 2. Aortic valve anatomy	09
Figure 3. Kaplan-Meier curve for both groups	24
Figure 4. Box-Plot shows the mean pressure gradient	26
Figure 5. Study flow chart	26

8.2. List of Photos

	Page
Photo 1. BioValsalva conduit	13
Photo 2. BioIntegral conduit	14

8.3. List of Tables

	Page
Table 1. Baseline patient characteristics	19
Table 2. Operative characteristics	20
Table 3. 30-day outcomes	22
Table 4. Follow-up outcomes	23
Table 5. Echocardiographic follow-up	25

8.4. List of Abbreviations

AR	Aortic regurgitation
ASCP	Antegrade selective cerebral perfusion
AVR	Aortic valve replacement
BI	BioIntegral™ Conduit
BMI	Body mass index
BSA	Body surface area
BV	BioValsalva™ Conduit
CABG	Coronary artery bypass grafting
COPD	Chronic obstructive pulmonary disease
CPB	Cardiopulmonary bypass
DHCA	Deep hypothermic circulatory arrest
EF	Ejection fraction
EOA	Effective orifice area
ET	Elephant frozen trunk
EuroSCORE	European System for Cardiac Operative Risk Evaluation
IABP	Intra-aortic ballon pump
ICU	Intensive care unit
LOS	Length of stay
MHCA	Moderate hypothermic circulatory arrest
MPG	Mean pressure gradient
MVR	Mitral valve replacement or repair
Pmax	Peak pressure gradient
PVD	Peripheral vascular disease
SD	Standard Deviation
TTE	Transthoracic 2D echocardiographic
Vmax	Peak aortic jet velocity

9. ACKNOWLEDGMENT

I would like to thank my father Prof. Abdulwahab Raweh and my mother Fatima Beshr for their support.

I would like to thank my wife, Sarah Soofan, and two kids, Layan and Al-Ayhem for their endless support.

10. CURRICULUM VITAE

Der Lebenslauf ist in der Online-Version aus Gründen des Datenschutzes nicht enthalten.