

Neo-aortic root dilatation following Ross procedure in school-aged children

Zeynep Gulben Kuk Ozalp

zeynepgulben.kuk@gmail.com

The Sydney Children's Hospitals Network - The Children's Hospital at Westmead

Elie Sawan

The Sydney Children's Hospitals Network - The Children's Hospital at Westmead

Gerald Riordan

The Sydney Children's Hospitals Network - The Children's Hospital at Westmead

Julian Ayer

The Sydney Children's Hospitals Network - The Children's Hospital at Westmead

Ian Nicholson

The Sydney Children's Hospitals Network - The Children's Hospital at Westmead

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Abstract

Objectives

Neo-aortic root dilatation after Ross procedure is more commonly seen in the young adult population rather than in neonates, and reinforced neo-aortic graft applications are being performed for this group. However, there is limited compiled data regarding the risk of dilatation in the pediatric population. We aimed to identify the age period the risk of neo-aortic dilatation begins to increase and investigate whether a specific threshold exists.

Methods

Data on neo-aortic dilatation and AR after the Ross procedure were compiled through a retrospective review of patients treated between 2006 and 2025 at The SCHN – The Children's Hospital at Westmead.

Results

69 patients who underwent the Ross/Ross–Konno procedure at our institution had available follow-up data. Among 69 patients, 29 (42.0%) were infants (9 neonates), 9 toddlers, 4 preschool-aged, 17 (24.6%) school-aged, and 10 adolescents. The median follow-up duration was 5.5 years. None of these patients required reoperation for neo-aortic root dysfunction. Excluding patients who underwent reinforced root techniques, neo-aortic root dilatation (Z-score 4–6) was observed in 1 infant, 1 toddler, 1 preschool-aged child, and 5 school-aged children. Comparing the school-aged group with the infant group, school-aged patients demonstrated a higher incidence of neo-aortic root dilatation ($p = 0.020$).

Conclusions

The limited availability of data for school-aged children continues to create uncertainty, even experienced surgeons, regarding the optimal age and BSA thresholds for the application of reinforcement strategies. Our cohort analysis and thorough literature review underscore the importance of closer scrutiny of this patient group.

Introduction

The Ross procedure has been performed since 1967, particularly by congenital heart surgeons [1]. Regardless of how successful the surgical technique is, the development of neo-aortic root dilatation and aortic valve regurgitation in the postoperative period has led surgeons to modify the existing technique. Based on our clinical experience, we have observed that neo-aortic root dilatation is more commonly seen in the young adult population rather than in neonates. Consequently, reinforced neo-aortic graft applications are being performed for this group. However, there is very limited compiled data

regarding the risk of dilatation in the school-aged (paediatric) population. In this study, we aimed to identify the age period the risk of neo-aortic dilatation begins to increase and investigate whether a specific threshold exists.

Patients and Methods

Study design and population

Data on neo-aortic dilatation and aortic valve regurgitation after the Ross procedure were compiled through a retrospective review of patients treated between 2006 and 2025 at The Sydney Children's Hospitals Network – The Children's Hospital at Westmead. A waiver of informed consent was granted due to its retrospective design.

Patients were categorized into predefined age groups as neonates (0–28 days), infants (29 days to 1 year), toddlers (> 1 to < 3 years), preschool-aged children (≥ 3 to < 5 years), school-aged children (≥ 5 to < 13 years), and adolescents (≥ 13 to < 18 years).

Ethic Committee number is 2025/ETH02295. It was approved on 13/11/2025 by the Sydney Children's Hospitals Network (SCHN) Human Research Ethics Committee (HREC).

A waiver of informed consent was used due to the retrospective design of the study and the impracticality of obtaining individual consent.

Inclusion and Exclusion Criteria

Patients undergoing the Ross procedure at the Children's Hospital at Westmead with available postoperative follow-up data were included, while those without adequate follow-up and patients operated in adulthood were excluded. A total sample of 69 patients, with age-stratified analyses, was considered sufficient based on detectable effect sizes, precision, and consistency with comparable single-centre studies.

Statistical Analysis

Categorical variables were compared using the chi-square test or Fisher's exact test. Statistical significance was defined as a p-value < 0.05.

Ross Procedure Technique

All patients had surgery under general anaesthesia. After intubation, transoesophageal echocardiography (TOE) was used in all patients to check the size, structure, and coaptation of the aortic and pulmonary valves. After median sternotomy and pericardiotomy, cardiopulmonary bypass was

initiated using high ascending aortic arterial cannulation and bicaval (or dual-stage atrial) venous cannulation. After aortic cross-clamping, antegrade Del Nido cardioplegia [2] was administered to achieve cardiac arrest. If the cross-clamp time was expected to exceed 90 minutes, a maintenance dose was given at 60 minutes.

The anterior wall of the pulmonary artery was marked vertically. After aortotomy, the native aortic valve was inspected, and the decision to proceed with the Ross procedure was made. The pulmonary artery was then divided proximally to the bifurcation, and the pulmonary valve was examined. The pulmonary autograft was harvested with a small cuff of ventricular muscle while carefully preserving the adjacent aortic root and coronary arteries. After re-inspection, it was placed in a saline solution. Haemostasis was ensured. Coronary artery buttons were prepared, and the native aortic valve leaflets were resected. In patients with annular stenosis, the Konno root enlargement procedure was performed. In adolescent patients, the pulmonary autograft was implanted in the aortic position using a reinforced technique, while in infants and paediatric patients, it was implanted in a free-standing fashion [3]. After the coronary buttons were implanted onto the neo-aortic root, the distal anastomosis between the neo-aortic root and the native distal aorta was completed. The cross-clamp was then removed. After the Right Ventricle – Pulmonary Artery (RV-PA) homograft conduit replacement was completed on the beating heart, the patient was weaned from cardiopulmonary bypass. Modified ultrafiltration (MUF) was applied in infants. Following reassessment with TOE, the patient was decannulated, and the chest was closed [4].

Clinical Follow Up

At our institution, paediatric cardiology, cardiac surgery, neonatology, and paediatric intensive care specialists provide coordinated care for this patient group.

In the preoperative period, newborns diagnosed with critical aortic stenosis are admitted to our neonatal unit for treatment. Outpatients are monitored with regular echocardiographic evaluations. Each patient is discussed in joint cardiology and cardiac surgery (JCC) meetings, and an individualized treatment plan is established.

Postoperative follow-up after the Ross procedure is performed in the paediatric intensive care unit, followed by care on the ward.

After discharge, patients continue follow-up with paediatric cardiology at 1, 3, 6, and 12 months, and then annually. If any pathology requiring intervention is identified during follow-up, these cases are reviewed in the JCC meeting, and a treatment plan is created.

Echocardiographic assessment

Echocardiographic measurements of the neo-aortic root were performed according to standard parasternal long-axis views. Z-scores were calculated using the PedZ application, based on body surface area-adjusted normative data. Given that the pulmonary autograft sinus demonstrates a mean Z-score

elevation of approximately + 1.3 ($\pm$ 1.7) relative to normal aortic standards immediately after implantation [5], a threshold of Z-score $\geq$ 4 was selected to identify patients with dilatation beyond this expected baseline. This threshold is consistent with Zimmermann et al. [6], who applied the same cutoff in a comparable paediatric cohort.

Results

Between 2006 and 2025, a total of 97 patients underwent the Ross or Ross–Konno procedure at our institution; however, this study was conducted on the 69 patients (19 females, 50 males) with available postoperative follow-up data.

Among these 69 patients, 29 patients (42.0%) were classified as infants (including 9 neonates, 13.0%), 9 (13.0%) as toddlers, 4 (5.8%) as pre-school-aged children, 17 (24.6%) as school-aged children, and 10 (14.5%) as adolescents.

Of the 69 patients, 30 (43.5%) had previously undergone an aortic valve intervention – 24 balloon valvuloplasties and 6 surgical valvuloplasties.

The median follow-up duration for 69 patients is 5.5 years, for the 17 patients in the school-aged group is 8.5 years. The median follow-up duration for the 21 patients in the infant group (including 9 neonates) is 9 years.

None of these patients required reoperation for neo-aortic root dilatation or neo-aortic valve regurgitation during the follow-up period.

Detailed evaluation, excluding patients who underwent reinforced root techniques, revealed that among the 59 patients (infants, toddlers, preschool-aged, and school-aged children), neo-aortic root dilatation (Z-score 4–6) was observed in 1 infant, 1 toddler, 1 preschool-aged child, and 5 school-aged children.

Six patients (28.6%) in this group demonstrated *mild aortic regurgitation and neo-aortic root Z-scores between 4 and 6*. Notably, five of these six patients had undergone the initial surgery between 8.7 and 11.2 years of age.

When comparing the school-aged group with the infant group, school-aged patients demonstrated a significantly higher incidence of neo-aortic root dilatation ($p = 0.020$).

Discussion

The Ross procedure is considered an important surgical option for the treatment of aortic valve disease in children and young adults, as it does not require anticoagulation, provides an excellent hemodynamic profile, and the autograft has the potential for growth. However, the most important complication limiting the long-term success of the procedure is neo-aortic root dilatation, which can lead to aortic regurgitation [6]. Neo-aortic root dilatation increases the risk of reoperation after the Ross procedure [7].

Therefore, the long-term success of the Ross procedure depends on understanding the behaviour of the autograft in the systemic circulation, its tendency to dilate, and the ability to control this dilatation.

Neo-aortic Root Dilatation: Incidence and Clinical Significance

As is well known, the diameter of the pulmonary artery autograft is significantly larger than normal aortic dimensions at the time of surgery.

In 1999, Tantengco et al. compared the follow-up data of 30 patients aged 3–31 years who underwent the Ross procedure using the freestanding technique with data from 217 healthy individuals aged 1–17 years. They observed significant dilatation of the aortic root by the first postoperative year [8].

In a study of 48 school-aged children, Horer et al. found that the mean Z-values of the neo-aortic annulus, sinus, and sinotubular junction at the time of autograft implantation were significantly higher than normal values ($p < 0.001$ for all). They also observed that the mean Z-values significantly increased during follow-up at the level of the sinus ($p < 0.001$) and the sinotubular junction ($p < 0.001$), while no significant increase was noted at the annular level. Additionally, AR increased with follow-up time ($p < 0.001$), and with sinotubular junction diameter ($p = 0.028$) [9].

Zimmermann et al. Also published their series of 76 patients in 2016 and mentioned that neo-aortic root dilatation (Z-score > 4) was observed in 28% of patients, and ascending aortic dilatation in 50% of patients, at a median follow-up of 5.2 years [6].

Pathophysiology: Adaptation of the Pulmonary Autograft to Systemic Pressure

In an ex-vivo study, native aortic roots and pulmonary autografts were exposed to the same systemic pressure for 30 minutes and evaluated using echocardiographic and histological analysis. The neo-aortic pulmonary roots demonstrated equivalence to the native aortic roots in terms of valve function and distensibility; however, changes in biomechanical properties and morphology were observed. Notably, a significant decrease in pulmonary autograft leaflet thickness was observed after 30 minutes [10].

Van Hoof et al. reported that when the pulmonary autograft is exposed to systemic circulation, elastic fibers become stretched, collagen fibers are activated, and intimal thickening and adventitial fibrosis develop. If this adaptation process fails, degradation of elastic fibers and the formation of a rigid structure occur, leading to dilatation. This remodeling process is particularly critical during the first 3–6 months, and uncontrolled hypertension or high systolic pressure load can accelerate dilatation [11].

Seiler et al. evaluated MRI findings in 132 patients aged 5.2 to 30 years who underwent the Ross procedure. This study demonstrated that under systemic pressure, the pulmonary autograft develops dilatation over the years in the root segments, particularly at the sinus and sinotubular junction, and that

this dilatation correlates with the progression of aortic regurgitation. They also found that patients operated on at an older age had a higher incidence of dilatation. Additionally, root reinforcement techniques were shown to prevent dilatation and aortic regurgitation, thereby improving long-term outcomes.

In our clinical experience, we also noted that autograft dilatation is more frequently observed in older children. Therefore, we aimed to examine this issue more closely. We began to explore whether the reinforced technique or other support methods that we use in adolescents could be applied to younger patients, and to determine the appropriate cutoff age or BSA for implementing these strategies.

Solutions For Younger Patients

Congenital heart surgeons have developed various modified reinforcement and inclusion techniques to prevent neo-aortic root dilatation and valve regurgitation without compromising growth potential.

Guirgis et al. mentioned a modified reinforced Ross technique, the reimplantation technique, to prevent aortic root bulging toward the coronary buttons seen after conventional reinforcement. In this approach, the Dacron conduit size is calculated by adding 2 mm to the diameter of the largest Hegar dilator that can easily pass through the autograft's sinotubular junction. The autograft is placed inside the Dacron graft, and the proximal end is secured with a continuous locking running suture. The commissures are fixed to the graft using pledged sutures. The autograft–Dacron composite is then implanted into the left ventricular outflow tract. Coronary buttons are reimplanted onto the Dacron graft, and the distal anastomosis is completed. The smallest graft used in this technique was 20 mm, applied in a 12-year-old patient who maintained preserved neo-aortic valve function over 12 years of follow-up. Their youngest patient was 6 years old, with a history of neonatal aortic valvotomy, VSD closure, and coarctation repair. A 24 mm Dacron graft was used in this case.[12]

Bojko et al. applied the reinforcement technique [13] originally described by Starnes et al. for adult patients [14] to a paediatric cohort aged 5 to 18 years. Except for two selected cases, they considered 18 mm as the minimum acceptable aortic valve diameter based on adult criteria and applied reinforcement only in patients with a preoperative pulmonary valve diameter of 18 mm or greater. Dacron grafts were chosen to be 2–3 mm larger than the pulmonary autograft diameter, with 20 mm being the smallest size used in most cases. In two patients, 18 mm grafts were used. The authors reported acceptable postoperative valve hemodynamics, survival, and freedom from reintervention.

Ozturk and colleagues described an inclusion technique in which the pulmonary autograft is implanted directly into the native aortic root without the coronary button mobilization. They reported that, they have frequently and successfully applied this method over the past 10 years, not only in adolescents and young adults, but also in paediatric patients, including children as young as 3 years old. They observed that this technique is particularly suitable for patients with bicuspid aortic valves, which are more accurately described as unicommissural valves, as these patients often have a naturally dilated aortic

root that offers an excellent fit for the autograft. The absence of coronary rotation risk was also noted as an additional advantage.[14]

Konstantinov recently published another modified root inclusion technique, which includes an autologous pericardial wrap support. [15]

Table : *Summary of Ross Procedure modifications for young patients*

Study	Bojko et al. 2025	Guirgis et al. 2022	Ozturk et al. 2022	Ruzmetov et al. 2014
Technique	External reinforcement with Dacron tube graft	External reinforcement with Dacron tube graft	Implantation into the native aortic root	Free standing-root implantation
Youngest Patient Age	5 years	6 years	3 years	1 week
Patients Number	19 (< 13 years)	61 (pediatric + adult)	Not specified multiple cases over 10 years)	78
Median Follow-up (years)	2.01	7.5	Not reported	10
Reintervention due Neo-aortic stenosis	1/19	0	Not reported	29% due to failed autograft
Autograft Dilatation Incidence	0	Not reported	Not reported	7% for 5 years 29% for 15 years
Advantages	Good early hemodynamic, low mortality	Stable aortic valve function for long term	No coronary manipulation, good anatomical support	Natural growth and simpler technique
Limitations	Potential growth restriction in youngest patients	Potential growth restriction in youngest patients	More suitable for the patients with dilated aortic root	High rate of long-term root dilatation and reintervention

Conclusions

The Ross procedure is a landmark surgical technique that has provided an important option for aortic valve replacement in the paediatric population. As its use has become more widespread, several complications have been identified, leading to the development of various technical modifications. One of the most important of these is reinforcement techniques, which aim to prevent neo-aortic root dilatation.

In our centre, reinforced Ross procedures are routinely performed in adolescents; however, neo-aortic root dilatation remains a concern in younger patients. Based on our clinical experience, we observed a higher tendency of dilatation in school-aged children compared to younger age groups.

Our cohort analysis and thorough literature review underscore the significantly increased risk of neo-aortic root dilatation in school-aged children undergoing the Ross procedure. Although limited in number, available reports also demonstrate that, when appropriate reinforcement techniques are used, acceptable outcomes can be achieved in this age group. Therefore, we believe that these patients should be carefully evaluated preoperatively, and that surgical planning should take these options into account.

Declarations

Informed Consent Statement: A waiver of informed consent was granted due to the retrospective design of the study

Ethics Committee Number and Date: 2025/ETH02295 was approved on 13/11/2025.

Data availability statement: The data underlying this article will be shared on reasonable request to the corresponding author.

Corresponding author: Zeynep Gulben Kuk Ozalp, MD. Department of Paediatric Cardiothoracic Surgery, The Sydney Children's Hospitals Network - The Children's Hospital at Westmead, Sydney, Australia.

Phone: +61 404 688 562

E-mail: zeynepgulben.kuk@gmail.com

ORCID number: 0000-0001-9230-8368

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Conflict of Interest Statements

The authors reported no conflicts of interest.

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