Is aortic valve-sparing root reimplantation (David-I) justified in cardiac redo surgery?

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Abstract

OBJECTIVES: Aortic valve-sparing root reimplantation (AVSRR) is a complex procedure, which offers the benefit of preserving the native aortic valve. Cardiac redo surgery is complex and time-consuming, and it is not known if David procedure is safe or beneficial in this context.

METHODS: Between 1993 and 2019, we performed a total of 544 elective AVSRR operations at our centre. Patients were assigned to either group A (n = 30, redo) or group B (n = 514, first-time sternotomy).

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RESULTS: Aortic cross-clamp time was higher in the redo group (173[62] vs 125[31], P < 0.001). Cardiopulmonary bypass time was higher in the redo group as well (250[78] vs 179[51], P < 0.001). There were significantly more concomitant total arch replacements in the redo group (43.3% vs 5.8%, P < 0.001) using the ‘beating heart’ technique (20.0% vs 1.9%, P < 0.001). In-hospital mortality was comparable in both groups (3.3% vs 1.8%, P = 0.44). The rates for perioperative complications in terms of permanent neurological deficit and rethoracotomy were comparable between the 2 groups, too. Follow-up was complete for 99.6% of all patients and comprised a total of 584 patient-years. The 1-, 5-, 10- and 15-year survival rates were 90%, 81%, 60% and 55%, in group A (redo) and 96%, 90%, 78% and 67% in group B (native, P = 0.16), respectively. The rates for freedom from valve-related reoperation at 1, 5, 10 and 15 years after initial surgery were 96%, 92%, 92% and 92% in group A (redo) and 97%, 92%, 87% and 84% in group B (native, P = 0.52), respectively.

CONCLUSIONS: Despite significantly more concomitant total arch replacements in the redo group, early mortality was comparable in both groups. We conclude that AVSRR can be performed in redo cardiac surgery without compromising the early postoperative outcome. Careful patient assessment and selection are mandatory when evaluating patients with a history of previous cardiac surgery for David procedure.

Keywords: Aortic valve-sparing root replacement • David procedure • Reimplantation procedure • Total aortic arch replacement

ABBREVIATIONS

| AVSRR       | Aortic valve-sparing root reimplantation |
|-------------|----------------------------------------|
| CPB         | Cardiopulmonary bypass                  |

INTRODUCTION

Aortic valve-sparing root reimplantation (AVSRR) has been introduced in 1992 [1]. Nowadays, AVSRR is widely performed to preserve the native aortic valve during aortic root replacement. AVSRR avoids the disadvantages of conventional composite root replacement (Bentall procedure). This includes the need for lifelong anticoagulation with the associated risks of thromboembolism and haemorrhage in mechanical valve conduits [2] or prosthetic leaflet degeneration with the need for reoperation as in tissue valve conduits [3]. In addition, the risk of endocarditis is lower after AVSRR as well [4].

One of the potential disadvantages of AVSRR is its longer cardiopulmonary bypass (CPB) and aortic cross-clamp times when compared to Bentall procedure. Furthermore, there is the potential risk of intraoperative conversion to composite root replacement. Lastly, there is the potential risk of late failure of the preserved aortic valve with the need for reoperation.

Cardiac redo operations, especially on the aortic root, are more complicated than conventional procedures on patients who have not undergone previous cardiac surgery [5–8]. Redo surgery usually involves longer CPB and cross-clamp times when compared to first-time sternotomy operations. The risks for perioperative complications and morbidity are also increased. Mortality is also increased in redo operations and may be as high as 18% [7].

The risks and outcomes of AVSRR in redo surgery have rarely been investigated. Mookhoek et al. [9] analysed AVSRR after failed Ross procedure and reported low perioperative risks. Besides this study, we are not aware of any further publications on this topic. Against this background, we think that there is marginal evidence available whether or not AVSRR can or should be performed in cardiac redo settings. Since AVSRR is technically complex and time-consuming, one could assume that AVSRR might be too risky to apply in redo settings. Therefore, we have designed this study to analyse and compare the clinical outcome of AVSRR in redo operations with AVSRR in the setting of a first-time sternotomy.

METHODS

Ethics

This is a retrospective study with follow-up. This study has been approved by our institution’s ethics committee (Nr. 3552-2017). Thus, this study was in line with our institution’s ethical policies and standards.

Study design

We screened our centre’s database for AVSRR that have been performed between 1993 and 2018. All patients with acute aortic dissection type A were excluded. A total of 544 patients were identified. The study groups were defined as a redo group (A, n = 30) with patients who had previously undergone cardiac surgery and a first-time group (B, n = 514) with patients who underwent a first-time sternotomy. The study design and the most relevant findings are summarized in the central image.

Surgical technique

All patients in this study underwent AVSRR with a straight tube graft (David-I). Concomitant procedures were performed as needed. A detailed description of our centre’s surgical technique can be found in previous publications [10]. In redo cases, we prefer the oscillating saw to open the sternum. Careful dissection and preparation of the ascending aorta and the aortic root are performed. The aortic root must be carefully mobilized from surrounding structures, which is more complicated in redo cases due to adhesions. The patient is cannulated via the right atrium and the ascending aorta in all cases, including redo cases. Only in selected high-risk redo cases, arterial cannulation is established via the right subclavian artery or the femoral artery. In these cases, venous cannulation is established either centrally via the right atrium or via the femoral vein.

Postoperative follow-up

We obtained individual consent from patients to allow for a follow-up examination. Follow-up was performed as suggested by common guidelines [11]. We contacted patients by telephone or met them in our centre’s aortic clinic. We contacted primary care
physicians and cardiologists to obtain the most recent echocardiography results.

Statistical analysis

The data analysis was performed by the usage of SPSS 26 Statistics software (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp.). Normal distribution of variables was analysed with the Shapiro–Wilk test. Normally distributed continuous variables are stated as mean and standard deviation, while continuous variables without normal distribution are stated as median and interquartile range. Continuous variables were analysed with the Student’s t-test, while categorical variables were compared with Fisher’s exact test. Kaplan–Meier analysis was used for the evaluation of both survival and reoperation of the aortic valve, and the log–rank test was used to test for differences. The median follow-up time was calculated using the reverse Kaplan–Meier method. In Kaplan–Meier curves, survival was defined as the time from surgery until the event of aortic valve-related reoperation, with patients not experiencing this event censored at their last available follow-up time. Reoperation-free survival was defined as the time from surgery until the event of aortic valve-related reoperation, with patients not experiencing this event censored at their last available follow-up time. A value of $P < 0.05$ was considered statistically significant.

RESULTS

Patient demographics

The preoperative patient demographics are shown in Table 1. All patient demographics were distributed equally between the 2 groups, except for hyperlipidemia which was less commonly present in the redo group [group A: $n = 3$ (10.0%), group B: $n = 137$ (26.7%), $P = 0.033$]. Of note, 8 (1.6%) patients of group B were operated on urgently, but not emergently. All other cases were operated on electively. The previous cardiac operations of patients in group A are shown in Table 2. The majority of patients ($n = 14$, 46.7%) had a previous ascending aortic repair for aortic dissection.

Intraoperative data

The intraoperative data are shown in Table 3. The mean aortic cross-clamp time was higher in the redo group [group A: $173[51]$, group B: $125[31]$, $P < 0.001$]. The mean CPB time was higher in the redo group, as well [group A: $250[78]$, group B: $179[51]$, $P < 0.001$]. There were significantly more concomitant total arch replacements in the redo group [group A: $n = 13$ (43.3%), group B: $n = 30$ (5.8%), $P < 0.001$]. The ‘beating heart arch surgery’ approach was also more often applied in the redo group [group A: $n = 6$ (20%), group B: $n = 10$ (1.9%), $P < 0.001$]. All other concomitant cardiac procedures were comparable between the 2 groups.

Postoperative outcome

The early postoperative outcome is shown in Table 4. In-hospital mortality was comparable in both groups [group A: $n = 1$ (3.3%), group B: $n = 9$ (1.8%), $P = 0.44$]. The rethoracotomy rate was similar in both groups [group A: $n = 1$ (3.3%), group B: $n = 31$ (6.0%), $P = 1.00$]. Although the mean mechanical ventilation time was longer in the redo group [group A: 0.6 (0.7) days, group B: 0.5 (0.4), $P = 0.030$], the incidences of prolonged mechanical ventilation and tracheostomy were comparable between the 2 groups. The mean stay in ICU was slightly longer in the redo group [4.2[5.3]] than in the first-time group [2.5[4.4], $P = 0.041$]. All other rates for perioperative complications were similar in both groups.

The detailed echocardiography data are shown in Table 5. Postoperative echocardiography was available for 503 patients (92%), with 27 echocardiographies in group A and 476 in group B. Echocardiography showed aortic insufficiency ≥2 in 27 (10%) patients of group A and 460 (97%) patients of group B.

Table 1: Patient demographics

| Characteristics                      | Entire group | Redo | Native | P-Value |
|--------------------------------------|-------------|------|--------|---------|
|                                     | $n = 544$   | $n = 30$ | $n = 514$ |         |
| Sex (male), n (%)                    | 381 (70.0)  | 24 (80.0) | 357 (69.5) | 0.22    |
| Age (years), median (IQR)/mean ± SD | 57 (41–66)  | 48.2 ± 18.4 | 57 (42–66) | 0.18    |
| Marfan syndrome, n (%)               | 105 (19.3)  | 6 (20.0) | 99 (19.3) | 0.92    |
| Status of procedure                  |             |       |        |         |
| Urgent, n (%)                        | 8 (1.5)     | 0 (0) | 8 (1.6) | 1.00    |
| Elective, n (%)                      | 536 (98.5)  | 30 (100) | 506 (98.4) | 1.00    |
| BMI (kg/m²), median (IQR)/mean ± SD | 25.8 (23.3–28.4) | 25.5 ± 4.1 | 25.8 (23.3–28.6) | 0.58    |
| LVEF (%), median (IQR)               | 60 (55–70)  | 60 (52.65) | 60 (55.70) | 0.20    |
| Coronary artery disease, n (%)       | 108 (19.9)  | 7 (23.3) | 101 (19.6) | 0.62    |
| Arterial hypertension, n (%)         | 321 (59.0)  | 14 (46.7) | 307 (59.7) | 0.091   |
| Hyperlipidaemia, n (%)               | 140 (25.7)  | 3 (10.0) | 137 (26.7) | 0.03    |
| Diabetes, n (%)                      | 24 (4.4)    | 1 (3.3) | 23 (4.5) | 1.00    |
| COPD, n (%)                          | 98 (18.0)   | 5 (16.7) | 93 (18.1) | 1.00    |
| Bicuspid aortic valve, n (%)         | 67 (12.3)   | 2 (6.7)  | 65 (12.6) | 0.57    |
| Previous stroke, n (%)               | 2 (0.4)     | 0 (0)   | 2 (0.4)  | 1.00    |

BMI: body mass index; COPD: chronic obstructive pulmonary disease; IQR: interquartile range; SD: standard deviation.
Long-term outcome

The clinical follow-up completion rate was 99.6% and comprised a total of 584 patient-years. The median follow-up time was 14.3 (7.3–18.9) years. Figure 1 shows the Kaplan Meier curves for survival after aortic valve-sparing root reimplantation. The 1-, 5-, 10- and 15-year survival rates were 90%, 81%, 60% and 55%, in group A (redo) and 96%, 90%, 78% and 67% in group B (native, P = 0.16), respectively.

Follow-up echocardiography was available for 324 (59.6%) of patients, with 18 echocardiographies in group A and 306 in group B. The median echocardiography follow-up time was 12.1 (5.9–16.5) years. In the redo group, 16 (88.9%) patients showed aortic insufficiency <_I/C14. In the native group, 261 (90.1%) patients showed aortic insufficiency <_I/C14.

During follow-up, 66 patients required reoperation of the aortic valve. Figure 2 shows the Kaplan–Meier curves for freedom from aortic valve-related reoperation. The rates for freedom from valve-related reoperation at 1, 5, 10 and 15 years after initial surgery were: 96%, 92%, 92% and 92% in group A (redo) and 97%, 92%, 87% and 84% in group B (native, P = 0.52), respectively.

DISCUSSION

As to our knowledge, this is the first study investigating the outcome of AVSRR in redo settings. We found that the early postoperative outcome was comparable between the redo and the first-time sternotomy groups, despite significantly more concomitant total arch replacements in the redo group. We conclude that AVSRR can be performed in redo cardiac surgery without compromising the early postoperative outcome. The usage of supportive strategies incl. ‘beating heart arch surgery’ may help to reduce the risk for intraoperative complications during complex operations of the aortic root and arch.

Table 2: Previous cardiac operations

| Characteristics                        | Redo | Native |
|----------------------------------------|------|--------|
| Ascending aortic replacement, n (%)    | 14 (46.7) | 7 (23.3) |
| Fallot repair, n (%)                   | 4 (13.3) | 4 (13.3) |
| Coronary artery bypass grafting, n (%) | 3 (10.0) | 2 (6.7) |
| Heart transplantation, n (%)           | 3 (10.0) | 2 (6.7) |
| VSD repair, n (%)                      | 3 (10.0) | 2 (6.7) |
| Mustard repair, n (%)                  | 1 (3.3) | 1 (3.3) |
| Ross procedure, n (%)                  | 1 (3.3) | 1 (3.3) |
| Pectus excavatum repair, n (%)         | 1 (3.3) | 1 (3.3) |

VSD: ventricular septal defect.

Table 3: Intraoperative data

| Characteristics                        | Entire group | Redo | Native | P-Value |
|----------------------------------------|--------------|------|--------|---------|
| Aortic X-clamp time (min), median (IQR)/mean ± SD | 122 (105–143) | 173.5 ± 62.5 | 121 (104–141) | <0.001 |
| CPB time (min), median (IQR)/mean ± SD | 171 (146–204) | 250.4 ± 78.4 | 169 (145–201) | <0.001 |
| Cusp plasty, n (%)                      | 75 (13.8) | 3 (10.0) | 72 (14.0) | 0.79 |
| Concomitant procedures                 |              |       |        |         |
| CABG, n (%)                            | 99 (18.2) | 4 (13.3) | 95 (18.5) | 0.44 |
| Mitral valve surgery, n (%)            | 33 (6.1) | 3 (10.0) | 30 (5.8) | 0.42 |
| Prox. arch surgery, n (%)              | 99 (18.2) | 4 (13.3) | 95 (18.5) | 0.44 |
| Subtotal arch surgery, n (%)           | 28 (5.1) | 2 (6.7) | 26 (5.1) | 0.67 |
| Total arch surgery, n (%)              | 43 (7.9) | 13 (43.3) | 30 (5.8) | <0.001 |

CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; IQR: interquartile range; SD: standard deviation.

Table 4: Postoperative outcome

| Characteristics                          | Entire group | Redo | Native | P-Value |
|------------------------------------------|--------------|------|--------|---------|
| Mech. ventilation time (days), median (IQR) | 0.5 (0.4–0.7) | 0.6 (0.4–1.1) | 0.5 (0.4–0.7) | 0.030 |
| Prolonged mechanical ventilation (>72 h), n (%) | 33 (6.1) | 1 (3.3) | 32 (6.2) | 1.00 |
| Tracheostomy, n (%)                      | 14 (2.6) | 1 (3.3) | 13 (2.5) | 0.56 |
| ICU stay (days), median (IQR)            | 1 (1–3) | 3 (1–4.3) | 1 (1–3) | <0.001 |
| In-hospital mortality, n (%)             | 10 (1.8) | 1 (3.3) | 9 (1.8) | 0.44 |
| Stroke, n (%)                            | 12 (2.2) | 1 (3.3) | 11 (2.1) | 0.50 |
| Renal failure, n (%)                     | 13 (2.4) | 1 (3.3) | 12 (2.3) | 0.53 |
| Dialysis, n (%)                          | 6 (1.1) | 1 (3.3) | 5 (1.0) | 0.29 |

ICU: intensive care unit; IQR: interquartile range.
Early outcome

AVSRR is a complex surgical technique and may result in longer CPB and aortic cross-clamp times when compared to conventional root replacement using a composite graft. However, preserving the native aortic valve can make a big difference for the patient. Cardiac redo surgery is also associated with prolonged operation times, and the combination of AVSRR and redo surgery has the potential to lead to extremely long cross-clamp times, in turn exceeding the myocardial ischaemia time. This study tried to answer the question of whether complex AVSRR combined with redo surgery can be performed safely.

Indeed, this study found that both CPB and aortic cross-clamp times were significantly longer in the redo group when compared to the first-time surgery group. However, this did not result in an increased rate of mortality in the redo group. We think that supportive perioperative strategies, including the 'beating heart arch surgery' approach, can help to reduce the risk for perioperative complications [12].

In previously published studies, the in-hospital mortality rate after aortic root replacement in redo surgery ranges from 5% to 18% [5–8]. The early mortality rate in our study was only 3.3% in the redo group. This is an extremely low number when compared to the previously published literature. In addition, one has to notice that all previous studies on this topic focused on conventional composite root replacement ('Bentall procedure'), while our study comprised AVSRR only.

Furthermore, we did not detect any statistically significant difference in the in-hospital mortality rate between the redo and the first-time surgery group. Given that both groups had comparable preoperative characteristics, we think that this underlines the comparability and validity of our analysis. Furthermore, one has to keep in mind that almost half of the patients in the redo group underwent additional total aortic arch replacement while the rate of this procedure was only 5.8% in the first-time surgery group.

Only 1 patient in the redo group required rethoracotomy for bleeding. Interestingly, the rate for bleeding-related rethoracotomy was similar in both groups. We compared our data to previously published reports, and we think that our rethoracotomy seems to be comparable to these reports. For instance, Jassar et al. [5] reported a bleeding-associated rethoracotomy rate of 7% after redo root replacement.

The mean mechanical ventilation time was slightly longer in the redo group, but this did not lead to a higher rate of

| Table 5: Echocardiographic data |
|---------------------------------|
| Preoperative | Entire group | Redo | Native |
| Degree of AI | n=511 | n=27 | n=484 |
| AI 0–1, n (%) | 43 (8.5) | 2 (7.4) | 41 (8.5) |
| AI 1, n (%) | 86 (16.8) | 6 (22.2) | 80 (16.5) |
| AI 1–2, n (%) | 32 (6.3) | 1 (3.7) | 31 (6.4) |
| AI >2, n (%) | 350 (68.4) | 18 (66.7) | 332 (68.6) |

| Postoperative | Entire group | Redo | Native |
| Degree of AI | n=503 | n=27 | n=476 |
| AI 0–1, n (%) | 375 (74.5) | 21 (77.8) | 354 (74.4) |
| AI 1, n (%) | 112 (22.3) | 6 (22.2) | 106 (22.3) |
| AI 1–2, n (%) | 11 (2.2) | 0 (0) | 11 (2.3) |
| AI >2, n (%) | 5 (1.0) | 0 (0) | 5 (1.1) |

| Follow-up | Entire group | Redo | Native |
| Degree of AI | n=324 | n=18 | n=306 |
| AI 0–1, n (%) | 196 (60.5) | 11 (61.1) | 185 (60.4) |
| AI 1, n (%) | 81 (25.0) | 5 (27.8) | 76 (24.8) |
| AI 1–2, n (%) | 23 (7.2) | 1 (5.6) | 22 (7.5) |
| AI >2, n (%) | 24 (7.3) | 1 (5.6) | 23 (4.5) |

AI: aortic insufficiency.

Figure 1: Survival after aortic valve-sparing root reimplantation. This figure shows the Kaplan–Meier survival curves for patients who underwent David-I procedure. The blue curve shows the redo group (group A), while the red curve shows the first-time surgery group (group B). Time origin on x-axis denotes day of surgery.
postoperative prolonged mechanical ventilation or tracheostomy. The mean stay in ICU was slightly longer in the redo group than in the first-time group. Fortunately, all rates for major adverse events including new permanent neurological deficit (‘stroke’) and dialysis were low, and similar in both groups.

In summary, we conclude that AVSRR can be performed in cardiac redo settings without compromising the early postoperative outcome.

Late outcome

The Kaplan–Meier survival curves for the 2 groups were comparable. One could suspect a slightly less favourable course of the redo group; however, this difference was not statistically significant. Although all except for 1 preoperative patient characteristics were similar in both groups, we think that the less optimal survival rates and curves of the redo group can be explained by the suspicion that the redo patients could be more morbid than their counterparts of the native group. For instance, the redo patients underwent significantly more total aortic arch replacements, indicating more advanced aortic disease. Also, the fact that these patients already had previous cardiac surgery indicates more advanced disease. Future studies with larger patient cohorts will have to address and clarify this issue.

The long-term durability of the preserved aortic valve is a major issue after AVSRR. Our group has demonstrated in previous publications sustainable valve function after AVSRR in the setting of elective surgery [13], bicuspid aortic valve [14] and aortic dissection [15] in the long term. In the present study, the rates for freedom from aortic valve-related reoperation were completely similar in both groups. There was no statistically significant difference. When compared to our previous publications which focused on AVSRR in other clinical scenarios [13–15], the rate for freedom from aortic valve-related reoperation in redo surgery seems to be absolutely comparable. Also, the echocardiographic results of the redo group during follow-up were not different from the native surgery group. Therefore, we conclude that AVSRR can be performed with the same quality and durability as in first-time cardiac surgery.

Limitations

This is a retrospective study, with all potential disadvantages associated with this kind of analysis. This study represents one of the few publications on AVSRR in the setting of redo surgery and the sample size of the redo group is relatively small. The postoperative echocardiography data are available for 92.4% of all patients. The missing postoperative echocardiography data can be explained by the retrospective nature of the present study. Furthermore, the echocardiography during follow-up is incomplete and we would like to acknowledge this issue as another limitation of the present study. The present study does not include a multivariable analysis, which might represent another limitation.

CONCLUSIONS

We found that the early postoperative outcome was comparable between the redo and the first-time sternotomy groups, despite significantly more concomitant total arch replacements in the redo group. We conclude that AVSRR can be performed in redo cardiac surgery without compromising the early postoperative outcome.

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Conflict of interest: none declared.
Data availability statement

The data underlying this article cannot be shared publicly due to privacy issues. The International Committee of Medical Journal Editors emphasizes that patients and study participants have a right to privacy that should not be infringed without informed consent. Study participants should know exactly how their data will be used and shared. Although our patients gave informed consent to participate in this study, we did not ask them to give consent to share their anonymized data publicly. For this reason and to be in line with the recommendations of the International Committee of Medical Journal Editors, we cannot make the data publicly available. Reasonable requests to the corresponding author will be evaluated.

Author contributions

**Erik Beckmann:** Conceptualization; Formal analysis; Investigation; Methodology; Supervision; Writing—original draft; Writing—review & editing.  
**Andreas Martens:** Formal analysis; Software; Supervision.  
**Linda Rudolph:** Formal analysis; Methodology; Software; Validation; Visualization.  
**Heike Krüger:** Data curation; Formal analysis; Software; Validation.  
**Tim Kaufeld:** Data curation; Project administration.  
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**Axel Haverich:** Funding acquisition; Project administration; Resources; Supervision.  
**Malakh Lal Shrestha:** Conceptualization; Funding acquisition; Investigation; Methodology; Resources; Writing—review & editing.

Reviewer information

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