Personalized external aortic root support for elective treatment of aortic root dilation in 200 patients

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Abstract

Background and objectives

In Personalised External Aortic Root Support (PEARS) a custom-made, macroporous mesh is used to stabilise a dilated aortic root and prevent dissection, primarily in patients with genetically driven aortopathies. Data are needed on the safety and postoperative incidence of aortic events.

Methods

We present a multicentre cohort study evaluating the first 200 consecutive patients (median age 33y) undergoing surgery with an intention to perform PEARS for aortic root dilatation in 23 centres between 2004-2019. Perioperative outcomes were collected prospectively while clinical follow-up was retrieved retrospectively. Median follow-up was 21.2 months.

Results

The main indication was Marfan syndrome (73.5%) and the most frequent concomitant procedure was mitral valve repair (10%). An intervention for myocardial ischemia or coronary injury was needed in 11 patients, 1 case resulting in perioperative death. No ascending aortic dissections were observed in 596 documented postoperative patient years. Late reoperation was performed in 3 patients for operator failure to achieve complete mesh coverage. Among patients with at least mild AR preoperatively, 68% had no or trivial AR at follow-up.

Conclusions

This study represents the clinical history of the first 200 patients to undergo PEARS. To date, aortic dissection has not been seen in the restrained part of the aorta, yet long-term follow-up is needed to confirm the potential of PEARS to prevent dissection. While operative mortality is low, the observed coronary complications reflect the learning curve of aortic root surgery in patients with connective tissue disease. PEARS may stabilise or reduce aortic regurgitation.

Keywords

Aortic aneurysm, Marfan syndrome, pre-emptive, personalised, mesh, aortic dissection

Abbreviations

CABG=coronary artery bypass grafting
CPB=cardiopulmonary bypass
PEARS = personalised external aortic root support
TRR = total root replacement
VSRR = valve sparing root replacement
MFS = Marfan syndrome
IQR = interquartile range
AR = aortic regurgitation (or aortic insufficiency)

Key questions

- **What is already known about this subject?**

Personalised External Aortic Root Support (PEARS) stabilises aortic root dimensions and has been used primarily in patients with genetically driven aortopathies. The ExoVasc implant becomes incorporated at a cellular level and reduces wall stress.

- **What does this study add?**

This study represents the clinical history of a new surgical technique from patient 1 to 200, including the learning curve while surgical indications expand and the procedure is implemented at an increasing number of centres worldwide. No ascending aortic dissections were observed in 596 postoperative patient years. While operative mortality is low, the observed coronary complications reflect the learning curve of aortic root surgery in patients with connective tissue disease.

- **How might this impact on clinical practice?**

As PEARS preserves the native aorta, earlier intervention in the disease progression can be justified. This suggests that the diameter cut-off values in current guidelines on the surgical management of aortic root aneurysm do not accommodate many patients who may be eligible for PEARS. PEARS stabilises or even reduces AR, adding to its pre-emptive value and justifying the application in patients with mild AR.

INTRODUCTION

Genetically determined aortic root aneurysms are conventionally treated by pre-emptive aortic root replacement at a threshold size judged to minimise the balance of risk between proceeding and deferring operation.[1] Total root replacement (TRR) with a mechanical or biological valved conduit does not completely restore the life-expectancy of these patients, typically under 50 years old at time of surgery.[2,3] A mechanical valve exposes patients to lifelong anticoagulant therapy and risks of thrombo-embolism or bleeding while the likelihood of biological valve failure in young patients remains a concern.[2,4] Although the haemodynamic outcome of valve sparing root replacement (VSRR) is superior and anticoagulation is avoided, it remains a technically demanding procedure with a risk of reoperation.[3] Personalised External Aortic Root Support (PEARS) is a pre-emptive, total tissue-sparing alternative whereby a custom-made, macroporous mesh (ExoVasc®) is used to stabilise the aortic root and ascending aorta (Figure 1). The first 30 cases were reported in Heart in 2014.[5] A descriptive report of a consecutive series of 117 patients with at least two year follow up was published in 2020.[6]

The principal indication has been a moderately dilated aortic root (40-50mm) with at most mild aortic regurgitation (AR), primarily in patients with Marfan syndrome (MFS) and other genetically driven aortopathies. Technical details of the manufacturing process, surgical procedure and early outcomes have been systematically reported.[5–7] PEARS has the potential to eliminate the risk of aortic dissection by augmenting the mechanical properties of a compromised aortic wall while reducing circumferential and longitudinal wall stress.[5,8–13]

To confirm the ability of PEARS to prevent aortic dissection, the long-term incidence of aortic and device-related events must be followed. The aim of this study is to report clinical outcomes for the first 200 primary aortic PEARS cases as the procedure was implemented at an increasing number of centres worldwide.

METHODS

Study design

We present a retrospective multicentre cohort study evaluating all consecutive patients undergoing surgery with an intention to perform PEARS for aortic root dilatation between May 2004 and June 2019. The study protocol was approved by the Ethical Committee of the University Hospitals Leuven (S63787) as the majority of data analysis took place at this centre. The need for further patient consent was waived.

Data collection

For all procedures, a case report form was returned to Exstent Ltd, ensuring that patient demographics, operative characteristics and in-hospital outcomes were collected prospectively. The recorded aortic root size is the largest diameter at the level of aortic leaflet coaptation, measured on the MRI or CT scan used to manufacture the implant. These data were stored securely on a server at Exstent Ltd. in accordance with local regulations and anonymised prior to further data collection. For the purpose of this study, surgeons were contacted and asked to provide detailed demographics, in-hospital outcomes and clinical follow-up data via anonymised spreadsheets (Supplementary material online, Table S2). Data collection commenced in October 2019 and was finalised in August 2020.

Data analysis

Follow-up completeness was defined as the follow-up index for the entire study population, calculated by dividing “documented postoperative patient years” by “optimal follow-up”.[14] The date representing optimal follow-up for each patient was defined by when follow-up data was returned, or when the patient died. As such, discrepancies between optimal and documented follow-up years may be related to (a) the interval between last clinical follow-up and when data was returned for a patient (b) patient lost to follow-up or died without the researchers being aware. Continuous variables were reported as median (interquartile range (IQR), range) or mean ± SD, categorical variables as n (%). Comparison of continuous variables between subgroups was performed using the Mann–Whitney *U* test, categorical data

were compared using the chi-squared test. To estimate survival and survival free from reoperation, a Kaplan-Meier analysis was performed.

The effect of PEARS on AR was evaluated by comparing preoperative AR grade with immediate postoperative AR recorded by the surgeon and with the independent recording of valve function during follow-up. For the analysis of AR evolution, patients reported to have no or trivial AR preoperatively (grade 0/4 or 0.5/4) were distinguished from patients reported to have at least mild AR (grade ≥1/4). Patients who previously underwent aortic valve replacement or who did not receive the ExoVasc implant were excluded. A logistic mixed effects model was used to evaluate the change in probability of having at least mild AR over time during follow-up. Random intercepts were used to capture the correlation of the repeated measurements in patients. Data analysis was performed using Microsoft Office Excel 2016 (Microsoft), Prism (GraphPad Software) and RStudio (RStudio, PBC).

Patient and public involvement

Tal Golesworthy is the inventor of the ExoVasc device and was the first patient to undergo PEARS in 2004. No other patients were involved in the design, conduct or reporting of this study.

RESULTS

Between May 2004 and June 2019, 200 patients underwent surgery with the intention to perform PEARS for primary aortic root dilatation. The operations were performed by 27 surgeons in 23 centres. The number of operations per surgeon ranged from 1 to 45 (median 3, IQR 1-9). The majority of cases (119/200, 59.5%) were performed in 2017, 2018 or 2019 (Supplementary material online, Figure S1). There was an expansion in the number of surgeons joining so there was a disproportionate number with, as yet, few operations performed.

Variable	Total population (n=200)
Male	138 (69)
Age (y)	33 (23-45; 3-75)
Height (cm)	185 (178-193; 107-206)
Root diameter (mm)	47 (44-49; 28-60)
Surgical indication	
Marfan syndrome	147 (73.5)
BAV	17 (8.5)
Loeys-Dietz syndrome	15 (7.5)
ACTA2 mutation	2 (1)
Idiopathic/other	19 (9.5)
Previous cardiac surgery	8 (4)
Mechanical AVR	2 (1)
MV repair	2 (1)
Coarctation repair	2 (1)
Fallot tetralogy repair	1 (0.5)
VSD closure	1 (0.5)
Preop AR grade*	
0/4	130 (65)
0.5/4	17 (8.5)
1/4	45 (22.5)
2/4	6 (3)
LVEF (%)	60 (57-64; 40-72)
LVEDD (mm)	52 (46-56; 31-68)

Table 1. Demographic characteristics of the first 200 patients to undergo primary aortic PEARS. Categorical variables shown as n (%), continuous variables shown as median (IQR; range). *n=198 as 2 patients with history of aortic valve replacement (AVR) are excluded. AR= aortic regurgitation, BAV=bicuspid aortic valve, LVEF=left ventricular ejection fraction, LVEDD=left ventricular end-diastolic diameter, MV=mitral valve, VSD=ventricular septum defect.

Patient demographics and operative characteristics

For the 147 patients with MFS, median root diameter was 47mm whereas for patients with Loeys-Dietz syndrome or a bicuspid aortic valve, it was 42mm and 48mm, respectively. 11 patients had a root diameter <40mm and either had Loeys-Dietz syndrome, an aggressive manifestation of MFS or a primary indication for mitral valve repair with PEARS performed concomitantly. Similarly, the 19 children in this cohort underwent concomitant mitral valve repair or had a malignant phenotype, the youngest patient a 3 year old girl with a root diameter of 38.4mm. Conversely, those patients with a root diameter ≥55mm (n=8) or above 65 years old (n=7), had an explicit preference for PEARS or an indication for concomitant

CABG. The demographic characteristics of the described population are shown in Table 1, the distribution of patient age and preoperative aortic root diameter in the Supplementary material online, Figure S2-3. 194 patients received the ExoVasc implant (Figure 2). For 166 isolated aortic PEARS cases, cardiopulmonary bypass (CPB) was used in 21.1%. A full overview of operative characteristics and concomitant procedures is shown in Table 2.

Perioperative adverse events

In 1 patient with MFS and a severe pectus deformity, the left main stem was injured. The case has already been reported.[15] This patient, in whom the ExoVasc was not implanted, represents the only early death in this study, resulting in a 0.5% perioperative mortality.

An intraoperative conversion (TRR n=2; VSRR n=3) was performed in 5 patients in whom the surgeon judged that the fragility of the aorta was a contra-indication to PEARS (n=3) or after coronary injury (n=2). An intra- or postoperative intervention was carried out in 11 patients (5.5%) for myocardial ischemia or coronary complications (Table 2). The indications were coronary impingement caused by the implant (n=2) or coronary injury (n=6). In 3 patients who received an ExoVasc, the adverse event was not caused by the implant or implantation thereof (Supplementary material online, Table S1 for additional details). Five of these patients (2.5%) suffered a myocardial infarction with repercussions on ventricular function. There was one limited intraoperative aortic dissection during an isolated PEARS procedure, related to aortic cannulation. The dissection was treated conservatively and was stable on postoperative imaging. Postoperatively, 2 patients developed a cerebrovascular event with hemiparesis, attributed to atrial fibrillation after off-pump PEARS. Both patients recovered completely. There were no revisions for bleeding.

In-hospital outcome for 200 procedures with intention to perform PEARS	
PEARS completed	194 (97)
Isolated aortic PEARS	166 (83)
PEARS + mitral valve repair	20 (10)
PEARS + elective OPCAB	3 (1.5)
PEARS + mitral valve replacement	1 (0.5)
PEARS + pulmonary homograft	1 (0.5)
PEARS + PFO closure	1 (0.5)
PEARS + pectus repair	1 (0.5)
PEARS from aortic annulus to distal arch	1 (0.5)
Converted to VSRR	3 (1.5)
Converted to TRR	2 (1)
Procedure aborted *	1 (0.5)
Implant size (n=194)	
95%	106 (54.6)
100%	88 (45.4)
Completed PEARS procedures (n=194)	
Operative duration (min)	183 ± 65
Isolated aortic PEARS (n=166)	
Operative duration (min)	174 ± 51
CPB used	35 (21.1)
CPB time (min)	62 ± 24
Length of stay (d) (n=194)	6 (5-7)
Adverse events	
Perioperative mortality *	1 (0.5)
Intervention for ischemia or coronary injury	11 (5.5)
CABG	6 (3)
CABG + PCI	1 (0.5)
CABG + IABP	1 (0.5)
CABG + VA-ECMO *	1 (0.5)
IABP	1 (0.5)
Revision to release tension on implant	1 (0.5)
Myocardial infarction	5 (2.5)
Intraoperative aortic dissection	1 (0.5)
Cerebrovascular event	2 (1)

Table 2. Operative characteristics and adverse events for all patients undergoing surgery with the intention to perform PEARS. *This is the same patient. Categorical variables shown as n (%), continuous variables shown as mean ± SD or median (IQR). CABG=coronary artery bypass grafting, CPB=cardiopulmonary bypass, IABP=intra-aortic balloon pump, OPCAB=off-pump coronary artery bypass grafting, PCI=percutaneous coronary intervention, PFO=patent foramen ovale, TRR=total root replacement, VA-ECMO=veno-arterial extracorporeal membrane oxygenation, VSRR=valve-sparing root replacement.

Clinical follow-up

Optimal clinical follow-up for the 200 patients corresponded to 753 postoperative patient years. In this study, 603 years were documented, representing 80% follow-up completeness calculated according to the follow-up index.[14] Median follow-up duration was 21.2 months (IQR 10-44.1, range 0-190.5) and clinical follow-up beyond 12 months was available for 142/197 (72.1%). One patient had documented follow-up beyond 15 years, 13 patients beyond 10 years and 34 patients beyond 5 years. Among the 194 patients who received the ExoVasc implant, 596 postoperative patient years were documented. For 2 patients who received the implant and had travelled overseas to undergo surgery, no follow-up could be obtained, amounting to 6 lost follow-up years. For 1 patient in whom a conversion to TRR was performed, no follow-up could be obtained (Figure 2), amounting to 1.3 lost follow-up years.

Aortic events

No ascending aortic dissections were observed. In 1 asymptomatic patient, a new type B dissection was discovered on imaging 3 years postoperatively. No device-related aortic events occurred, nor were there any late thrombo-embolic or bleeding events. Nine female patients had one or more successful pregnancies without cardiovascular complications after undergoing PEARS surgery.

A late reoperation was performed in 3 patients for failure to achieve complete coverage by the ExoVasc implant. In 1 patient, the implant had been cut off at the level of the coronaries contrary to the operation protocol, resulting in proximal dilatation and progressive AR.[16] At 39 months postoperatively, his root was reduced down to its original size and supported by a new implant. In another patient, right ventricular stunning occurred postoperatively and the implant was partially reopened. She underwent uncomplicated revision surgery (bioprosthetic root replacement) 6 years later and was well at 10 year follow-up. In the third patient, the opening for the right coronary artery was larger than required. At reoperation 9.5 years postoperatively, a local dilatation was resected and the coronary artery reimplanted. She remains well 11.4 years postoperatively.

Survival

Among patients who received the ExoVasc implant, there were 4 late deaths. One patient, with a history of aortic valve replacement, a flow-limiting lesion in the left circumflex artery and alcoholic cardiomyopathy for which he had an implantable cardioverter-defibrillator (ICD), was offered PEARS because he was deemed unfit for root replacement. He suffered circumflex artery occlusion postoperatively, unrelated to PEARS, for which surgical revascularisation was performed. He was discharged home with systolic heart failure and died 7 months postoperatively unrelated to PEARS. One patient died 14 months postoperatively from an unknown cause. The two other deaths were unrelated to PEARS: 1 patient died 3 years postoperatively due to COVID-19 and the other died in his sleep 4.5 years postoperatively. At post mortem his aortic valve was competent and coronary arteries healthy and unimpeded, as previously reported.[11] The three patients converted to VSRR were well at 13, 27 and 32 months follow-up, respectively. The patient who had TRR after coronary injury died 5 months postoperatively, attributed to an arrhythmia. No follow-up could be obtained for 1 remaining patient who underwent TRR. The Kaplan-Meier estimate for survival and survival free from reoperation for all patients undergoing surgery with the intention to perform PEARS, while also including the 1 perioperative death, is shown in Figure 3.

Aortic regurgitation

AR grade was recorded preoperatively and immediately postoperatively for all patients. For 80.2% (154/192) of patients who received the ExoVasc implant, AR grade was documented at one time point at least 2 weeks postoperatively (median 24.1 months). For patients with no or trivial AR preoperatively (74.2%, 147/198), the postoperative changes in AR were limited and deemed unlikely to be clinically significant. Sankey diagrams depicting the evolution in AR grade between measurement points are included in the Supplementary material online, Figures S4-8.

Patients with AR ≥1/4 at the time of PEARS (n=48) were significantly older (median 40 vs 32 years, p=0.025) and had a larger root diameter (48 vs 46 mm, p=0.002) than patients with no or trivial AR.

Immediately after PEARS, 42% (20/48) had a reduction in AR grade of at least 1 point, such that 63% (30/48) had no or trivial AR postoperatively (Supplementary material online, Figure S6 and S9A). Among patients receiving an ExoVasc implant scaled to 95% luminal diameter, a significantly greater proportion had no or trivial AR postoperatively compared to patients receiving a 100% implant (77%, 23/30 vs 39%, 7/18, p=0.009).

For patients with preoperative AR ≥1/4 and a follow-up echocardiography (n=37), 54% (20/37) had a reduction in AR grade of at least 1 point compared to preoperatively. At follow-up (median 22.3 months), 68% (25/37) of patients had no or trivial AR (Supplementary material online, Figure S7 and S9A). While not significant, patients receiving a 95% implant were more likely to have no or trivial AR at follow-up than patients receiving a 100% implant (75%, 15/20 vs 59%, 10/17, p=0.3) (Supplementary material online, Figure S9B and S9C).

Figure 4 illustrates the evolution in AR grade per patient between different measurement points, with patients with AR grades 0 and 0.5 combined into one group. There were no statistically significant differences with regards to preoperative AR grade, aortic root diameter, age or implant size between patients who did or did not have at least a 1 point reduction in AR grade when comparing any of the 3 time points. In a logistic mixed effects model, there was no change in the probability of having at least mild AR over time (OR:0.97 95%CI [0.93-1.02], p=0.213) between the postoperative and follow-up echocardiography.

DISCUSSION

This study represents the clinical history of the first 200 consecutive patients to have personalised external aortic root support (PEARS) for aortic root aneurysm, from the 1st patient onwards. With follow-up beyond 1 year available for 72.1% and median follow-up of 21.2 months, this is the most extensive report on PEARS to date.

From the outset we explored the possibility of a controlled trial but advice at the highest level of research methodology was that the different inclusion criteria and cogent patient preferences about timing of intervention and avoidance of anticoagulation precluded equipoise.[15,17] A recent independent expert analysis of the question reached the same conclusion.[18]

In the absence of a direct randomised comparison, we refer to available data on root replacement. In the multicentre AVIATOR registry including 4896 patients in expert centres, the perioperative mortality after VSRR and TRR was 1.2% and 2% respectively. Among 200 patients in this report there was one perioperative death (0.5%). In a meta-analysis of TRR and VSRR for root aneurysm in MFS, the annual rate of major bleeding was 1.3% and 0.1%, of thrombo-embolism was 0.7% and 0.4%, with reoperation rates of 1.3% and 0.6% respectively.[3] The cumulative burden of these complications during 603 postoperative years would be considerable. PEARS completely preserves the blood-endothelial interface and there were no late thromboembolic or bleeding events. There were 3 late reoperations, each attributable to failure to achieve the intended complete coverage of the ascending aorta, all errors avoidable with greater experience.[16]

In making these comparisons we recognise that the 200 PEARS patients were mainly young, low risk patients with predominantly normal aortic valve function. In large series of root replacement in patients with MFS, median preoperative root diameter was 48-54mm for VSRR and 54-55mm for TRR as compared to 47mm in our study.[19–21] We are also mindful that in reported series, the cases are categorised on the basis of the operations as completed. So if VSRR proves difficult to achieve, the

default is to resort to TRR, thus favouring the results for valve sparing surgery. We chose to report results according to intention to treat.

The effectiveness of PEARS must be measured by its ability to prevent ascending aortic dissection, historically the main cause of morbidity and mortality in patients with genetic aortopathies.[22,23] The absence of type A dissections in our study is consistent with previous reports showing that PEARS stabilises aortic dimensions while becoming incorporated histologically and reducing wall stress.[5,8–13] It is unknown how many dissections were effectively prevented in our study as it is currently not possible to predict who would have dissected without surgery.[24] Because many patients were operated at an earlier disease stage than at which root replacement is typically performed, and because follow-up is short for many patients, long-term follow-up is needed to monitor the occurrence of aortic events.[25]

Positioning the implant around the coronary artery origins, typically on a beating heart, is challenging and one of the main technical pitfalls of PEARS. In 8 patients, an intervention was carried out after coronary injury occurred (n=6) or for coronary impingement caused by the implant (n=2). While it may provide a safety net, the most experienced PEARS surgeons consider operating without CPB preferable, preserving normal anatomical relations rather than working on a collapsed heart. Avoidance of heparinisation allows for a bloodless dissection of the ventriculo-aortic junction. It is recognised that manipulation of the proximal coronary arteries is also a feature of root replacement, yet coronary complications are uncommon after root replacement nowadays.[26,27] Both patients and surgeons must be aware of these risks which reflect the learning curve of root surgery in patients with connective tissue disease.

In patients with no or trivial AR preoperatively, the observed changes in AR grade were subtle and probably of limited clinical significance. In these patients, PEARS has the potential to stabilise AR by fixing root dimensions.[5,6,9] For the majority of patients with mild AR preoperatively, it seems that PEARS achieves a durable reduction of AR. While this makes sense from a mechanistic point of view – reduction of root dimensions improves leaflet coaptation – long-term echocardiographic follow-up is

needed.[28] Importantly, as ExoVasc implants are scaled to aortic luminal diameter without including wall thickness, even the 100% implant represents an undersizing.

There are several important limitations to this study. Because many patients were operated at an earlier disease stage than at which root replacement is typically performed, long-term follow-up is needed to monitor the occurrence of aortic events. While perioperative data was collected prospectively, follow-up was retrieved retrospectively. 603 documented postoperative patient years represented 80% follow-up completeness.[14] For patients with no or trivial AR preoperatively, we were unable to statistically evaluate changes in AR grade over time because we could not differentiate true changes in AR from the inter-observer variability of echocardiography in a multicentre study. Due to the limited number of patients with AR ≥1/4 and a follow-up echocardiography (n=37), it was not possible to determine associations between patient characteristics or implant size (scaled to 95% or 100% diameter) and the probability of having at least mild AR during follow-up. Furthermore, we are unable to compare our observations with the natural evolution of MFS. While we did not study aortic diameters, PEARS has previously shown to stabilise aortic root dimensions.[5,9,12]

Conclusions

This study represents the clinical history of a new surgical technique from patient 1 to 200. As PEARS preserves the native aorta and aortic valve, earlier intervention in the disease progression is justifiable. This suggests that the diameter threshold values in current guidelines do not accommodate many patients who may benefit from PEARS. While operative mortality is low, the observed coronary complications reflect the learning curve of root surgery in patients with connective tissue disease. No ascending aortic dissections were observed in 596 postoperative patient years yet long-term follow-up is needed. PEARS has the potential to stabilise or reduce AR, adding to its pre-emptive value and justifying the application in patients with mild AR. PEARS provides an alternative for the treatment of aortic root aneurysm in the

hands of surgeons who are willing to train in its use and may be considered in well–informed patients in a shared decision making process.

Figures

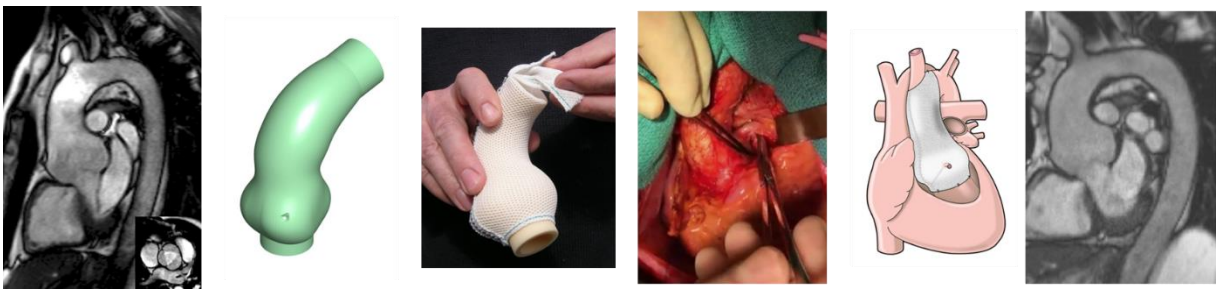


Figure 1. Illustration of the PEARS concept. A preoperative CT or MRI scan is used to create a model of the patient's aorta, which is 3D-printed. A sleeve of polyethylene terephthalate mesh is shaped on this former. The resulting ExoVasc is implanted around the patient's aorta, from the ventriculo-aortic junction to the brachiocephalic artery. Postoperative imaging shows stable aortic dimensions and patent coronary orifices at 16 years postoperatively in the first patient. Figure reproduced with permission.[6]

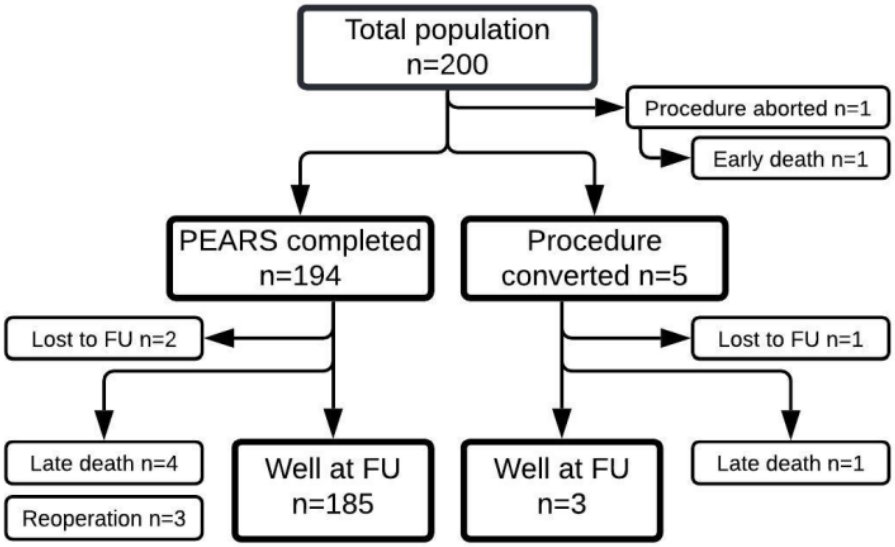
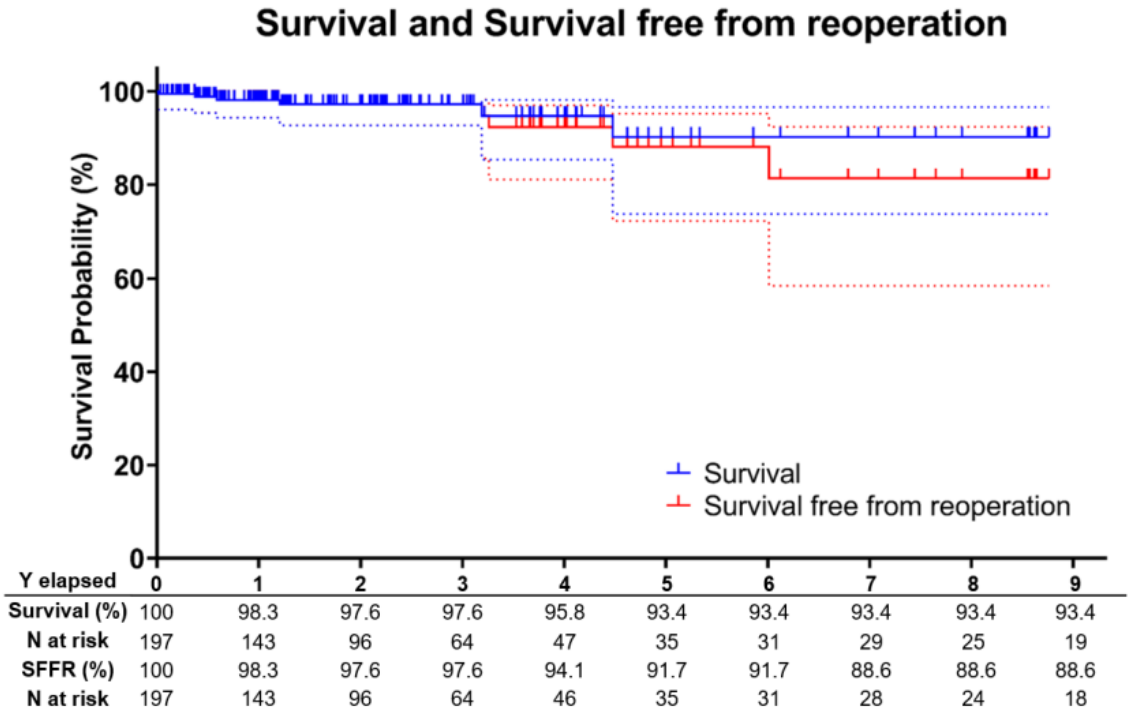


Figure 2. Flow chart of the first 200 patients operated on with the intention to perform PEARS for aortic root aneurysm. 3 patients were lost to follow-up. FU=follow-up.



Y elapsed	0	1	2	3	4	5	6	7	8	9
Survival (%)	100	98.3	97.6	97.6	95.8	93.4	93.4	93.4	93.4	93.4
N at risk	197	143	96	64	47	35	31	29	25	19
SFFR (%)	100	98.3	97.6	97.6	94.1	91.7	91.7	88.6	88.6	88.6
N at risk	197	143	96	64	46	35	31	28	24	18

Figure 3. Kaplan-Meier estimates for survival and survival free from reoperation for all patients with postoperative follow-up, while also including the 1 perioperative death (n=197). The 3 patients lost to follow-up were excluded for this analysis. Dotted lines indicate 95% confidence intervals. Survival curves were truncated at 9 years postoperatively because, at this time, less than 10% of the initial population remains. SFFR=survival free from reoperation.

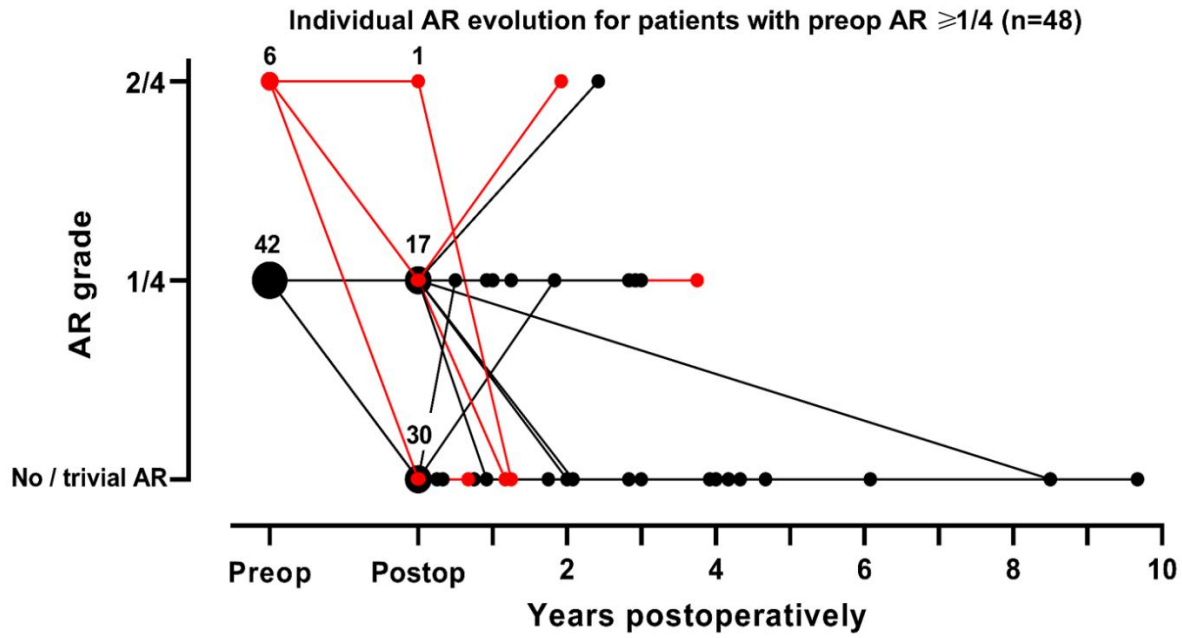


Figure 4. Evolution of AR grade over time for all patients with AR grade ≥1/4 at the time of PEARS surgery (n=48). For 37 patients, one measurement of AR is available during follow-up. Each point corresponds to at least 1 patient/measurement at a certain time point. Patients with AR 2/4 preoperatively are shown in red. Patients with AR 0 and 0.5 are combined into 1 group.

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Conflict of Interest statement

The only author with a potential conflict of interest is TG, the inventor of the ExoVasc device. He was the first patient to undergo Personalised External Aortic Root Support (PEARS) surgery in 2004 and is a shareholder in Exstent Ltd., the company that manufactures the PEARS ExoVasc device. Exstent Ltd holds a family of Patents and Registered Trademarks covering the ExoVasc PEARS implant. All other authors have no conflict of interest to disclose.

Author Responsibility Information

TG invented the procedure, developed the implant and was the first patient to undergo Personalised External Aortic Root Support (PEARS) surgery. JRP performed the first 26 operations. CA is the lead surgeon and performed 45 of the operations described in this study. This study was designed by LVH, TT, JRP, TG and FR. Perioperative data was collected prospectively by TG as standard protocol for the reporting of device-related issues. Detailed in-hospital outcomes and follow-up data were collected retrospectively by LVH, TT, JRP, CA and TG. Data analysis was performed by LVH, FR, PV and JJMT with input from all co-authors. The first draft of the manuscript was prepared by LVH, FR, PV and TT. All authors approved the final version to be published.

Data availability statement

The data underlying this article will be shared upon reasonable request to the corresponding author.

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