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Comparative study of aortic root replacement versus aortic root enlargement in small aortic root

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Abstract

Background For patients with aortic stenosis (AS) and small annulus, aortic root replacement (RR) and aortic root enlargement (RE) are proven methods to prevent prosthesis-patient mismatch (PPM). Our goal was to compare the results of those two categories of operations. This prospective study used our hospitals' database of aortic valve replacements from 2021 to 2024. Patients who had aortic stenosis treated with RE or RR were compared. The post-operative results and reoperations were compared. Kaplan–Meier survival estimation and log-rank test were used to compare time-to-event data.

Results A total of 72 patients had aortic stenosis treated with either RE or RR. Thirty-eight (52%) and 34 (47%) patients underwent RR and RE, respectively. In RR cases, significant postoperative bleeding was noted in 13 patients vs. only 4 patients in RE group (P-value = 0.001). The length of stay did not differ significantly (P-value = 0.918) in both groups and the same in early postoperative mortality (2.6% for the RR group vs. 5.9% for the RE group (P = 0.17)). Additionally, there were no considerable variations in the reoperation rate (2.6% in RR cases vs. 2.9% in RE cases). Patients in the RR group had lower trans-prosthetic gradients and larger valves implanted (P < .001). The median follow-up period was 24.5 (25th–75th percentiles: 1–48) months. Kaplan–Meier survival estimates for the two groups were similar and did not show a significant difference in mortality.

Conclusions Aortic valve reoperations, 4-year survival, and postoperative complications were all similar for AS patients treated with RE and RR. The study showed comparable reoperation rate, postoperative complications and survival rates between root replacement and enlargement in patients with small aortic root.

Keywords Aortic root replacement, Aortic root enlargement, Small aortic root

Background

Aortic valve replacement (AVR) has developed as a standard operation with low mortality and morbidity over the last century. The main target of aortic valve replacement is to decrease the volume and pressure overload on the left ventricle (LV), treat symptoms, improve the process of ventricle remodeling, and increase the survival [1].

Aortic valve replacement started in 1950 s. This surgical operation has been improved to decrease the risk of surgical complications. After the initial use of mechanical ball-caged valves, several monoleaflet and bileaflet valves have been introduced and examined [2]. Aortic root enlargement at the time of aortic valve replacement in patients with small aortic roots is a safe procedure that decreases postoperative gradients and the incidence of prosthesis-patient mismatch [3].

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The pressure gradient across the prosthetic valve after surgery should be as low as possible. However, even with a prosthesis that functions normally, high-pressure gradients may occur after surgery. This is more common in patients who received small prosthetic valves, and it can result in a condition known as prosthesis-patient mismatch (PPM) [4].

Following AVR, patients with a small aortic root and those with a large body surface area (BSA) are particularly vulnerable to PPM [5]. A number of techniques have been developed to enlarge the small aortic root during surgery in order to accommodate a larger valve, thereby reducing the postoperative pressure gradient across the prosthetic valve and left ventricular outflow obstruction (LVOTO) [5].

For more than five decades, the cardiac surgery literature has addressed the surgical treatment of the small aortic root at the time of AVR. Following early trials at supra-annular enlargement, Nicks and colleagues reported the first aortic annular enlargement with a posterior incision in 1970 [6]. Konno and associates then demonstrated their anterior annular enlargement surgical technique for congenital aortic stenosis (AS) in 1975 [7], and Rastan and associates followed a year later [8]. Although all of these surgical techniques were developed to implant a prosthetic valve as large as possible to minimize postoperative gradient, no clear guidelines for this problem have been established, and the decision is typically tailored according to the surgeon's experience and preference. In the late 1970 s, Manouguian reported a novel enlargement technique also through a posterior approach [5–8].

Donald Ross first implemented the pulmonary autograft in clinical practice in 1967 to replace the damaged aortic valve. More recent experience with pulmonary autografts for partial or total aortic root replacement made it possible for the valve to function satisfactorily [9].

In the 1960 s, the first biological stentless prostheses used in clinical practice was homograft for aortic valve replacement [10]. Mechanical AVR emerged as the preferred surgical option because of homograft restricted availability and comparatively challenging implantation procedure [10]. Drawback of lifelong anticoagulation therapy in mechanical AVR spurred the creation of xenogeneic bioprostheses [10]. In the early 1990 s, the use of stentless bioprostheses was resurrected through hemodynamic optimization to avoid patient-prosthetic mismatch and enhance durability [11].

This study is essential to determine the optimal surgical approach, as both techniques aim to prevent patient-prosthesis mismatch (PPM) while balancing invasiveness and long-term outcomes. The lack of consensus on superiority in terms of survival, reoperation rates, and PPM risk necessitates structured research to guide surgical decision-making, particularly in high-risk or anatomically challenging cases. Such a study would provide evidence-based insights into which method delivers better durability, hemodynamics, and clinical outcomes for patients with small aortic roots.

So, the objective of this study was to compare five surgical procedures including two aortic root replacements and three aortic root enlargements in patients with small aortic root in terms of preoperative echocardiography and intraoperative and postoperative outcome.

Methods

Study population

This is a prospective cohort study conducted on patients who were presented to the Cardiothoracic Surgery Department at Assiut University Heart Hospital and Aswan Heart Center and underwent aortic valve surgery during the period between January 2021 and January 2024.

Inclusion criteria

Patients undergoing aortic valve surgery with small aortic root were included. To date, no clear consensus has been established regarding the cut-off value for defining small aortic root, which results in multiple definitions being used in different studies for the same concept. In surgical series, a small aortic root is most frequently defined as an annulus that would not accommodate a prosthesis size >21 mm [12]. Patients with aortic annulus ≤23 mm were included in the study, indicating that "small and borderline-small" annuli are included here [13]. The age was not a limit to be included in the study.

Exclusion criteria

Patients who have dilated aortic root were excluded (≥ 45–50 mm indicates significant dilation) [14]. Redo cases or combined valvular surgery or additional cardiac procedures (e.g., CABG) were excluded from the study.

Patients were divided into two groups: Group A included 38 patients who were diagnosed with small aortic annulus preoperatively and underwent one of the two different strategies of small aortic root replacement (RR group), and all patients were done at Aswan Heart Center. Group B included 34 patients who were diagnosed with small aortic annulus preoperatively and underwent one of 3 strategies of aortic root enlargement (RE group). All patients in this group were done at Assiut Heart University Hospital.

Outcomes

After the patients were transported to the intensive care unit (ICU), the postoperative bleeding, re-exploration, ventilator stay, total ICU stay, and any postoperative complications were recorded. After the patients were discharged from the ICU and before home discharge, an echocardiographic evaluation was performed to evaluate the function of the valve, cardiac function, pressure gradient across the valve, and the presence or absence of pericardial collection.

Data collection

The following data were required for the study: age, gender, and BSA (body surface area): equation [weight (kg) × height (cm)/3600]$^{1/2}$.

Aortic valve pathology was reported and included aortic stenosis or regurgitation and patient's prostheses mismatch.

Other pathologies included severe tricuspid regurge (TR), ostial LAD (left anterior descending coronary artery), severe MS (mitral stenosis), severe MR (mitral regurge), ostial RCA (right coronary artery) lesion, subaortic membrane, and small apical VSD (ventricular septal defect).

Preoperative echocardiography data included the following: AVA (aortic valve area) and the severity of aortic stenosis. An aortic valve area less than 1 cm is defined as severe aortic stenosis. End-systolic left ventricle dimension and end-diastolic dimension were recorded. Aortic annulus (mm) size corresponds to a virtual ring formed by linking the basal attachments of the three aortic leaflets and measured by preoperative transthoracic echocardiography. Ejection fraction reflected both cardiac function and remodeling and is widely recognized as a valuable diagnostic and prognostic tool.

Intraoperative data included the following: valve size (mm) in mechanical aortic valve, size of stentless bioprosthesis (Freestyle), and the size of homograft in Ross. Cardiopulmonary bypass and cross-clamp times, inotropic support, significant bleeding (more than 3 ml/kg/h) [15], and open sternum were collected.

Postoperative outcomes included the following: mechanical ventilation (MV), ICU stay, hospital stay, postoperative pressure gradient across the new aortic valve, ejection fraction (EF), and PPM were reported.

Long-term records were collected from the hospital clinics that have all follow-up data for patients who underwent cardiac surgeries. Patients' status data were obtained by phone calls. Data collection was stopped in January 2025.

Statistical analysis

All collected data were statistically analysed using R software (R Core Team 2023, licensed by the GNU Project and available under the GNU General Public License). Initially, the Shapiro–Wilk test was performed to check normality. To ensure data quality, outliers were identified using Rosner's test. The quantitative variables are presented as means ± standard deviations and were compared using analysis of variance (ANOVA) or Kruskal–Wallis test, as appropriate. The qualitative variables are presented as numbers with percentages (%) and were compared using chi-square test. In addition, Pearson correlation coefficients for pairwise comparisons between numerical traits were computed. The statistical significance was set at a level of 0.05.

Results

Patients' baseline and preoperative characteristics

Patients' sex were distributed almost equally: 51.4% female and 48.6% male (Fig. 1). In total, 52% of surgeries were aortic root replacement (RR), and 47% was aortic root enlargement (RE). Surgery styles overall in the patient group were distributed as follows: 39% stentless bioprosthesis (Freestyle), 36% Nicks operation, 14% Ross procedure, 6% Konno-Rastan operation, and 6% Manouguian operation. Half of the women were older than 40 and had a stentless bioprosthesis (Freestyle) surgery; additionally, 30% of women older than 30 had Nicks operation, and 8% of women younger than 30 had Manouguian operation. The youngest female patients had the Ross procedure or Konno-Rastan operation. Forty-seven percent (47%) of men around 30 had Nicks operation, 26% of oldest male patients had a stentless bioprosthesis (Freestyle) surgery, and 23% of men younger than 20 had Ross procedure (Fig. 1).

For patients with the highest BSA (from 1.5 to 2), the stentless bioprosthesis (Freestyle) operation (39%) and 36% Nicks operation (Fig. 2) were performed. Patients with BSA in ranges from 1 to 1.5 had the Ross procedure (13%), and 6% had the Manouguian operation. The Konno-Rastan operation was performed for patients with BSA less than 1 (Fig. 2).

Patients with bigger aortic annulus size (around 19 mm and more) had stentless bioprosthesis (Freestyle) aortic root replacement and Nicks and Manougian aortic root enlargement procedures (Table 1). Patients with smaller aortic annulus sizes (around 16 mm and less) had Ross aortic root replacement and Konno-Rastan aortic root enlargement procedures.

For preoperative echocardiographic data, including EDD, ESD, ejection fraction, and AVA, only EDD had significant differences between surgery style groups.

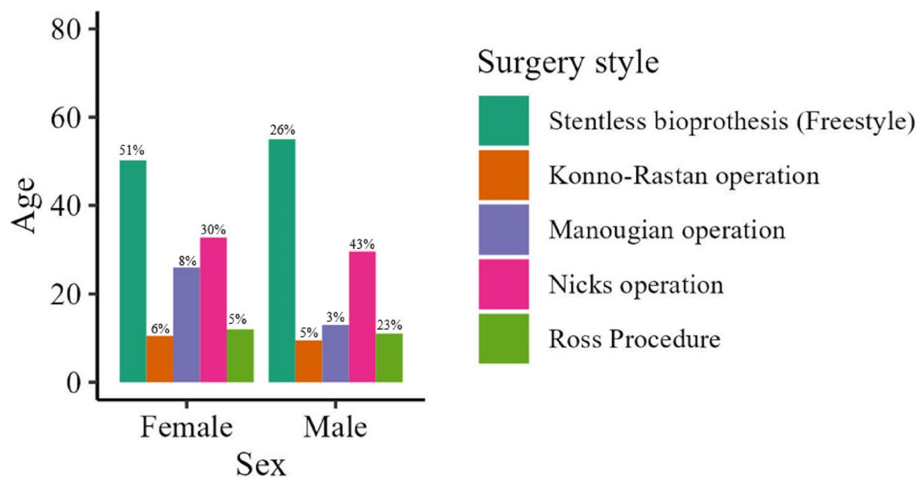

Fig. 1 Patients' distribution according to age, sex, and surgery style

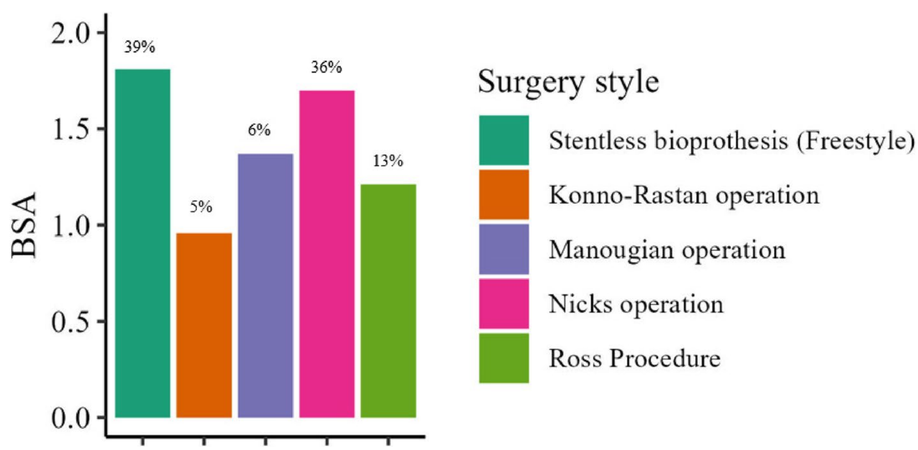

Fig. 2 Patients' distribution according to BSA (m^2) and surgery style

Table 1 Patient's baseline preoperative characteristics by procedure type and style

Type	Aortic root replacement (N= 38)		Aortic root enlargement (N= 34)			*P (type)*	*P (style)*
Style	Stentless bioprosthesis (Freestyle)	Ross	Manougian operation	Nicks operation	Konno-Rastan operation		
Age, y ± SD	51.8 ± 11.7	10 ± 2.2	22.8 ± 11.4	30.9 ± 10.1	11.2 ± 6.7	0.002	0.001
BSA, m^2 ± SD	1.8 ± 0.2	0.9 ± 0.2	1.4 ± 0.3	1.7 ± 0.3	1.2 ± 0.4	0.160	0.001
Aortic ann., mm ± SD	19.2 ± 1.6	16.5 ± 0.6	19 ± 1.2	19.3 ± 1.2	15.9 ± 1.7	0.361	0.001
Ejection fraction, % ± SD	61.3 ± 8.6	54.8 ± 4.1	60.8 ± 5.6	61.5 ± 5.8	61.7 ± 10.4	0.422	0.348
ESD	3.0 ± 0.7	2.2 ± 0.3	3.1 ± 0.7	2.9 ± 0.4	2.7 ± 0.5	0.932	0.023
EDD	4.7 ± 0.7	3.3 ± 0.3	4.6 ± 0.8	4.7 ± 0.6	4 ± 0.7	0.843	0.001
AVA	0.7 ± 0.2	0.7 ± 0.1	0.8 ± 0.1	0.7 ± 0.2	0.8 ± 0.2	0.404	0.328

BSA Body surface area, *AVA* Aortic valve area, *ESD* End-systolic dimension, *EDD* End-diastolic dimension

Patients with the smallest EDD had Ross-style aortic root replacement surgery.

Patients' intraoperative and postoperative data

The biggest valve size (valve size, mm), around 25 mm and more, was used in stentless bioprosthesis (Freestyle) and Ross aortic root replacement (Table 2).

Valve size of around 21 mm was used for Manouguian aortic root enlargement or Konno-Rastan aortic root enlargement operation. The smallest valve, around 19 mm, was used in Nicks aortic root enlargement operation. The longest cross-clamp and bypass time was recorded during Ross aortic root replacement surgery, and the shortest was during Nicks aortic root enlargement operation.

The pressure gradient across the new aortic valve had a significant difference between surgery types and styles. The highest-pressure gradient was found after Nicks' aortic root enlargement operation with the smallest valve size. The smallest pressure gradient was obtained after stentless bioprosthesis (Freestyle) aortic root replacement operation with the biggest valve size. The postoperative ejection fraction (EF post, %) and left ventricular postoperative function showed no significant differences between surgery types and styles. Mechanical ventilation had a significant difference between surgery types. The longest MV stay hours were recorded after Nicks aortic root enlargement procedure and the shortest after Manouguian aortic root enlargement operation. The duration of ICU stay had a significant difference between surgery styles. The shortest ICU stay was recorded after Nicks aortic root enlargement procedure and the longest after Ross aortic root replacement operation. Hospital stay had no significant difference between surgery types or styles. Bleeding was significantly different between surgery types or styles. Most postoperative bleeding cases were recorded during aortic root replacement group in a percentage of 42% with a strong significant difference in comparison with aortic root enlargement group ($P <$ 0.001). Significant bleeding happened in seven patients of Ross operation subgroup "70%" and nine patients in the Freestyle operation subgroup "32%." A lower bleeding rate was recorded during the aortic root enlargement operations in a percentage of 11.8% (3 patients in Nicks' operation group "11.5%" and one patient in Konno-Rastan operation group "25%"). Two patients were transferred into ICU with open sternum due to excessive bleeding. One patient was post-Ross operation, and the second one was post-Freestyle operation.

In total, 2 patients of 72, one female and one male, died. One 24-year-old man died after Nicks aortic root enlargement procedure. The patient developed renal impairment and high postoperative pressure gradient across the new aortic valve. A 65-year-old woman had other pathology (severe MR and RCA lesion); had a longer cross-clamp, wound infection, limb amputation, and renal injury; needed longer mechanical ventilation; and had long ICU/hospital stay. Only one late mortality was registered during the overall patients' follow-up with unknown reason (died at home).

The overall mean follow-up was 24.5 (1–48) months for both groups. Four-year Kaplan–Meier mortality calculations were 2.6% for the RR group vs. 5.9% for the RE group ($P = 0.17$). The overall survival rate was 69 from 72 patients (95.8%), and Kaplan–Meier survival calculations did not find a significant difference between both groups (Fig. 3).

Two patients needed reoperation after discharge. The first case had infective endocarditis after aortic root replacement and underwent aortic root re-replacement

Table 2 Intraoperative and postoperative outcome characteristics

Type	Aortic root replacement ($N = 38$)		Aortic root enlargement ($N = 34$)			*P (type)*	*P (style)*
Style	Stentless bioprosthesis (Freestyle)	Ross	Manougian operation	Nicks operation	Konno-Rastan operation		
Valve size, mm ± SD	24.8 ± 1.5	25.5 ± 2.1	21 ± 0	19.6 ± 1.1	21 ± 0	0.001	0.001
Cross clamp, min ± SD	143 ± 32	192 ± 22	145 ± 15	109 ± 21	152.4 ± 39.9	0.002	0.001
Bypass time, min ± SD	214 ± 66	236 ± 20	184 ± 25	137 ± 25	219 ± 47	0.001	0.001
Gradient post	5.8 ± 2.4	8.5 ± 1.7	9 ± 2.8	11.7 ± 3.6	8.2 ± 3.9	0.001	0.001
EF post	56 ± 11	52 ± 2.4	56 ± 3	53.3 ± 5.7	53. 8 ± 3.6	0.081	0.233
MV stay, h ± SD	8.8 ± 4.2	5 ± 0.8	6 ± 1.4	11.9 ± 6.4	3.7 ± 1.8	0.001	0.001
ICU stay, d ± SD	3.9 ± 1.5	6.5 ± 0.6	4.5 ± 0.6	4 ± 1.2	3 ± 0.9	0.005	0.001
Hospital stay, d ± SD	9.8 ± 3.7	14.5 ± 0.6	9.3 ± 0.9	8.7 ± 1.9	9.8 ± 4.1	0.918	0.07
Bleeding, no., %	9/28, 32%	7/10, 70%	0	3/26, 11.5%	1/4, 25%	0.001	0.001

EF Ejection fraction, *SD* Standard deviation, *h* hours, *d* days, *MV* Mechanical ventilation

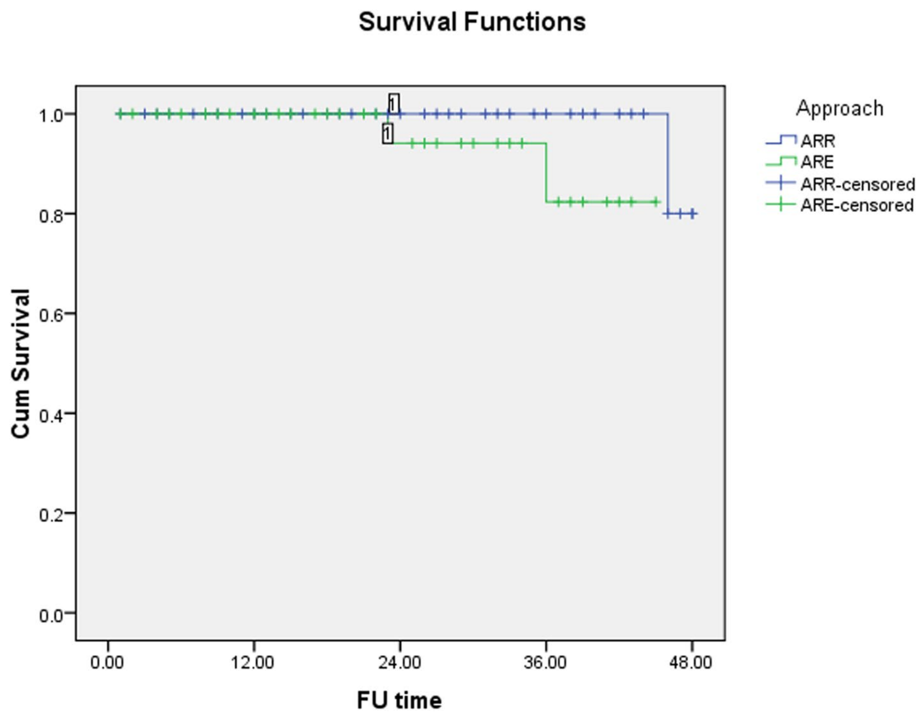

Fig. 3 Four-year Kaplan–Meier survival calculations for the aortic root replacement (RR) versus aortic root enlargment (RE)

(2.6% of RR cases). The second case (2.9% of RE cases) underwent mitral valve replacement due to the development of severe mitral valve regurge after aortic root enlargement operation (Manougian procedure).

Discussion

The main objectives of aortic valve replacement are to reduce the pressure and volume overload on the left ventricle (LV), relieve symptoms, aid in the ventricle's remodeling process, and improve survival. To achieve these goals, the valve—whether it be a mechanical, tissue, homo, or autograft—must allow for smooth flow without any obstructions [1].

In this study, 72 patients underwent aortic valve surgery and met our inclusion criteria. In total, 38 patients (52%) had aortic root replacement, and 34 patients (47%) had aortic root enlargement.

In our study, hospital mortality within 30 days was two patients. One belongs to aortic root replacement (RR) group, and the other was in aortic root enlargement (RE) group. Early mortality rate was 2.78%. There were no significant differences in operative mortality or overall Kaplan–Meier survival estimates between the two groups in 4 years. In Ennker et al. study, operative mortality was about 6.6%, which may be due to the large sample size [16]. According to some studies, the operative mortality rate for aortic root replacement is typically low, ranging from 1 to 3%. However, the risk of death rises sharply in emergency situations, like acute aortic dissection. RE may have similar or even slightly higher early mortality in some analyses compared to AVR alone, but recent large studies indicate that it does not significantly increase the risk of inhospital mortality when performed in isolated AVR cases [17].

The rates of reoperation were similar among the groups. The data indicate that RE and RR can be carried out in patients with AS with equal safety, although these conclusions should be supported by larger propensity score-matched investigations. Long-term studies suggest that RR provides greater durability, particularly in patients with progressive aortic root pathology. Mookhoek et al. [18] reported a 10-year freedom from reoperation rate of 92% after RR compared to 85% after RE, largely due to the progression of native root disease in the latter group [18].

Conversely, RE may be sufficient in older patients with limited life expectancy or those without connective tissue disorders. Ghoneim et al. [19] found that RE provided acceptable long-term outcomes in low-risk patients, with a 5-year survival rate comparable to RR [19].

According to postoperative bleeding and reopening or transferring, open sternum in our study has a significant difference between the two groups (P-value = 0.001). Thirteen out of 38 in aortic root replacement group had postoperative bleeding and were reopened, in comparison to other group which had only 4 patients out of 34 patients. But, in Mazine et al. study, there was no significant differences noted in the incidence of bleeding or reoperation. This could be due to different types of surgery included in our group, not only Ross but also stentless bioprosthesis [20, 21]. Postoperative bleeding is a recognized complication of aortic root replacement, sometimes requiring re-exploration. Meticulous surgical technique and hemostasis are crucial to minimize this risk. Aortic root enlargement involves an additional suture line on the aortic root, which theoretically could increase the risk of bleeding. However, techniques such as using a pericardial collar and Teflon-buttressed sutures in procedures like the Nicks' technique have been shown to result in a very low incidence of bleeding at the enlargement site [17].

Postoperative gradient across the new aortic valve significantly differed between surgery types and styles. The highest-pressure gradient was found after Nick's aortic root enlargement operation with the smallest valve size. The minimal pressure gradient was obtained after stentless bioprosthesis (Freestyle) aortic root replacement operation with the biggest valve size. The postoperative ejection fraction had no significant differences between surgery types and styles. Postoperative gradient up to 2 weeks postoperatively had significant difference between the two groups (*P*-value 0.001), and the mean gradient postoperatively in Ross was 8.5 ± 1.7, and in Mazine et al. study, the mean gradient in Ross was 9 mmHg and had a significant difference from mechanical valves [20].

A small aortic root increases the risk of PPM, which is associated with poorer long-term survival and suboptimal hemodynamics [22]. RE (e.g., Nicks, Manouguian, or Konno procedures) allows for the implantation of a larger prosthetic valve, reducing the likelihood of PPM [23]. A study by Bakhtiary et al. [24] demonstrated that RE significantly improved effective orifice area (EOA) and transvalvular gradients compared to standard AVR in small roots [24]. However, in cases of severe annular hypoplasia, RE may still result in residual gradients if the enlargement is insufficient [4].

In contrast, RR (e.g., Bentall procedure or valve-sparing root replacement) permits the implantation of an optimally sized prosthesis or a composite graft, virtually eliminating PPM [25]. David et al. [26] reported excellent hemodynamic outcomes with RR, particularly in younger patients, with low transprosthetic gradients and no significant PPM at long-term follow-up [26].

According to cross-clamp and bypass times, there was significant difference between the two groups (*P*-value 0.001). Aortic root replacement had longer cross-clamp and bypass time due to lengthy procedure. Hospital stay and ICU stay did not have significant difference between two groups. RR is inherently a more extensive surgical procedure. It involves the complete excision of the diseased aortic root, including the aortic annulus and the proximal ascending aorta. It necessitates meticulous reimplantation of the coronary arteries onto the graft and the subsequent anastomosis of the graft to the ascending aorta [27].

Consequently, ARR typically requires significantly longer cross-clamp and CPB times compared to isolated AVR or AVR combined with ARE. The increased duration is attributed to the complexity of the root reconstruction and coronary artery handling. Adding RE to AVR naturally increases the complexity and duration of the surgery, leading to longer cross-clamp and bypass times compared to AVR alone but still lesser than in cases of RR. However, these increases are generally considered acceptable in experienced centers, especially when balanced against the benefits of avoiding patient-prosthesis mismatch [27].

Bo Yang recently published Y-incision approach that has demonstrated to increase the annulus by about four valve sizes. This novel procedure has shown promising early outcomes, with 100% survival at 18 months in 50 consecutive instances. It also enlarges the proximal ascending aorta and the sinotubular junction [28, 29]. It is considered to be one of the aortic valve enlargement techniques, and we expect it to be the dominant technique in the near future.

Limitations

There are numerous significant limitations to this study. The sample sizes are small which may limit the statistical power to detect subtle but clinically significant differences in certain outcomes, particularly those with a lower incidence rate, such as reoperation. This could result in significant selection bias. The surgical techniques for both RR and RE can vary between surgeons and institutions. Although we aimed to capture the general approaches, this heterogeneity in surgical practice could introduce variability in the outcomes observed. Furthermore, the follow-up duration in this study may be insufficient to fully assess long-term outcomes such as late valve degeneration or the very late incidence of re-interventions. Longer-term follow-up studies are necessary to provide a more comprehensive understanding of the durability of these procedures. Finally, our study was conducted at two centers which allowed for consistency in some aspects of patient management; the findings may not be fully generalizable to other centers with different patient populations, surgical expertise, or postoperative care protocols.

Conclusions

Although aortic root replacement has longer bypass time and more bleeding in early postoperative period, it had lower postoperative pressure gradient which could affect LV mass and better outcome in the long term. No significant differences were found between the two surgical techniques in terms of hospital stay, mortality, and reoperation rate.

In our centers, there is no homograft or Freestyle stentless bioprosthesis, so aortic root enlargement could consider a safe procedure for patients with severe AS and small aortic annulus. Homograft and Freestyle could be better options due to less postoperative gradients and no need for lifelong anticoagulant. Long-term follow-up revealed no differences in survival rate. Longer and larger studies are required to confirm our results.

Abbreviations

AS	Aortic stenosis
RR	Aortic root replacement
RE	Aortic root enlargement
PPM	Prosthesis-patient mismatch
AVR	Aortic valve replacement
LV	Left ventricle
CABG	Coronary artery bypass graft
BSA	Body surface area
LVOTO	Left ventricular outflow obstruction
ICU	Intensive care unit
TR	Tricuspid regurgitation
LAD	Left anterior descending artery
MS	Mitral stenosis
MR	Mitral stenosis
MR	Mitral regurgitation
RCA	Right coronary artery
VSD	Ventricular septal defect
AVA	Aortic valve area
ESD	End-systolic dimension
EDD	End-diastolic dimension
OR	Operation room
MV	Mechanical ventilation
EF	Ejection fraction

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Not applicable.

Authors' contributions
I confirm that the manuscript is the authors' original work, has not received prior publication, and is not under consideration for publication elsewhere. On behalf of all co-authors, I shall bear full responsibility for the submission. I confirm that all authors listed on the title page have contributed significantly to the work, have read the manuscript, attest to the validity and legitimacy of the data and its interpretation, and agree to its submission.

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Data availability
I confirm that all data and materials of the manuscript will be available for any request.

Declarations

Ethics approval and consent to participate
All procedures performed in this study involving human participants were conducted ethically according to the ethical standards of the Institutional Review Board of the Faculty of Medicine in Assiut University, Assiut, Egypt. This study got the local approval of the ethical committee (17200743). Informed consent was obtained from all individual participants included in the study.

Consent for publication
I confirm that I have read, understand, and agreed to the submission guidelines, policies, and submission declaration of the journal. I confirm that the paper now submitted is not copied or plagiarized version of some other published work.

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

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