Scientific Reports

https://doi.org/10.1038/s41598-025-34107-y

Article in Press

Long term outcomes of valve sparing aortic root replacement versus conventional aortic root replacement using a mechanical prosthesis by propensity score matching

Received: 17 November 2024

Accepted: 24 December 2025

Published online: 04 January 2026

Cite this article as: Güneş G., Tel Üstünışık Ç., Arapi B. *et al.* Long term outcomes of valve sparing aortic root replacement versus conventional aortic root replacement using a mechanical prosthesis by propensity score matching. *Sci Rep* (2026). https://doi.org/10.1038/s41598-025-34107-y

Gökhan Güneş, Çiğdem Tel Üstünışık, Berk Arapi, Deniz Göksedef, Suat Nail Ömeroğlu, Gökhan İpek & Ozan Onur Balkanay

We are providing an unedited version of this manuscript to give early access to its findings. Before final publication, the manuscript will undergo further editing. Please note there may be errors present which affect the content, and all legal disclaimers apply.

If this paper is publishing under a Transparent Peer Review model then Peer Review reports will publish with the final article.

ARTICLE IN PRESS

© The Author(s) 2026. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

ARTICLE IN PRESS

Title Page

Title: Long Term Outcomes of Valve Sparing Aortic Root Replacement Versus Conventional Aortic Root Replacement Using a Mechanical Prosthesis by Propensity Score Matching

Keywords: Valve-Sparing; Aortic Root Replacement; David procedure; Modified Bentall procedure; Bio-Glue–Reinforced; Aortic Valve, Survival Rate, Propensity Score Matching; Long-Term Outcome

Gökhan Güneş[1]	Orcid ID: 0000-0003-4163-8951	gokhaangunes@gmail.com
Çiğdem Tel Üstünışık[2]	Orcid ID: 0000-0003-2210-1817	cigdemtel@gmail.com
Berk Arapi[2]	Orcid ID: 0000-0003-2724-450X	berkarapi@hotmail.com
Deniz Göksedef[2]	Orcid ID: 0000-0003-2350-4722	denizgoksedef@yahoo.com
Suat Nail Ömeroğlu[2]	Orcid ID: 0000-0003-0646-1716	suatnail@yahoo.com
Gökhan İpek[2]	Orcid ID: 0000-0003-0267-0545	gokhanipek@superonline.com
Ozan Onur Balkanay[2,*]	Orcid ID: 0000-0002-3550-671X	ozanonur.balkanay@iuc.edu.tr

[1]: Basaksehir Cam ve Sakura City Hospital, University of Health Sciences, Istanbul, Turkey

[2]: Istanbul University-Cerrahpasa, Cerrahpasa Medical Faculty, Department of Cardiovascular Surgery, Istanbul, Turkey

***: Corresponding Author:** Ozan Onur Balkanay, ozanonur.balkanay@iuc.edu.tr

Istanbul University-Cerrahpasa, Cerrahpasa Medical Faculty, Department of Cardiovascular Surgery, Istanbul, Turkey

ARTICLE IN PRESS

ARTICLE IN PRESS

Abstract

Introduction: This study aimed to compare the early and long-term postoperative outcomes of valve-sparing and Bio-Glue–reinforced non-valve-sparing aortic root replacement surgeries in patients diagnosed with aortic root aneurysms and/or aortic dissection.

Materials and Methods: A total of 107 patients, aged 15 to 84, diagnosed with aortic root aneurysm and/or aortic dissection, underwent aortic root replacement using either the David procedure (n=30) or the Bio-Glue–Reinforced Modified Bentall procedure (n=77). All surgeries were performed by the same surgical team at a tertiary university hospital's cardiovascular surgery clinic between April 2007 and April 2018. The patients' preoperative characteristics, early postoperative outcomes, and long-term results were retrospectively reviewed. Further analyses were conducted after propensity-score matching to evaluate survival outcomes.

Results: Among the 30 patients who underwent the David procedure, 4 required reoperation due to aortic insufficiency (13.3%). In contrast, no reoperation was required in the Bentall group due to aortic valve pathology (p=0.001). Survival analysis showed similar 30-day survival rates between the groups; however, after propensity-score matching, the Bentall group demonstrated significantly higher long-term survival compared to the David group (96.7% vs. 76.7%, p=0.005).

Conclusion: Valve-sparing techniques, such as the David procedure, have a higher reoperation rate compared to non-valve-sparing techniques like the modified Bentall procedure. While the valve-sparing David procedure achieves good outcomes, the Bio-Glue–Reinforced modified Bentall procedure should be recognized for its comparable and potentially superior long-term survival outcomes.

ARTICLE IN PRESS

ARTICLE IN PRESS

Introduction

Treatment options for aortic root replacement, indicated for aneurysm and/or dissection, include valve-sparing and non–valve-sparing surgical techniques. The most common valve-sparing method is the David procedure, in which the aortic root is replaced with a Dacron graft placed beneath the annulus, preserving both the annulus and the native valve to prevent dilation (reimplantation technique).[1,2] Alternatively, total replacement of the aortic valve, root, and ascending aorta is performed using a mechanical valve with a tubular polyester graft, known as the "*Bentall procedure with a mechanical valve"*.[3] Its main drawbacks include higher risk of early bleeding and late pseudoaneurysm, often at anastomotic sites such as the coronary ostia [4-9] and the requirement for lifelong anticoagulation. To reduce these risks, we modified the Bentall procedure by reinforcing the coronary button anastomoses with Bio-Glue (Bio-Glue–reinforced modified Bentall)(Figure 1).

ARTICLE IN PRESS

ARTICLE IN PRESS

Figure 1. Bio-Glue–reinforced modified Bentall procedure



The photograph was taken by the corresponding author during routine clinical care at our institution.

White asterisk: *Left coronary button anastomosis to the Bentall graft*

Yellow arrow: *Bio-Glue used to reinforce the button anastomosis*

White arrow: *Standard suction device aspirating excess Bio-Glue material*

ARTICLE IN PRESS

The aim of this study is to compare the early and long-term outcomes of patients undergoing either the Bio-Glue–reinforced modified Bentall or the David procedure. Despite ongoing debate, this study seeks to clarify which approach can be applied with long-term confidence, particularly regarding survival and reoperation.

Materials and Methods

Approval from the university clinical research ethics committee was obtained prior to the study. This study included 107 patients, aged 15–84, who underwent aortic root replacement due to aortic aneurysm and/or dissection, performed by the same surgical team of a tertiary between April 2007 and April 2018. Retrospective data were used. All patients who underwent valve-sparing and non–valve-sparing aortic root replacement were included, and early, mid-, and long-term follow-up results were evaluated. To ensure a more homogeneous comparison between the Bentall and David procedures, only Bentall patients with mechanical valve grafts were included. Consequently, cases involving non–valve-sparing replacement with a bioprosthetic valve were excluded.

ARTICLE IN PRESS

Human Ethics and Consent to Participate

Our study was conducted following the approval of the University Local Clinical Trials, Research Ethics Committee (Reference number: 83045809-604.01.02-368026). Informed consent was obtained from all individual participants included in the study. For participants under the age of 18, additional informed consent was obtained from a parent and/or legal guardian. All data were kept anonymous and analyzed retrospectively. Our study was conducted in accordance with the Declaration of Helsinki.

ARTICLE IN PRESS

Surgical Indications for Valve-Sparing Aortic Root Replacement (David Procedure)

Valve-sparing aortic root replacement was performed in selected patients who met the following criteria:

Aortic Root Aneurysm

Aneurysmal dilation of the aortic root had reached the following thresholds:

- ≥ 45 mm in patients with genetic syndromes associated with an increased risk of rupture (e.g., Marfan syndrome or other heritable aortopathies),
- ≥ 55 mm in patients with a tricuspid aortic valve and no additional risk factors.

and

Aortic Root Aneurysm with Favorable Valve Morphology

- Aortic valve function was normal or near-normal (none or mild regurgitation/stenosis),
- The valve leaflets were pliable and mobile, without significant calcification or fenestration.

and/or

Acute Type A Aortic Dissection Involving the Aortic Root

- The aortic valve was intact or minimally affected,
- Patients were hemodynamically stable enough to undergo a more complex valve-sparing procedure.

Surgical Indications for the Bio-Glue–Reinforced Modified Bentall Procedure

The Bio-Glue–reinforced modified Bentall procedure was preferred in cases where valve preservation was not feasible, including:

Ascending Aortic and Aortic Root Aneurysms

Aneurysmal dilation had reached:

ARTICLE IN PRESS

ARTICLE IN PRESS

- ≥ 45 mm in patients with genetic risk factors (e.g., Marfan syndrome or other heritable aortopathies),
- ≥ 50 mm in patients with a bicuspid aortic valve,
- ≥ 55 mm in patients with a tricuspid aortic valve and no additional risk factors.

and

Aortic Root Aneurysm with Poor Valve/Root Morphology

- Aortic valve function was severely compromised (severe regurgitation or stenosis),
- Valve leaflets exhibited significant calcification or fenestration, rendering them unsuitable for valve-sparing techniques,
- Tissue quality was poor or root anatomy was too complex for safe dissection and reimplantation.

and/or

Acute Type A Aortic Dissection Involving the Aortic Root

- The aortic valve and/or annulus were destructed,
- Patients had severe aortic valve insufficiency,
- Significant valve calcification or fenestration was present,
- Aortic root tissue was fragile or irreparable,
- Patients were hemodynamically unstable, precluding a valve-sparing approach.

Surgical Techniques

All procedures were performed by two experienced surgeons. A median sternotomy was performed on the patients, and cardiopulmonary bypass was initiated after systemic heparinization. Alpha-stat pH management was applied. The aorta was most commonly used as the cannulation site. Alternatively, axillary and femoral cannulation were performed. For patients

ARTICLE IN PRESS

undergoing antegrade cerebral perfusion, axillary cannulation was usually employed. Venous cannulation was performed from the right atrium, and a vent was placed in the right superior pulmonary vein. Myocardial protection was achieved with intermittent antegrade and retrograde isothermic blood cardioplegia.

In patients undergoing the David reimplantation technique, the aortic valve was inserted into a straight tubular Dacron graft. The dilated aortic sinuses were resected in a manner that preserved approximately 4–5 mm of arterial tissue from the annulus. Using 4-0 double-armed polyester sutures, stitches were passed from inside to outside in a single horizontal plane through the left ventricular outflow tract. On the right side, sutures were aligned in a single horizontal plane, whereas on the left, care was taken to place them in accordance with the scalloped contour of the aortic annulus. The diameter of the selected Dacron graft was matched to the length of the free edge of the aortic leaflet. After dividing the graft into three equal parts, it was advanced downward by placing the scalloped aortic valve into the graft in a manner that aligned the segments with the right, left, and non-coronary commissures. The sutures passed through the annulus were brought out through the graft wall and tied externally. If annuloplasty was required, it was performed using the sutures placed at the non-coronary commissure. All three commissures of the aortic valve were suspended within the graft using 4-0 pledgeted polypropylene sutures. Implantation was completed with a continuous suture technique by passing through the 4–5 mm of arterial tissue preserved for suturing. The graft was then filled with serum, and the condition of the aortic valve was assessed. Subsequently, the coronary buttons were reimplanted into the appropriate sinuses.

In patients undergoing the modified Bentall procedure, the aortic valve and the entire aortic root were resected, while approximately 1 cm of aortic tissue was preserved around the coronary

ARTICLE IN PRESS

artery ostia. A composite graft was then constructed by suturing a prosthetic valve to a vascular graft of matching diameter using 4-0 polypropylene sutures. The conduit was implanted into the aortic root by placing pledgeted sutures individually through the native aortic annulus and then through the sewing ring of the prosthetic valve at the base of the composite graft.

Subsequently, the coronary ostial buttons were anastomosed to corresponding openings created in the graft using the inclusion technique and continuous 5-0 polypropylene sutures. The anastomosis was performed first for the left coronary ostium, followed by the right.

Patients who underwent the Bentall procedure with biological valve prostheses were excluded from the analysis. Only those receiving mechanical composite grafts were included to ensure homogeneity within the study cohort. This criterion was applied to avoid variability in outcomes associated with prosthesis type and to enable a more valid comparison with patients undergoing the valve-sparing David procedure.

To minimize the risk of early postoperative bleeding and late pseudoaneurysm formation at the coronary ostial anastomosis sites, BioGlue was selectively applied to reinforce the coronary button anastomoses in the modified Bentall group, a technique referred to as the BioGlue-reinforced modified Bentall procedure. This approach was chosen based on the lower anticipated likelihood of future reoperations in these patients, as the use of BioGlue has been associated with increased technical challenges during reintervention due to tissue stiffness and adhesions. BioGlue reinforcement of coronary reimplantation sites was performed exclusively in the modified Bentall group, where the anticipated need for future reoperation is relatively low. In contrast, in valve-sparing procedures—where reoperation is more likely—the use of surgical adhesives was deliberately avoided to preserve the natural compliance of the aortic root and to

ARTICLE IN PRESS

minimize surgical morbidity during potential reinterventions. Following coronary artery reimplantation, the distal graft anastomosis was then completed in standard fashion.

Statistical Analysis

Patient data and follow-up information were collected retrospectively, anonymized, and subsequently analyzed. Continuous variables were expressed as mean ± standard deviation, while categorical variables were reported as counts and percentages (n, %). To evaluate the distribution of continuous variables, normality was assessed using the Shapiro–Wilk test and confirmed by visual inspection of histograms and Q-Q plots. For the comparisons of demographic data, preoperative, intraoperative, and postoperative continuous variables were performed using Student's T-test. Categorical variables were analyzed using the chi-square, Fisher's exact test, or the Fisher–Freeman–Halton exact test, as appropriate. Survival analysis was conducted using the Kaplan-Meier method, with comparisons between groups made using the log-rank test. To assess the risk of reoperations, cumulative incidence analysis was performed using Gray's test. A histogram of propensity score matching was utilized to illustrate the distribution of predicted probabilities. A p-value of less than 0.05 were considered statistically significant.

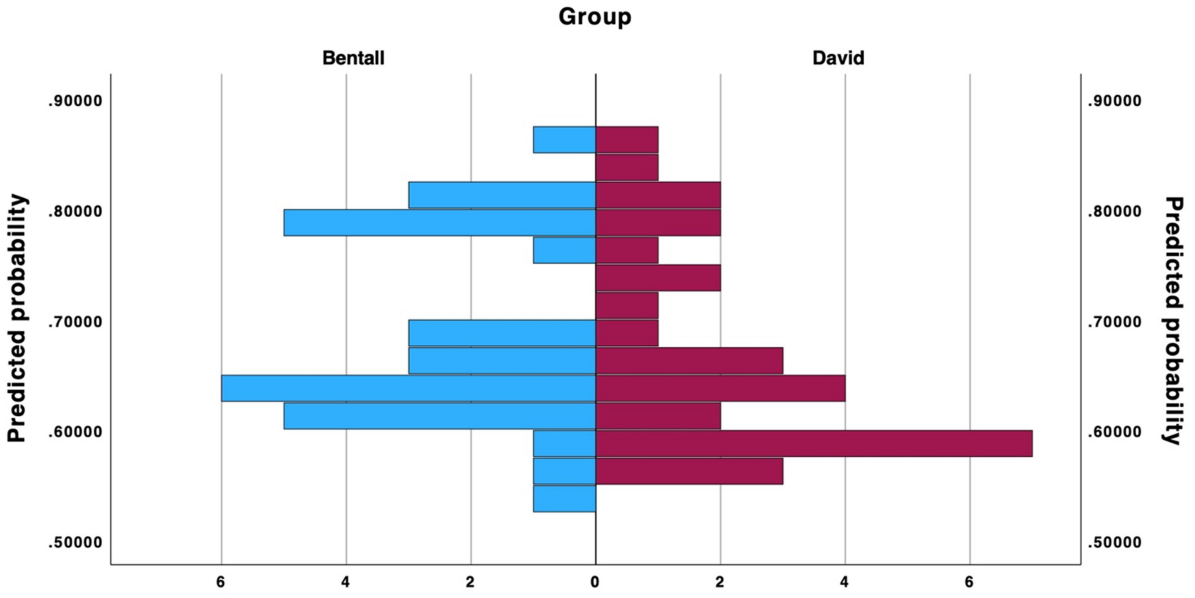
ARTICLE IN PRESS

Propensity Score Matching

Propensity score matching (PSM) was performed between the groups (Figure 2). Age, sex, body mass index (BMI), emergency surgery, and the presence of aortic dissection were included as covariates in the analysis. The nearest-neighbor 1:1 matching method was employed for the matching process. A caliper width of 0.1 standard deviations of the propensity score was used. Following PSM, a total of 60 patients—30 from each group—were included in the matched cohort.

ARTICLE IN PRESS

Figure 2. Histogram showing the distribution of predicted probability (population pyramid frequency) by groups.



ARTICLE IN

ARTICLE IN PRESS

Results

The study was conducted on a total of 107 cases operated on by the same surgical team between April 2007 and April 2018 for aortic root aneurysm and/or proximal (Stanford Type A) aortic dissection. The ages of the cases ranged from 15 to 84, with a mean age of 54.54 ± 15.47 years. Of the cases, 30 (28%) were female and 76 (72%) were male. The mean body mass index (BMI) was found to be 28.06 ± 5.44 kg/m². In terms of the timing of operations, 26 of the 107 patients (24.5%) underwent surgery under emergency conditions, with 21 of them (80.7%) operated on due to acute dissection. A total of 84 patients (79.2%) were operated on for ascending aortic aneurysm, and 21 patients (25.6%) were operated on for acute dissection. Additionally, 9 patients (8.5%) presented with a rupture threat, 6 patients (5.7%) had a penetrating aortic ulcer, and 1 patient (0.9%) had an intramural hematoma.

When the preoperative clinical characteristics of the patients were evaluated, 36 patients (40.4%) had hyperlipidemia, 49 patients (50.5%) had hypertension, 13 patients (13.3%) had diabetes mellitus, 33 patients (36.3%) had coronary artery disease, and 23 patients (27.1%) had chronic obstructive pulmonary disease (COPD). A total of 49 patients (50.5%) were smokers, 4 patients (3.7%) had Marfan syndrome, 1 patient (0.9%) had Takayasu arteritis, and 1 patient (0.9%) had rheumatoid arthritis. A total of 68 patients (64.8%) had NYHA class 1 symptoms, 35 patients (33.3%) had NYHA class 2 symptoms, and 2 patients (1.9%) had NYHA class 3 symptoms. A total of 11 patients (10.8%) underwent surgery in a state of cardiogenic shock. In terms of comorbidities, 6 patients (5.9%) had a history of stroke, and 12 patients (11.3%) had a history of previous cardiac intervention. One patient (0.9%) had a history of gastrointestinal bleeding, 1 patient (0.9%) had a diagnosis of laryngeal carcinoma, and 2 patients (1.9%) had a history of thrombocytopenia.

ARTICLE IN PRESS

When the preoperative clinical characteristics of the patients were examined, no statistically significant differences were found between the groups in terms of hyperlipidemia, hypertension, diabetes mellitus, smoking, the presence of coronary artery disease, heart failure (NYHA), cardiogenic shock, chronic obstructive pulmonary disease, previous stroke, Marfan syndrome, or other connective tissue diseases ($p>0.05$) (Table 1). It was found that the rate of previous cardiac intervention was significantly higher in the Bio-Glue–reinforced modified Bentall group compared to the David group ($p=0.018$) (Table 1).

When the preoperative data of the patients were examined, the mean blood creatinine level was found to be 1.02±0.43 mg/dL, and the mean FEV_1/FVC value was 75.68±10.41. In the evaluation of preoperative echocardiography findings, the mean left ventricular ejection fraction (EF) was determined to be 55.81±7.30%. Aortic insufficiency was observed in 82 patients (94.2%), and mitral insufficiency was found in 47 patients (55.3%).

No statistically significant differences were found between the groups in terms of age, BMI, gender, creatinine levels, EF, FEV_1/FVC, the presence of mitral insufficiency, aortic insufficiency, or the severity of mitral insufficiency ($p>0.05$) (Table 2). It was observed that the proportion of patients with advanced aortic insufficiency was higher in the Bio-Glue–reinforced modified Bentall group compared to the David group ($p=0.011$) (Table 2).

When evaluating the diameter of the ascending aorta, dissection types, and presenting symptoms of the patients, the mean aneurysm diameter was found to be 53.93±10.01 mm, and 21 patients had Type A dissection. Among the patients who underwent surgery, 9 (64.4%) had isolated chest pain, 1 (7.1%) had chest and abdominal pain, 1 (7.1%) had chest and back pain, and 3 had isolated back pain.

ARTICLE IN PRESS

When examining the timing and indications for surgery, no statistically significant differences were found between the groups in terms of ascending aorta diameter, the presence of an aneurysm, acute dissection, or rupture threat ($p>0.05$) (Table 3).

When examining the graft diameter, surgical procedures, and additional surgical interventions performed on the patients, the average diameter of the grafts used was found to be 28.35±2.05 mm. A valve-sparing David procedure was performed on 30 patients (28%), while a non-valve-sparing modified Bentall procedure was performed on 77 patients (72%). In addition to aortic root replacement, hemiarch replacement was performed on 58 patients (54.2%), total arch replacement and the elephant trunk procedure were performed on 7 patients (6.5%). In 3 cases (2.8%) where total arch replacement was performed, the proximal part of the arch aorta was prepared in an island form, while in 4 cases (3.7%) the arch elements were separated into branches and anastomosed to the graft. Coronary artery bypass grafting (CABG) was performed on 38 patients (35.5%), and mitral valve repair or replacement was performed on 8 patients (7.5%). No hybrid interventions or open stent graft implantation were performed on any patients.

When the surgical procedures and additional surgical interventions applied to the patients were evaluated, no statistically significant differences were found between the groups in terms of hemiarch replacement, total arch replacement, types of total arch replacement, or the elephant trunk procedure ($p>0.05$) (Table 4). There was also no statistically significant difference between the groups in terms of the rates of coronary bypass and mitral valve surgery as additional surgical interventions ($p>0.05$) (Table 4).

When examining the cannulation techniques and cerebral perfusion strategies used during surgery, the total perfusion time was found to be an average of 212.12±76.66 minutes (minimum 63 minutes, maximum 467 minutes), the aortic cross-clamp time was an average of

ARTICLE IN PRESS

150.30±52.80 minutes (minimum 48 minutes, maximum 335 minutes), the total circulatory arrest time was an average of 14.27±6.95 minutes (minimum 2 minutes, maximum 38 minutes), and the level of hypothermia was an average of 18.64±1.94 °C (minimum 15 °C, maximum 26 °C). Total circulatory arrest was performed in 76 patients (71%), and cerebral protection was applied in 8 patients (7.7%), with antegrade cerebral perfusion being the preferred cerebral protection strategy in all of these cases. Antegrade cerebral perfusion was applied unilaterally in 6 patients (5.7%) and bilaterally in 3 patients (2.9%). As for the arterial cannulation strategy, the aorta was used in 53 patients (50.5%), the axillary artery in 37 patients (35.2%), and the femoral artery in 15 patients (14.3%).

When comparing the cannulation and cerebral protection methods between the two groups, no statistically significant differences were found between the groups in terms of total perfusion time, total circulatory arrest time, cerebral perfusion time, or total arrest time for the lower extremities ($p>0.05$) (Table 5). It was found that the hypothermia levels in the Bentall group were statistically significantly higher than those in the David group ($p=0.027$) (Table 5). The rate of hypothermic circulatory arrest in the Bentall group was statistically significantly lower than in the David group ($p=0.026$) (Table 5). The aortic cross-clamp time in the Bentall group was statistically significantly lower than in the David group ($p=0.017$) (Table 5). No statistically significant differences were found between the groups in terms of SACP/RCP rates or whether SACP was unilateral or bilateral ($p>0.05$) (Table 5).

When the postoperative complications of the patients were examined, myocardial ischemia/infarction occurred in 1 patient (1%), low cardiac output syndrome in 17 patients (16.8%), arrhythmia in 28 patients (27.7%), pericardial effusion/tamponade in 19 patients (20.7%), pulmonary parenchymal complications such as atelectasis in 5 patients (5.2%), and

ARTICLE IN PRESS

pulmonary edema in 1 patient (1%). Pleural complications were observed in 9 patients (9.3%). Acute kidney injury developed in 10 patients (10.1%), all of whom required temporary hemodialysis. Acute liver injury was observed in 2 patients (2%), and hepatobiliary ischemia in 1 patient (1%). A total of 7 patients had perioperative strokes, with 4 patients (4.1%) showing temporary clinical effects and 3 patients (3.1%) experiencing permanent damage. In addition, 4 patients (4.2%) had diffuse neurological damage, and 5 patients (5.2%) had localized neurological damage. A total of 50 patients (50.5%) required the replacement of more than 3 units of blood products. Cardiac support with intra-aortic balloon pump or extracorporeal membrane oxygenation (ECMO) was provided to 15 patients (14.6%).

When the postoperative complications of the groups were examined, no statistically significant differences were found between the groups in terms of myocardial ischemia/infarction, low cardiac output syndrome, arrhythmia, pericardial effusion/tamponade, pulmonary parenchymal complications, pleural complications, acute kidney injury, stroke, postoperative bleeding, wound infection, systemic infections, the need for postoperative blood transfusion, or the need for intra-aortic balloon pump/ECMO ($p>0.05$) (Table 6). When comparing the reoperation rates due to aortic valve pathology between the groups, it was observed that reoperation was significantly more frequent following David procedures than Bio-Glue–reinforced modified Bentall procedures ($p = 0.001$) (Table 6). Moreover, Gray's test revealed a statistically significant difference in the cumulative incidence of reoperation for aortic valve pathology between the valve-sparing and non–valve-sparing groups (statistic = 5.875, $p = 0.015$).

ARTICLE IN PRESS

ARTICLE IN PRESS

When examining the postoperative follow-ups of the patients, it was found that the patients were followed in the intensive care unit for an average of 6.83±14.53 days. The average hospital stay was 15.34±17.23 days.

In-hospital mortality and 30-day mortality were observed in 18 patients (16.8%), with these patients surviving for an average of 7.32±8.13 days. The surviving patients (83.2%) were followed for an average of 42.52±29.60 months.

The EuroSCORE II predicted mortality rate before propensity score matching (PSM) was 10.69% ± 9.29% for the Bio-Glue–Reinforced Modified Bentall group and 14.02% ± 13.35% for the David group. After PSM, the predicted mortality rate was 5.95% ± 3.14% for the Bio-Glue–Reinforced Modified Bentall group and remained 14.02% ± 13.35% for the David group.

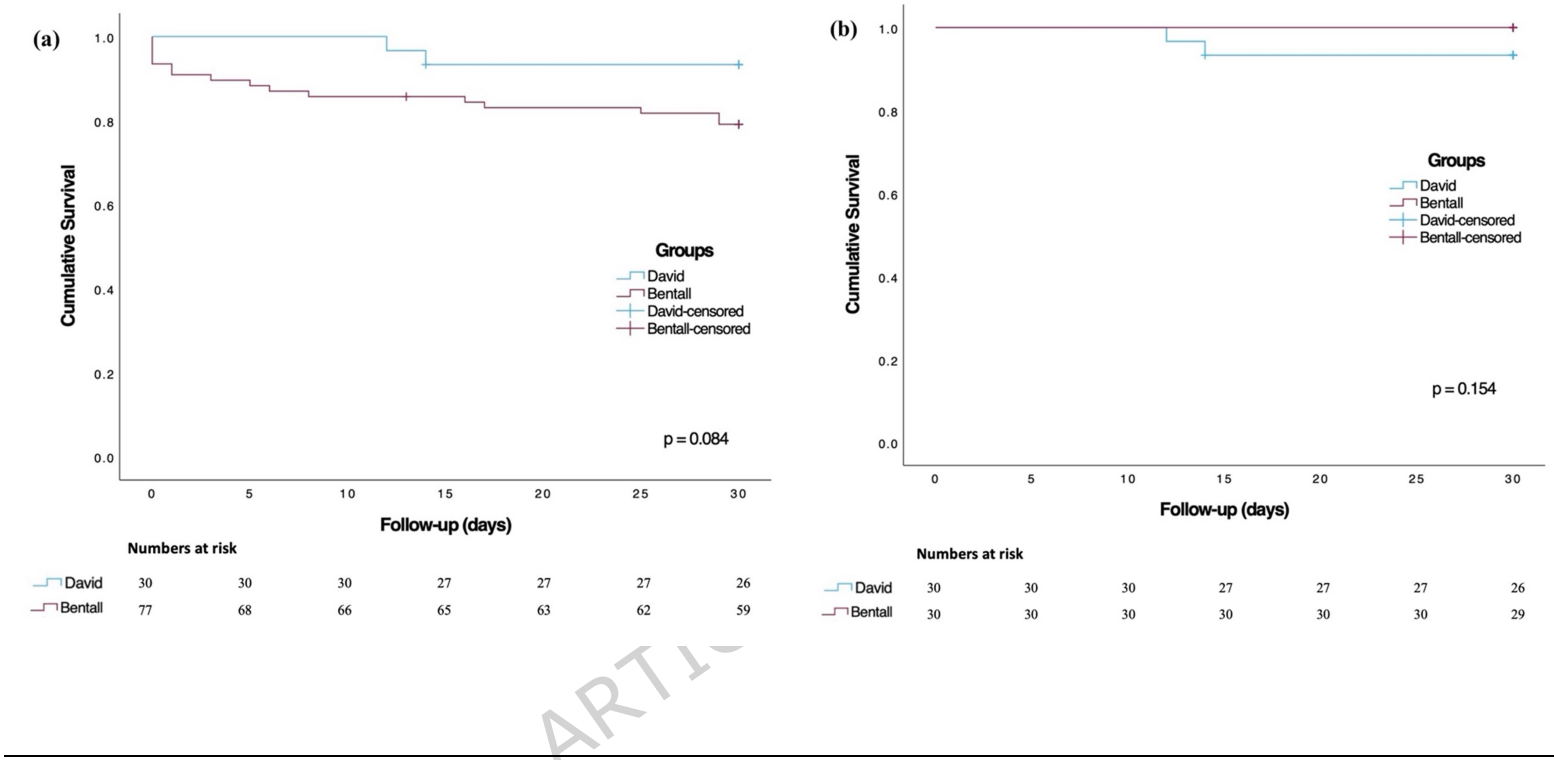
Operative mortality before PSM was observed in 8 patients (10.4%) in the Bio-Glue–Reinforced Modified Bentall group and 2 patients (6.7%) in the David group ($p = 0.080$; Table 8). After PSM, operative mortality was 0 (0%) in the Bio-Glue–Reinforced Modified Bentall group and 2 patients (6.7%) in the David group ($p = 0.246$; Table 8).

When examining the postoperative follow-ups between the groups, no statistically significant differences were found between the groups in terms of ICU stay, hospitalization duration, intubation time, bleeding (24 hours), total bleeding, in-hospital mortality, survival time, or time to the last follow-up for living patients, 30-day mortality, overall mortality, and long-term survival ($p > 0.05$; Tables 7 and 8; Figure 3 and 4).

ARTICLE IN PRESS

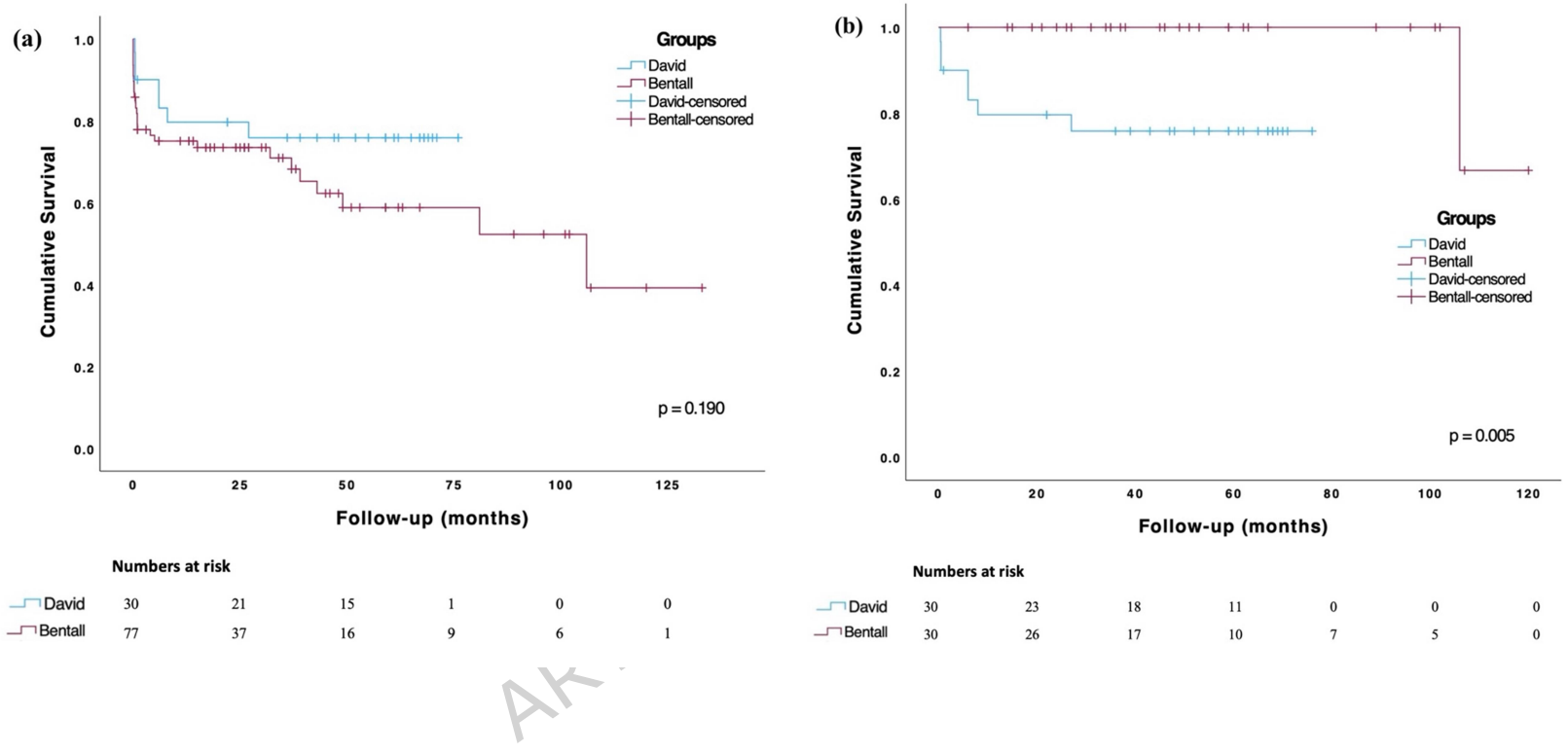
ARTICLE IN PRESS

Figure 3. Thirty-day survival curves for the groups before (a) and after propensity-score matching (b)



*: *Statistical comparisons were performed using the log-rank test.*

Figure 4. Long-term survival curves for the groups before (a) and after propensity-score matching (b)



*: *Statistical comparisons were performed using the log-rank test.*

ARTICLE IN PRESS

When the first month of the postoperative period was evaluated, mortality was observed in 18 out of 107 cases, corresponding to a survival rate of 83.2%. During this period, 61 out of 77 cases (79.2%) in the modified Bentall group survived, while 28 out of 30 cases (93.3%) in the David group survived. No statistically significant difference was observed between the modified Bentall and David groups in terms of 30-day survival rates (p=0.084) (Figure 3a). After propensity-score matching, mortality during the first month of the postoperative period was observed in 2 out of 60 cases, resulting in a survival rate of 96.7%. During this period, all 30 cases (100%) in the Bio-Glue–reinforced modified Bentall group survived, while 28 out of 30 cases (93.3%) in the David group survived. No statistically significant difference was observed between the groups in terms of 30-day survival rates (p=0.154) (Figure 3b).

In the long-term follow-up data, 73 out of 107 cases (68.2%) were alive, with an average follow-up period of 42.5±29.6 months. In the modified Bentall group, 50 out of 77 cases (64.9%) were alive, with an average follow-up of 40.4±32.3 months. In the David group, 23 out of 30 cases (76.7%) were alive, with an average follow-up of 42.5±26.3 months. No statistically significant difference was observed between the Bio-Glue–reinforced modified Bentall and David groups in terms of long-term survival rates during the follow-up period (p=0.190) (Figure 4a). After propensity-score matching, 52 out of 60 cases (86.7%) were alive, with an average follow-up period of 48±29.6 months. In the Bio-Glue–reinforced modified Bentall group, 29 out of 30 cases (96.7%) were alive, with an average follow-up of 53.4±32.1 months. In the David group, 23 out of 30 cases (76.7%) were alive, with an average follow-up of 42.5±26.3 months. A statistically significant difference was observed between the propensity-score-matched modified Bentall and David groups in terms of long-term survival rates during the follow-up period (p=0.005) (Figure 4b).

ARTICLE IN PRESS

ARTICLE IN PRESS

Discussion

The surgical techniques for managing aortic root and ascending aortic aneurysms have evolved significantly over the past four decades. While the majority of patients continue to be treated using the modified Bentall procedure with either mechanical or biological valve conduits, there has been a growing number of surgeons adopting valve-sparing techniques, and the indications for such procedures are expanding.[10-16] One of the most critical factors in achieving favorable outcomes in this field is appropriate patient selection, supported by thorough evaluation of aortic valve morphology and function. The Bentall procedure, a well-established valve-conduit technique used in the treatment of ascending aortic aneurysms and dissections associated with aortic valve pathology, remains widely practiced globally. Since the introduction of Dacron grafts by DeBakey, ongoing technical refinements have improved its safety and efficacy.[17] T.P. Lewis and colleagues emphasized the simplicity and reliability of the Bentall-De Bono technique with direct coronary reimplantation, highlighting its low complication rates and favorable short- and long-term outcomes.[19] However, compared to valve-sparing procedures, a notable disadvantage of the Bentall operation using a mechanical valve is the increased risk of early postoperative bleeding and late pseudoaneurysm formation—particularly at the anastomotic sites, including the coronary ostia.[4-9] Additionally, the requirement for lifelong anticoagulation is a significant limitation. As a modification of the conventional Bentall approach, we employed Bio-Glue to reinforce the coronary button anastomoses in what we define as the Bio-Glue–reinforced modified Bentall procedure. This technique was intended to reduce the risks of early bleeding and late pseudoaneurysm formation at the coronary ostial anastomosis sites (Figure 1). In our study, the Bio-Glue–reinforced modified Bentall group

ARTICLE IN PRESS

exhibited a similarly low complication rate compared to the David group. Hemorrhage related to coronary artery reimplantation remains a significant concern in Bentall procedures, particularly in patients with annuloaortic ectasia, where the coronary ostia are displaced distally and laterally, resulting in increased anastomotic tension.[19]

To mitigate such risks, our modified technique involved mobilizing the coronary ostia approximately 1–2 cm from the surrounding tissues prior to the button anastomoses. Anastomoses were performed using a continuous 5-0 polypropylene suture technique, followed by application of Bio-Glue to reinforce the coronary reimplantation sites. Postoperative outcomes in the Bio-Glue–reinforced modified Bentall group showed a similarly low and acceptable amount of bleeding and comparable transfusion requirements relative to the David group. In select cases, additional sutures and surgical tissue adhesives were applied intraoperatively to further control bleeding at the coronary button sites. This may explain why, contrary to prior literature suggesting higher postoperative bleeding rates in Bentall procedures, our findings demonstrated comparable outcomes between the groups.[12,14]

Valve-sparing aortic root surgery, such as the David procedure, can be safely performed in appropriately selected patients with acute type A dissections or aortic root aneurysms.[10,13,15,16] In such cases, this technique aims not only to address the life-threatening dissection but also to prevent long-term complications, including recurrent dissection, pseudoaneurysm at the proximal anastomosis, and recurrent aortic insufficiency.[4-9] While some previous studies have reported longer cardiopulmonary bypass times, total operative durations, and extended bleeding control periods in the Bentall procedure compared to the David procedure, our findings suggest otherwise.[12] In our study, the Bentall group had shorter cross-clamp times, consistent with other studies in the literature.[16] It should be noted that valve-

ARTICLE IN PRESS

sparing aortic root surgery is technically demanding, associated with longer cross-clamp times, and typically performed in specialized centers with significant experience managing acute aortic dissection. The reimplantation technique used in the David procedure provides structural support to weakened aortic tissue and may offer hemostatic advantages, particularly in cases of acute dissection where coagulopathy is common in the late intraoperative period. Nonetheless, despite these theoretical benefits, our findings revealed similar outcomes between groups in terms of bleeding and transfusion requirements. These results differ from studies that have recommended preferential use of the David procedure based on its perceived advantages in reducing blood loss and transfusion needs.

Although the modified Bentall procedure presents several technical challenges, it is widely regarded as the first-line approach for aortic root replacement, particularly in urgent settings and in patients with non-repairable aortic valves.[16] Accordingly, in our study, patients with more severe clinical presentations were more frequently included in the Bio-Glue–reinforced modified Bentall group. Although statistical significance was not achieved, the Bentall group exhibited a higher incidence of emergent surgery (28.9% vs. 13.3%; p = 0.092), acute aortic dissection (22.4% vs. 13.3%; p = 0.293), and the need for postoperative mechanical circulatory support, including intra-aortic balloon pump and extracorporeal membrane oxygenation (19.2% vs. 3.3%; p = 0.061), compared to the David group. Conversely, patients in the David group more frequently underwent extensive distal aortic procedures, though these differences were also not statistically significant. These included hemiarch replacement (60.0% vs. 51.9%; p = 0.453), total arch replacement (13.3% vs. 3.9%; p = 0.095), and elephant trunk procedures (13.3% vs. 3.9%; p = 0.095). This greater extent of distal aortic intervention likely accounts for the higher use of hypothermic circulatory arrest (86.7% vs. 64.9%; p = 0.026), lower average temperatures

ARTICLE IN PRESS

during circulatory arrest (18.8 ± 2.5°C vs. 21.4 ± 4.1°C; p = 0.002), and longer aortic cross-clamp times (169.8 ± 58.7 minutes vs. 142.7 ± 48.7 minutes; p = 0.002) observed in the David group. These findings suggest that more extensive surgical strategies were more feasible in the David group, likely reflecting better preoperative clinical conditions and allowing surgeons to focus on the distal aorta without the added complexity of proximal pathology under hemodynamically unstable conditions.

Importantly, during long-term follow-up after propensity score matching, the Bio-Glue–reinforced modified Bentall group demonstrated significantly higher survival compared to the David group [96.7% (53.4 ± 32.1 months) vs. 76.7% (42.5 ± 26.3 months); p = 0.005] (Figure 4b).

Surgical interventions for aortic dissections and aortic aneurysms remain among the most complex procedures in cardiovascular surgery due to their potential to cause life-threatening complications across multiple organ systems, particularly mortality and neurological deficits. Although elective cases of aortic root aneurysms without dissection are generally associated with lower mortality rates, patients undergoing urgent or emergent operations for aortic root aneurysms tend to experience significantly higher mortality.

In our study, operative mortality before propensity score matching (PSM) was 10.4% (n = 8) in the Bio-Glue–reinforced modified Bentall group (EuroSCORE II predicted mortality: 10.69% ± 9.29%) and 6.7% (n = 2) in the David group (EuroSCORE II: 14.02% ± 13.35%) (p = 0.080). After PSM, operative mortality was 0% in the Bentall group (EuroSCORE II: 5.95% ± 3.14%) and remained 6.7% in the David group (EuroSCORE II: 14.02% ± 13.35%) (p = 0.246; Table 8). Although relatively high, these mortality rates were consistent with the predicted risks based on the EuroSCORE II system. Furthermore, after matching, the observed mortality rates

ARTICLE IN PRESS

aligned with current findings in the literature.[20,21] The elevated early mortality observed in our cohort may be attributed to the high proportion of emergent, urgent, and salvage surgeries, the presence of acute aortic dissection, and the substantial burden of comorbidities, including a considerable number of patients with prior cardiac surgeries. Emergent presentations, such as type A aortic dissection, are known to be associated with high in-hospital mortality rates, ranging from 23.1% to 28.7% in reported series, and were likewise reflected in our findings as a likely contributing factor to increased early mortality.[22] In long-term follow-up, overall survival rates between the groups were comparable. However, after PSM, the Bentall group demonstrated statistically significantly higher survival rates than the David group. These findings support the clinical utility of both surgical approaches and suggest that the modified Bentall technique remains a reliable and effective option in appropriately selected patients, offering comparable and, in some cases, superior long-term outcomes.

Additionally, postoperative follow-up revealed no moderate or severe aortic valve regurgitation in either group, indicating successful valve preservation in the David cohort. Nevertheless, long-term data demonstrated a significantly higher rate of reintervention due to aortic valve pathology in the David group. Specifically, reoperation rates related to aortic valve pathology were significantly greater in the David group compared to the Bentall group ($p = 0.001$; Table 6). Gray's test further confirmed a statistically significant difference in the cumulative incidence of reoperation between valve-sparing and non–valve-sparing procedures (statistic = 5.875, $p = 0.015$).

To Spare or Not to Spare the Aortic Valve?

This question remains central to the evolving surgical management of aortic root disease.[23] Both the Bentall and David procedures have undergone significant technical

ARTICLE IN PRESS

refinements over recent decades. Despite the growing interest in valve-sparing techniques, the modified Bentall procedure continues to be widely regarded as the gold standard for aortic root replacement, especially in patients who are not ideal candidates for valve preservation.[20]

Conclusion

Valve-sparing and non–valve-sparing aortic root replacement surgeries can both be performed successfully in patients with aortic dissection and aortic root aneurysms. In our study, the valve-sparing approach was associated with a higher rate of reoperation due to aortic valve–related pathology compared to non–valve-sparing procedures. While it is widely acknowledged that non–valve-sparing procedures, such as the modified Bentall technique, carry a higher risk of complications related to lifelong anticoagulation therapy, our findings demonstrated similarly favorable outcomes in both surgical groups.

Notably, after propensity score matching, the Bio-Glue–reinforced modified Bentall procedure was associated with superior long-term overall survival and a lower incidence of aortic valve–related reoperations. Based on these findings, we conclude that although the valve-sparing David procedure yields favorable outcomes, the Bio-Glue–reinforced modified Bentall technique achieves comparable—and potentially superior—long-term survival, and should be regarded as a reliable and effective option in appropriately selected patients.

Limitations: This study has several limitations that should be acknowledged. First, its retrospective and observational design inherently introduces the risk of selection bias and unmeasured confounding, despite the use of propensity score matching (PSM) to balance baseline characteristics between groups. Second, the sample size was relatively small, and in particular the limited cohort sizes reduced the statistical power to detect significant differences

ARTICLE IN PRESS

and may have magnified the influence of individual events such as reoperations and early postoperative mortality.

Third, although all procedures were performed by two highly experienced surgeons, which reduces variability and the impact of technical learning curves, the case volume of David procedures included in the study period was relatively low. Nonetheless, these operations were conducted at a high-volume tertiary reference center with extensive expertise in complex aortic surgery, ensuring that results reflect practice beyond the early learning curve. Following PSM, the results demonstrated a reduction in baseline disparities, especially with regard to surgical urgency and preoperative risk, thereby supporting the effectiveness of the matching approach. Nonetheless, the findings should be interpreted with caution, as the limited sample size in subgroup analyses may restrict the generalizability of the results. Finally, the modest overall cohort size limited the ability to perform detailed subgroup analyses, and therefore the generalizability of some findings remains restricted. These limitations underscore the need for larger, prospective, multicenter studies to confirm and further explore the observations reported in this study.

ARTICLE IN PRESS

Competing interests: All of the authors declare no competing financial interests related to the manuscript.

Funding: None.

Ethical approval: Clinical Research Ethics Committee approve number is 83045809-604.01.02-368026.

Contributorship: G.G. primarily contributed in all of the steps of the study and writing processes of the manuscript including designing the study, analysing the data, conducting all of

ARTICLE IN PRESS

the processes. O.O.B. contributed in analysing the data, conducting all of the processes of the study and writing the manuscript, preparing tables and figures, revised the critical points in terms of content of the manuscript. All of the authors contributed all steps of the study and writing the final manuscript at varying rates and all of them approved final version of the manuscript.

Acknowledgements: None.

Data availability statement: The corresponding author can be contacted to obtain the anonymous dataset used and/or analyzed during the current study upon reasonable request.

ARTICLE IN PRESS

ARTICLE IN PRESS

References

1. David TE, Feindel CM. An aortic valve-sparing operation for patients with aortic incompetence and aneurysm of the ascending aorta. J Thorac Cardiovasc Surg 1992;103(4):617-21.
2. David TE, Feindel CM, Webb GD, Colman JM, Armstrong S, Maganti M. Aortic valve preservation in patients with aortic root aneurysm: results of the reimplantation technique. Ann Thorac Surg 2007;83(2):S732-5.
3. Bentall H, De Bono A. A technique for complete replacement of the ascending aorta. Thorax 1968;23(4):338-9.
4. Milano AD, Pratali S, Mecozzi G, et al. Fate of coronary ostial anastomoses after the modified Bentall procedure. *Ann Thorac Surg*. 2003;75(6):1797-1802. doi:10.1016/s0003-4975(03)00015-8
5. Meijboom LJ, Nollen GJ, Merchant N, et al. Frequency of coronary ostial aneurysms after aortic root surgery in patients with the Marfan syndrome. *Am J Cardiol*. 2002;89(9):1135-1138. doi:10.1016/s0002-9149(02)02290-7
6. Okamoto K, Casselman FP, De Geest R, Vanermen H. Giant left coronary ostial aneurysm after modified Bentall procedure in a Marfan patient. *Interact Cardiovasc Thorac Surg*. 2008;7(6):1164-1166. doi:10.1510/icvts.2008.183103
7. Grapow MT, Matt P, Zerkowski HR, Bernet F. Pseudoaneurysm in a marfan patient 16 years after Bentall operation. *Asian Cardiovasc Thorac Ann*. 2004;12(2):182-183. doi:10.1177/021849230401200222

ARTICLE IN PRESS

ARTICLE IN PRESS

8. Mesana TG, Caus T, Gaubert J, et al. Late complications after prosthetic replacement of the ascending aorta: what did we learn from routine magnetic resonance imaging follow-up?. *Eur J Cardiothorac Surg*. 2000;18(3):313-320. doi:10.1016/s1010-7940(00)00512-1

9. Dossche KM, Schepens MA, Morshuis WJ, de la Rivière AB, Knaepen PJ, Vermeulen FE. A 23-year experience with composite valve graft replacement of the aortic root. *Ann Thorac Surg*. 1999;67(4):1070-1077. doi:10.1016/s0003-4975(99)00162-9

10. Salehi Omran A, Aeen A, Nayebirad S, Vakili-Basir A, Najafi MS, Mohseni-Badalabadi R, Shirani S, Zoroufian A, Jalali A, Mostafanejad FA, Sahebjam M. Short and mid-term outcomes of valve-sparing, aortic root reimplantation (David's procedure). J Cardiothorac Surg 2024;19(1):36.

11. Sromicki J, Van Hemelrijck M, Schmiady MO, Greutmann M, Bonassin Tempesta F, Mestres CA, Vogt PR, Carrel TP, Holubec T. Twenty-five year experience with aortic valve-sparing root replacement in a single teaching center. Front Cardiovasc Med 2023;10:1104149.

12. Ushioda R, Shirasaka T, Kanamori T, Fujii A, Shirakawa M, Takeuchi T, Kamiya H. The David Operation Offers Shorter Hemostasis Time Than the Bentall in Case of Acute Aortic Dissection Type A. Cureus 2022;14(1):e21747.

13. Schamberger L, Leontyev S, Davierwala PM, Von Aspern K, Lehmann S, Misfeld M, Borger MA. David aortic valve-sparing reimplantation versus biological aortic root replacement: a retrospective analysis of 411 patients. Indian J Thorac Cardiovasc Surg 2020;36(Suppl 1):97-103.

ARTICLE IN PRESS

ARTICLE IN PRESS

14. Leontyev S, Schamberger L, Davierwala PM, Von Aspern K, Etz C, Lehmann S, Misfeld M, Borger MA. Early and Late Results After David vs Bentall Procedure: A Propensity Matched Analysis. Ann Thorac Surg 2020;110(1):120-126.

15. Mosbahi S, Stak D, Gravestock I, Burgstaller JM, Steurer J, Eckstein F, Ferrari E, Berdajs DA. A systemic review and meta-analysis: Bentall versus David procedure in acute type A aortic dissection. Eur J Cardiothorac Surg 2019;55(2):201-209.

16. Ergün S, Dedemoğlu M, Rabuş MB, Özbek B, Özgür MM, Tuncer MA, Balkanay M, Kirali MK. Short-term results of flanged Bentall de Bono and valve-sparing David V procedures for the treatment of aortic root aneurysms. Cardiovasc J Afr 2018;29(4):241-245.

17. Westaby S, Cecil B. Surgery of the thoracic aorta, in Westaby S (ed). Landmarks in cardiac surgery. Oxford, Isıs Medical Media 1997;223.

18. Lewis CT, Cooley DA, Murphy MC, Talledo O, Vega D. Surgical repair of aortic root aneurysms in 280 patients. Ann Thorac Surg 1992;53(1):38-45.

19. Coselli JS, Crawford ES. Composite valve-graft replacement of aortic root using separate Dacron tube for coronary artery reattachment. Ann Thorac Surg 1989;47(4):558-65.

20. Karangelis D, Tzertzemelis D, Demis AA, Economidou S, Panagiotou M. Eighteen years of clinical experience with a modification of the Bentall button technique for total root replacement. J Thorac Dis 2018;10(12):6733-6741.

21. Werner P, Gritsch J, Kaider A, Coti I, Osorio E, Mahr S, Stelzmueller ME, Kocher A, Laufer G, Andreas M, Ehrlich M. Long Term Results of the Modified Bentall Procedure With Mechanical and Biological Composite Valve Grafts. Front Cardiovasc Med 2022;9:867732.

ARTICLE IN PRESS

ARTICLE IN PRESS

22. Nappi F, Gambardella I, Singh SSA, Salsano A, Santini F, Spadaccio C, Biancari F, Dominguez J, Fiore A. Survival following acute type A aortic dissection: a multicenter study. J Thorac Dis 2023;15(12):6604-6622.

23. Iannacone EM, Lau C, Jr Soletti G, Olaria RP, Harik L, Dimagli A, Girardi LN. Aortic valve-sparing root replacement or Bentall? Ann Cardiothorac Surg 2023;12(3):168-178.

ARTICLE IN PRESS

ARTICLE IN PRESS

Table 1: Patients' Preoperative Clinical Characteristics

	Bentall (n:77) n (%)	**David** (n:30) n (%)	P value
Hyperlipidemia (n:89)	23 (37.7)	13 (46.4)	[a]0.436
Hypertension (n:91)	36 (52.2)	13 (46.4)	[a]0.608
DM (n:98)	10 (14.3)	3 (10.7)	[b]0.752
Smoking (n:97)	35 (50.7)	14 (50)	[a]0.948
NYHA (n:105)			
1	50 (66.7)	18 (60)	[c]0.110
2	25 (33.3)	10 (33.3)	
3	0 (0)	2 (6.7)	
4	0 (0)	0 (0)	
CAD (n:91)	22 (34.9)	11 (39.3)	[a]0.689
Cardiogenic Shock (n:102)	8 (11)	3 (10.3)	[b]0.999
Previous Stroke (n:102)	3 (4.1)	3 (10.3)	[b]0.348
COPD (n:85)	15 (23.8)	8 (36.4)	[a]0.254
Cardiac Intervention (n:106)	12 (15.8)	0 (0)	[b]0.018*
Marfan/CTD (n:77)	8 (10.4)	1 (3.3)	[b]0.440

CAD: *Coronary Artery Disease;* ***COPD****: Chronic Obstructive Pulmonary Disease;* ***CTD****: Connective Tissue Disease;* ***DM****: Diabetes Mellitus;* ***GI****: Gastrointestinal System;* ***NYHA****: New York Heart Association;* ***SD****: Standard deviation;*

**: p<0.05 indicates statistical significance.*

[a]*Pearson's chi-square test*

[b]*Fisher's exact test*

[c]*Fisher–Freeman–Halton exact test*

ARTICLE IN PRESS

ARTICLE IN PRESS

Table 2: Comparison of Patients' Demographic Data and Echocardiography Findings

	Bentall (n:77)		**David** (n:30)		
	Mean±SD	n (%)	Mean±SD	n (%)	P value
Age (years)	54.18±15.95		55.47±14.4		[a]0.702
BMI (kg/m²)	27.81±5.76		28.72±4.54		[a]0.436
‡**Creatinine**	0.9 (0.75, 1.11)		0.94 (0.8, 1.3)		[b]0.311
EF (%) (n:89)	56.43±7.25		54.31±7.34		[a]0.215
FEV_1/FVC (n:38)	78.08±6.07		72±14.31		[a]0.078
Gender (Female)		24 (31.2)		6 (20)	[c]0.248
AI (n:87)		58 (95.1)		24 (92.3)	[d]0.633
Mild		15 (24.6)		2 (7.7)	[e]0.011*
Mild-moderate		9 (14.8)		6 (23.1)	
Moderate		10 (16.4)		9 (34.6)	
Moderate-severe		11 (18)		7 (26.9)	
Severe		13 (21.3)		0 (0)	
MI (n:85)		34 (55.7)		13 (54.2)	[c]0.896
Mild		25 (41)		9 (37.5)	[e]0.865
Mild-moderate		5 (8.2)		1 (4.2)	
Moderate		2 (3.3)		1 (4.2)	
Moderate-severe		1 (1.6)		1 (4.2)	
Severe		1 (1.6)		1 (4.2)	

***AI:** Aortic insufficiency**; BMI:** Body mass index; **EF:** Left ventricular ejection fraction; **FEV1:** Forced expiratory volume in 1 second; **FVC:** Forced vital capacity; **MI:** Mitral insufficiency; **SD**: Standard deviation;*

‡ The relevant data are presented as median (first quartile, third quartile);

**: p<0.05 indicates statistical significance.*

[a]*Independent samples t-test*

[b]*Mann–Whitney U test*

[c]*Pearson's chi-square test*

[d]*Fisher's exact test*

[e]*Fisher–Freeman–Halton exact test*

ARTICLE IN PRESS

ARTICLE IN PRESS

Table 3: Surgery Timing and Surgical Indications

	Bentall (n:77)		**David** (n:30)		
	Mean±SD	n (%)	Mean±SD	n (%)	P value
AA Diameter (mm)	53.92±10.57		53.96±8.77		[a]0.985
Surgery Timing					
Elective		54 (71.1)		26 (86.7)	[b]0.092
Emergency		22 (28.9)		4 (13.3)	
Aneurysm		57 (75)		27 (90)	[b]0.086
Acute Dissection		17 (22.4)		4 (13.3)	[b]0.293
Rupture Threat		7 (9.2)		2 (6.7)	[c]0.999

***AA**: Aortic aneurysm; **SD**: Standard deviation.*
[a]*Independent samples t-test*
[b]*Pearson's chi-square test*
[c]*Fisher's exact test*

ARTICLE IN PRESS

ARTICLE IN PRESS

Table 4: Surgical Procedure and Additional Surgical Interventions

	Bentall (n:77) n (%)	**David** (n:30) n (%)	P value
Hemiarch Replacement	40 (51.9)	18 (60)	[a]0.453
Total Arch Replacement	3 (3.9)	4 (13.3)	[b]0.095
Total Arch Replacement Type			
None	74 (96.1)	26 (86.7)	[c]0.088
Island	2 (2.6)	1 (3.3)	
Multibrach	1 (1.3)	3 (10)	
ET Procedure	3 (3.9)	4 (13.3)	[b]0.095
CABG	29 (37.7)	9 (30)	[a]0.457
AVR*	0 (0)	2 (6.7)	[b]0.077
MVR	5 (6.5)	3 (10)	[b]0.684

AVR: *Aortic Valve Repair;* ***CABG:*** *Coronary Artery Bypass Grafting;* ***ET:*** *Elephant Trunk;* ***MVR:*** *Mitral Valve Repair/Replacement.*

[a]*Pearson's chi-square test*

[b]*Fisher's exact test*

[c]*Fisher–Freeman–Halton exact test*

**Includes minor aortic valve repair procedures, such as cusp plication or leaflet resuspension.*

ARTICLE IN PRESS

ARTICLE IN PRESS

Table 5: Cannulation and Cerebral Protection Methods

	Bentall (n:77)		**David** (n:30)		
	Mean±SD	n (%)	Mean±SD	n (%)	P value
Hypothermia (n:77) [°C]	21.4±4.1		18.8±2.5		[a]0.002*
TPT (min)	203.34±75.5		234.67±76.22		[b]0.057
ACCT (min)	142.71±48.67		169.77±58.65		[b]0.017*
TCAT (min)	13.28±6.56		16.24±7.41		[b]0.082
‡**CPT** (min)	24 (19, 38)		33 (33, 69)		[a]0.393
‡**BCAT** (min)	15 (9, 19)		14 (12, 25)		[a]0.211
Hypothermic Circulatory Arrest		50 (64.9)		26 (86.7)	[c]0.026*
SACP		5 (6.7)		4 (13.3)	[d]0.272
Arterial Cannulation Site					
Aorta		34 (45.3)		19 (63.3)	[c]0.084
Axillary artery		27 (36)		10 (33.3)	
Femoral artery		14 (18.7)		1 (3.3)	

ACCT: *Aortic Cross-Clamp Time;* ***BCAT:*** *Body Circulatory Arrest Time;* ***CPT:*** *Cerebral Perfusion Time;* ***SD****: Standard deviation;* ***TCAT:*** *Total Circulatory Arrest Time;* ***TPT:*** *Total Perfusion Time;*
**: p<0.05 indicates statistical significance;*
‡ The relevant data are presented as median (first quartile, third quartile).
[a]*Mann–Whitney U test*
[b]*Independent samples t-test*
[c]*Pearson's chi-square test*
[d]*Fisher's exact test*

ARTICLE IN PRESS

ARTICLE IN PRESS

Table 6: Postoperative Complications

	Bentall (n:77) n (%)	**David** (n:30) n (%)	P value
Myocardial Ischemia/Infarction	1 (1.5)	0 (0)	[a]0.999
Low Cardiac Output Syndrome	14 (19.7)	3 (10)	[b]0.233
Arrhythmia	21 (29.6)	7 (23.3)	[b]0.522
Pericardial Effusion/Tamponade	12 (19.4)	7 (23.3)	[b]0.659
Pulmonary Parenchymal Complications			
No	65 (97)	25 (86.2)	[c]0.070
Atelectasis	2 (3)	3 (10.3)	
Edema	0 (0)	1 (3.4)	
Pleural Complications	7 (10.4)	2 (6.7)	[a]0.716
Acute Kidney Injury	7 (10.1)	3 (10)	[a]0.999
Stroke			
No	65 (94.2)	26 (89.7)	[c]0.671
Temporary	2 (2.9)	2 (6.9)	
Permanent	2 (2.9)	1 (3.4)	
Postoperative Bleeding	8 (11.6)	7 (23.3)	[a]0.220
Wound Complications	7 (10.1)	2 (6.7)	[a]0.719
Systemic Infections	4 (5.8)	4 (13.3)	[a]0.240
Postoperative Blood Transfusion >3 units	34 (49.3)	16 (53.3)	[b]0.711
Intra-Aortic Balloon Pump/ECMO	14 (19.2)	1 (3.3)	[a]0.061

ECMO: Extracorporeal Membrane Oxygenation
**: p<0.05 indicates statistical significance;*
[a]*Fisher's exact test*
[b]*Pearson's chi-square test*
[c]*Fisher–Freeman–Halton exact test*

ARTICLE IN PRESS

ARTICLE IN PRESS

Table 7: Postoperative Follow-ups

	Bentall (n:77) Median (Q1, Q3)‡	n (%)	**David** (n:30) Median (Q1, Q3)‡	n (%)	P value
ICU Stay (days)	3 (2, 5)		3 (2, 11)		[a]0.310
Hospitalization Duration (days)	11 (8, 19)		12 (7, 21)		[a]0.771
Total Bleeding (mL)	1350 (1000, 2550)		1550 (1100, 2850)		[a]0.415
Bleeding (mL/24 hours)	850 (600, 1100)		1000 (700, 1500)		[a]0.208
Extubation Time (hours)	18 (15, 40)		20 (15, 39)		[a]0.933
Post-operative AR		0 (0)		0 (0)	[b]1
Late Reoperation*		0		4 (13.3)	(0)

AR: Aortic valve regurgitation (moderate to severe); ICU: Intensive care unit
‡: The relevant data are presented as median (first quartile, third quartile)
**: Late reoperation due to aortic valve pathology*
***: p<0.05 indicates statistical significance*
[a]*Mann–Whitney U test*
[b]*Fisher's exact test*

ARTICLE IN PRESS

ARTICLE IN PRESS

Table 8: Survival Data of the Study Groups

	Before PSM			After PSM		
	Bentall (n:77) n (%)	**David** (n:30) n (%)	P value	**Bentall** (n:30) n (%)	**David** (n:30) n (%)	P value
In-hospital mortality						
All cause	16 (20.8)	2 (6.7)	[a]0.080	0 (0)	2 (6.7)	[b]0.246
Operative	8 (10.4)*	0 (0)*		0 (0)**	0 (0)**	
LCOS	4 (5.2)	1 (3.3)		0 (0)	1 (3.3)	
Systemic Infection/Sepsis	2 (2.6)	1 (3.3)		0 (0)	1 (3.3)	
Acute Kidney Failure	1 (1.3)	0 (0)		0 (0)	0 (0)	
Acute Hepatic Injury	1 (1.3)	0 (0)		0 (0)	0 (0)	
Late Mortality‡						
All-cause	11 (14.3)	5 (16.7)	[b]0.768	1 (3.3)	5 (16.7)	[b]0.195
MI	5 (6.5)	2 (6.7)		1 (3.3)	2 (6.7)	
Malignancy	2 (2.6)	1 (3.3)		0 (0)	1 (3.3)	
Infection	1 (1.3)	1 (3.3)		0 (0)	1 (3.3)	
Other causes	3 (3.9)	1 (3.3)		0 (0)	1 (3.3)	

LCOS: Low Cardiac Output Syndrome; MI: Myocardial Infarction; PSM: Propensity Score Matching

‡: Mortality occurred beyond the first 30 postoperative days

**: The EuroSCORE II predicted mortality rate was 10.69% ± 9.29% for the Bentall group and 14.02% ± 13.35% for the David group*

***: The EuroSCORE II predicted mortality rate was 5.95% ± 3.14% for the Bentall group and 14.02% ± 13.35% for the David group*

[a]*Pearson's chi-square test*

[b]*Fisher's exact test*

ARTICLE IN PRESS