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ORIGINAL ARTICLE

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Long-term outcomes after ascending aortic replacement and aortic root replacement for type A aortic dissection

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Key question

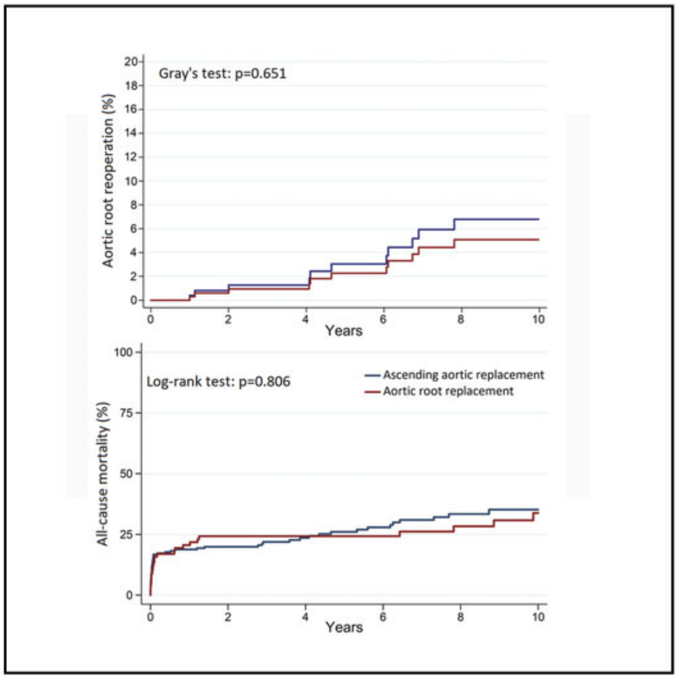
Is selective use of ascending aortic replacement TAAD a durable procedure?

Key finding(s)

Ascending aorta replacement was associated with limited risk of proximal reoperation and aortic root growth rate.

Take-home message

When stringent selection criteria were used, ascending aortic replacement achieved outcomes comparable to aortic root replacement for TAAD.



Abstract

OBJECTIVES: We investigated whether the selective use of supracoronary ascending aorta replacement achieves late outcomes comparable to those of aortic root replacement for acute Stanford type A aortic dissection (TAAD).

METHODS: Patients who underwent surgery for acute type A aortic dissection from 2005 to 2018 at the Helsinki University Hospital, Finland, were included in this analysis. Late mortality was evaluated with the Kaplan–Meier method and proximal aortic reoperation, i.e. operation on the aortic root or aortic valve, with the competing risk method.

RESULTS: Out of 309 patients, 216 underwent supracoronary ascending aortic replacement and 93 had aortic root replacement. At 10 years, mortality was 33.8% after aortic root replacement and 35.2% after ascending aortic replacement (*P* = 0.806, adjusted hazard ratio 1.25, 95% confidence interval, 0.77–2.02), and the cumulative incidence of proximal aortic reoperation was 6.0% in the aortic root replacement group and 6.2% in the ascending aortic replacement group (*P* = 0.65; adjusted subdistributional hazard ratio 0.53, 95% confidence interval 0.15–1.89). Among 71 propensity score matched pairs, 10-year survival was 34.4% after aortic root replacement and 36.2% after ascending aortic replacement surgery (*P* = 0.70). Cumulative incidence of proximal aortic reoperation was 7.0% after aortic root replacement and 13.0% after ascending aortic replacement surgery (*P* = 0.22). Among 102 patients with complete imaging data [mean follow-up, 4.7 (3.2) years], the estimated growth rate of the aortic root diameter was 0.22 mm/year, that of its area 7.19 mm^2/year and that of its perimeter 0.43 mm/year.

CONCLUSIONS: When stringent selection criteria were used to determine the extent of proximal aortic reconstruction, aortic root replacement and ascending aortic replacement for type A aortic dissection achieved comparable clinical outcomes.

Keywords: Type A aortic dissection • Aortic dissection • Ascending aortic replacement • Supracoronary • Aortic root replacement • Bentall procedure

ABBREVIATIONS

CI	Confidence interval
CT	Computed tomography
EuroSCORE	European System for Cardiac Operative Risk Evaluation
IQR	Interquartile range
HR	Hazard ratio
MRI	Magnetic resonance imaging
SHR	Subdistributional hazard ratio
TAAD	Type A aortic dissection

INTRODUCTION

Surgery for acute Stanford type A aortic dissection (TAAD) is associated with substantial mortality and morbidity [1, 2]. In these patients, surgical strategy is planned based on the patient's condition, the site of the intimal tear and the extent of the dissection. Considering the emergency nature of this condition, when feasible, most surgeons prefer an expeditious supracoronary ascending aortic replacement [3]. Still, extensive resection of the aorta during the primary surgery is thought to prevent degeneration of the remaining aorta, but it may increase operative risk due to prolonged end-organ ischaemia [4], without clear evidence of any benefit in preventing late aortic-related events [5, 6]. It is controversial whether replacement of the aortic root is indicated in the absence of aortic root aneurysm and/or aortic valve disease in patients with TAAD [3, 7–11]. Our goal was to evaluate whether the selective use of ascending aortic replacement achieves late outcomes comparable to those of aortic root replacement for acute TAAD in an institutional series.

PATIENTS AND METHODS

Study population

Consecutive patients who underwent surgical repair for acute Stanford TAAD from January 2005 to December 2018 at the Helsinki University Hospital, Finland, were the subjects of the present analysis.

Data were retrospectively collected into an electronic datasheet with pre-specified variables and were checked for completeness and consistency. Clinical variables were defined according to the European System for Cardiac Operative Risk Evaluation (EuroSCORE) II definition criteria [12]. Outcome criteria are reported in detail in the Supplementary Material. The data underlying this article cannot be shared publicly due to the need to protect the privacy of individuals who participated in the study.

Ethical statement

Permission to conduct this study was obtained from the review board of our institution (§25 HUS/60/2019, 19 August 2019).

Surgical technique

Details of the surgical technique are described in the Supplementary Material. In short, the ascending aorta was transected distal to the sinotubular junction, and the aortic root was inspected. A composite aortic grafting or a valve-sparing aortic root replacement was performed when the intimal tear involved the aortic root, dissection involved the coronary ostia or the aortic root diameter was >50 mm with or without severe aortic valve regurgitation. Patients with an intact aortic wall near the coronary ostia and without an aneurysmatic aortic root or tear involving it, underwent supracoronary aortic replacement with a Dacron prosthesis. The non-coronary sinus was left intact. Reapproximation of the dissected layers of the aorta was achieved with BioGlue (Cryolife Inc., Kennesaw, GA, USA), and a Dacron prosthesis was sutured to the remnant of the aorta at the sinotubular junction with a single running 4-0 polypropylene suture reinforced with a single or double strips of Teflon felt. Aortic valve replacement was performed in cases of severe aortic valve regurgitation with an intact and non-aneurysmatic aortic root.

Aortic imaging methods

Computed tomography (CT) or magnetic resonance imaging (MRI) follow-up examinations were scheduled at 3 months, 1 year, 2 years and then every second year after the operation. CT or MRI scans obtained immediately before the emergency surgery, early after surgery and at the last follow-up were reviewed by a radiologist (R.K.) with experience in aortic imaging. Both CT and MRI were considered suitable for this study because of the excellent agreement in thoracic aortic measurements between these imaging methods [13]. On CT, multiplanar reconstructions

Table 1: Baseline and operative characteristics of the study groups

Variables	Unmatched series			Propensity score matched pairs		
	Ascending aortic replacement (*n* = 216)	Aortic root replacement (*n* = 93)	Standardized differences	Ascending aortic replacement (*n* = 71)	Aortic root replacement (*n* = 71)	Standardized differences
Age (years)	63.6 ± 12.5	57.1 ± 16.6	0.497	61.0 ± 12.6	60.0 ± 12.6	0.082
Female, *n* (%)	85 (39.4)	17 (18.3)	0.478	10 (14.1)	14 (19.7)	0.151
Anaemia,[a] *n* (%)	90 (41.9)	39 (41.9)	0.002	33 (46.5)	34 (47.9)	0.028
eGFR (ml/min/1.73 m^2)	78 ± 27	82 ± 28	0.117	82 ± 31	79 ± 26	0.093
Peripheral vascular disease, *n* (%)	11 (5.1)	2 (2.2)	0.157	3 (4.2)	2 (2.8)	0.076
Diabetes, *n* (%)	18 (8.3)	7 (7.5)	0.030	7 (9.9)	2 (2.8)	0.049
Stroke, *n* (%)	13 (6.0)	4 (4.3)	0.078	5 (7.0)	2 (2.8)	0.196
Pulmonary disease, *n* (%)	16 (7.4)	6 (6.5)	0.037	6 (8.5)	5 (7.0)	0.053
Coronary artery disease, *n* (%)	23 (10.6)	6 (6.5)	0.151	5 (7.0)	4 (5.6)	0.057
Acute myocardial infarction, *n* (%)	2 (0.9)	1 (1.1)	0.015	1 (1.4)	1 (1.4)	0.000
LVEF ≤50%, *n* (%)	34 (16.6)	23 (25.3)	0.215	15 21.1)	13 (18.3)	0.043
Previous cardiac surgery, *n* (%)	11 (5.1)	2 (2.2)	0.157	0 (0)	1 (1.4)	0.169
Acute neurological event, *n* (%)	55 (25.6)	18 (19.4)	0.150	15 (21.1)	16 (22.5)	0.034
Cardiogenic shock, *n* (%)	55 (25.5)	14 (15.1)	0.261	9 (12.7)	8 (11.3)	0.043
Aortic rupture, *n* (%)	32 (14.8)	17 (18.3)	0.093	10 (14.1)	9 (12.7)	0.041
Connective tissue disorder, *n* (%)	3 (1.4)	4 (4.3)	0.176	2 (2.8)	2 (2.8)	0.000
Supra-aortic vessel dissection, *n* (%)	76 (37.3)	32 (37.2)	0.001	24 (33.8)	27 (38.0)	0.088
DeBakey type II dissection, *n* (%)	19 (8.8)	14 (15.1)	0.194	7 (9.9)	7 (9.9)	0.000
Aortic root diameter (mm)[b]	42.8 ± 74	50.7 ± 7.8	1.000	44.5 ± 7.3	50.9 ± 7.8	0.858
Bicuspid aortic valve, *n* (%)	11 (5.1)	15 (16.1)	0.364	7 (9.9)	8 (11.3)	0.046
Severe aortic valve regurgitation[c]	17 (7.9)	44 (47.3)	1.000	6 (8.5)	33 (46.5)	1.000
Partial or total arch repair,[d] *n* (%)	22 (10.2)	10 (10.8)	0.019	10 (14.1)	8 (11.3)	0.085
Hypothermic circulatory arrest, *n* (%)	195 (90.3)	78 (83.9)	0.192	65 (91.5)	61 (85.9)	0.179
Aortic cross-clamp time (min)	90 ± 31	135 ± 37	1.304	94 ± 29	139 ± 36	1.367

Continuous variables are reported as mean and standard deviation; categorical variables are reported as counts and percentages.

[a]Haemoglobin <12.0 g/l in women and <13.0 g/l in men.

[b]Data available for 244 patients.

[c]Variable not included in the estimation of propensity score.

[d]Any resection of the aortic arch requiring reimplantation of 1 or multiple supra-aortic vessels.

[e]GFR: estimated glomerular filtration rate according to the Modification of Diet in Renal Disease criteria; LVEF: left ventricular ejection fraction.

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were used to assess aortic root dimensions perpendicular to the axis of blood flow. On MRI, the aortic root was imaged with steady-state free precession cine sequences perpendicular to the aortic root axis. The widest sinus-to-sinus diameter, aortic root perimeter and aortic root area were evaluated at the mid-sinus level with aortic walls included in the measurements.

Outcomes

The primary outcomes of this study were all-cause mortality and proximal aortic reoperation, i.e. any reoperation on the aortic root and/or aortic valve. The secondary outcome was the growth rate of the aortic root diameter, area and perimeter from early to last postoperative follow-up, postoperative stroke/global brain ischaemia, acute kidney injury, deep sternal wound infection/mediastinitis, reoperation for bleeding and use of intra-aortic balloon pump or extracorporeal membrane oxygenation. Definitions of outcome criteria are reported in the Supplementary Material.

The date of death was retrieved from the national registry of statistics of Finland. Electronic files were reviewed to identify any aortic reoperation performed in patients residing in the Helsinki catchment area. Data on patients who moved from the Helsinki catchment area were gathered by contacting local doctors. No patient was considered missing at follow-up.

Statistical analyses

Continuous variables are summarized as means and standard deviation as well as median and 25th to 75th interquartile range (IQR). Categorical variables are summarized as counts and percentages. The outcome after ascending aortic replacement surgery was compared with that after aortic root replacement. Competing risk analysis was performed to estimate the cumulative incidence of proximal aortic reoperation considering all-cause mortality as a competing event.

The impact of the type of procedure on all-cause mortality was evaluated using Cox proportional hazard analysis adjusted for independent predictors of mortality during the study period. The impact of the type of procedure on the proximal aortic reoperation was evaluated using competing risk analysis adjusted for potential risk factors for reoperation on the aortic root. Risk estimates of late adverse events are summarized as hazard ratios (HR) or subdistributional hazard ratios (SHR) with 95% confidence intervals (CI).

Propensity score matching analysis was performed to adjust the outcomes for baseline covariates of patients who underwent ascending aortic replacement with those who had aortic root replacement. A propensity score was estimated using a non-parsimonious logistic regression model including the covariates listed in Table 1, excluding aortic root diameter and

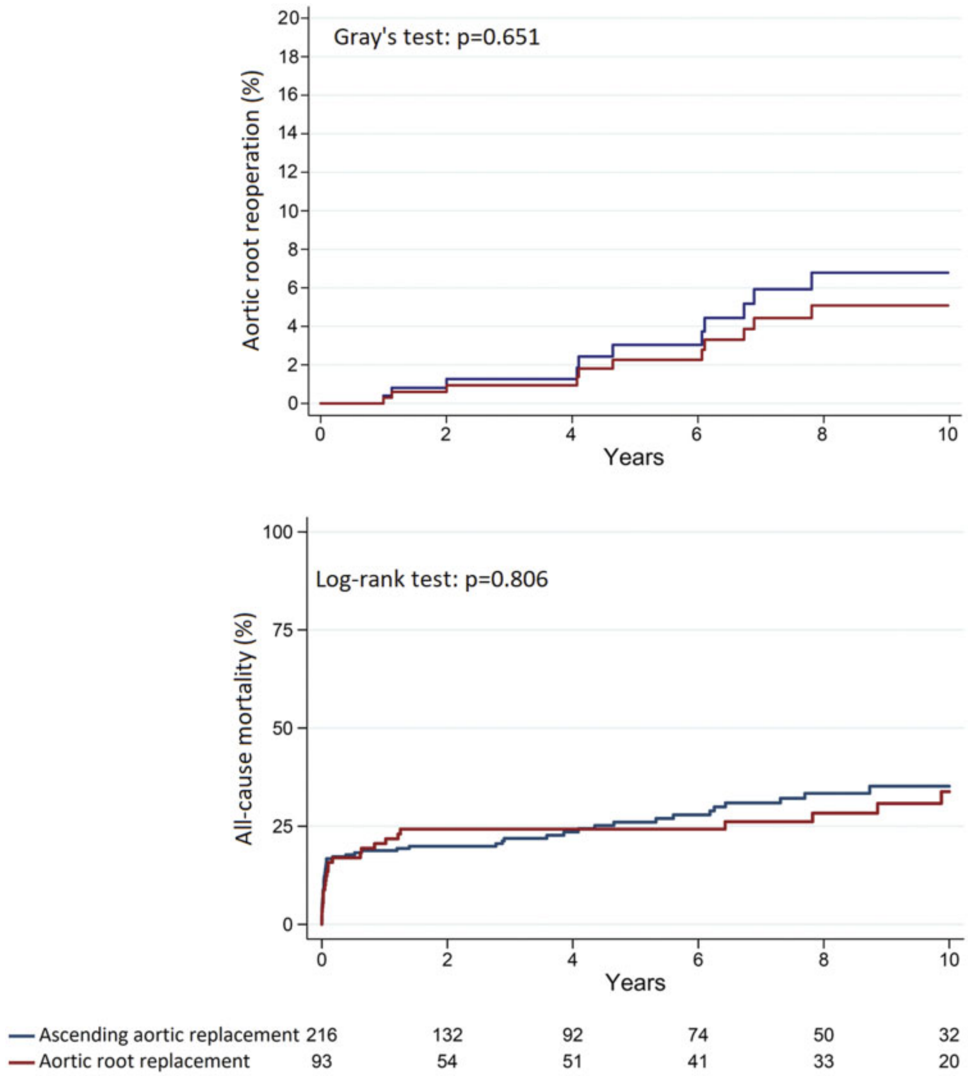

Figure 1: All-cause mortality and cumulative incidence of proximal aortic reoperation after aortic root replacement and ascending aorta replacement after surgical treatment of Stanford type A aortic dissection.

duration of aortic cross-clamp time. One-to-one propensity score matching was performed using a calliper width of 0.1, i.e. 0.2 of the logit standard deviation. Standardized differences <0.10 were considered an acceptable imbalance between the propensity score matched cohorts. The χ^2, Fisher exact and Mann–Whitney tests were used for analysis of early adverse events. Late outcomes in the unmatched and matched pairs were evaluated using the Kaplan–Meier method with the log-rank test and with the Klein–Moeschberger stratified log-rank test, respectively, and the competing risk analysis with Gray's K-sample test. Late outcomes were further adjusted for the following covariates having marginally increased standardized differences: adjusted for gender, prior stroke, prior cardiac surgery, use of hypothermic circulatory arrest and cardiopulmonary bypass time.

In the cohort of patients treated with supracoronary ascending aortic replacement, aortic root growth rate was estimated as a linear expansion rate in diameter (mm/year), area (mm^2/year) and perimeter (mm/year) between the first postoperative and the last CT/MRI follow-up divided by the duration of the imaging follow-up period. Furthermore, the instrumental variable estimation of aortic root growth rate was performed according to the method proposed by Rizzo *et al.* [14]. Changes in aortic root diameter, area and perimeter during the study intervals were compared using the Wilcoxon test and the test of within-subjects effects. Predictors of aortic root growth were identified using linear regression forcing the length of follow-up from early postoperative to last imaging examination into the regression model. $P < 0.05$ was considered statistically significant. Statistical analyses were performed using Stata v. 15.1 (StataCorp LLC, College Station, TX, USA) and SPSS v. 25.0 (IBM Corporation, Armonk, NY, USA) statistical software.

RESULTS

Overall series

Three hundred and nine consecutive patients [mean age 61.7 (3.2) years; women 33.0%; mean EuroSCORE II 13.9 (13.3)%] underwent surgery for acute TAAD from 2005 to 2017 at the Helsinki University Hospital, Finland (Table 1). The procedure was

Table 2: Data on proximal aortic reoperations in the study groups

	Ascending aortic replacement (n = 216)	Aortic root replacement (n = 93)
Overall, n (%)	8 (3.7)	3 (3.2)
Indications for reoperation, n (%)		
Aortic root pseudoaneurysm	4 (1.9)	
Aortic valve regurgitation	3 (1.4)	
Aortic root dilatation	1 (0.4)	
Tear of the Valsalva non-coronary sinus	1 (0.4)	
Native aortic valve endocarditis	1 (0.4)	1 (1.1)
Coronary button pseudoaneurysm		1 (1.1)
Prosthetic aortic valve endocarditis		1 (1.1)
Repeat procedures, n (%)		
Composite aortic grafting	4 (1.9)	3 (3.2)
Repair of pseudoaneurysm	2 (0.9)	
Aortic valve replacement	2 (0.9)	
David procedure	1 (0.4)	
Repair of the Valsalva non-coronary sinus	1 (0.4)	

performed by 24 surgeons. DeBakey type I TAAD was observed in 276 patients (89.3%). Supracoronary ascending aortic replacement without aortic valve replacement was performed in 211 (68.3%) patients, a composite aortic root replacement in 83 (26.9%), a David procedure in 9 (2.9%), a Yacoub procedure in 1 (0.3%) and a supracoronary ascending aortic replacement with aortic valve replacement in 5 (1.6%). Patients who underwent composite aortic root replacement, a David procedure or a Yacoub procedure were included in the aortic root replacement group.

The mean follow-up was 4.7 (4.5) years (median 3.3, IQR 0.2–11.8 years). At 30 days, mortality was 15.7% and at 10 years, it was 34.9%. The 10-year cumulative incidence of proximal aortic reoperation was 6.2% (11 patients).

The early outcome was comparable between study groups (Supplementary Material, Table S1). The 10-year mortality was 33.8% after aortic root replacement and 35.2% after ascending aortic replacement (log-rank test: P = 0.806; Fig. 1). Competing risk analysis showed that the risk of reoperation on the aortic root was comparable between aortic root replacement and ascending aortic replacement (10-year cumulative incidence: 6.0% vs 6.2%, P = 0.65, SHR 0.74, 95% CI 0.20–2.70; Fig. 1). The indications for proximal aortic reoperations are summarized in Table 2.

Cox regression analysis showed that, when adjusted for independent predictors of late all-cause mortality, i.e. advanced age, diabetes, preoperative acute neurological event and critical preoperative state (Supplementary Material, Table S2), patients who underwent aortic root replacement had late mortality comparable to those who underwent ascending aortic replacement (HR 1.25, 95% CI 0.77–2.02).

Competing risk analysis showed that, when adjusted for age, critical preoperative state, bicuspid aortic valve, connective tissue disorders, aortic aneurysm and family history of aortic disease, patients who underwent aortic root replacement had comparable outcomes from reoperation on the aortic root to those who underwent ascending aortic replacement (adjusted SHR 0.53, 95% CI 0.15–1.89).

Propensity score matching analysis

Propensity score matching resulted in 71 pairs of patients with comparable baseline characteristics, except for gender, history of stroke and prior cardiac surgery (Table 1). As expected, the aortic root replacement group had larger aortic root diameter [50.9 (7.8) vs 44.5 (7.3) mm, standardized difference: 0.858], and the procedure required longer aortic cross-clamp time [139 (36) vs 94 (29) min, standardized difference: 1.367] compared to the ascending aortic replacement group.

Thirty-day mortality was 14.1% after aortic root replacement and 12.7% after ascending aortic replacement (P = 1.00). Aortic root replacement was associated with significantly longer stays in the intensive care unit [7.6 (6.8) vs 5.7 (6.1) days; P = 0.050], whereas the proportion of other early outcomes was comparable between the study groups.

At 10 years, survival was 34.4% after aortic root replacement and 36.2% after ascending aortic replacement (Klein–Moeschberger stratified log-rank test, P = 0.70, adjusted for gender, prior stroke, prior cardiac surgery, use of hypothermic circulatory arrest and cardiopulmonary bypass time: HR 0.64, 95% CI 0.23–1.76), and cumulative incidence of proximal aortic reoperation was 7.0% after aortic root replacement and 13.0% after ascending aortic replacement (P = 0.22; adjusted for gender, prior stroke, prior cardiac surgery, use of hypothermic circulatory arrest and cardiopulmonary bypass time: SHR 0.44, 95% CI 0.11–1.80).

After excluding patients with connective tissue disease, the risk of proximal aortic reoperation was similar between the study groups (SHR 0.29, 95% CI 0.06–1.36).

Aortic root growth at imaging follow-up

A total of 102 patients survived to discharge and had complete imaging data. Four patients had their imaging follow-up performed with MRI; all the others were studied with CT. The mean follow-up from the preoperative to the early CT/MRI examination was 4.5 (5.0) months (median 3.2, IQR 2.8–3.9 months), whereas the mean follow-up from the first postoperative examination to the last CT/MRI examination was 4.7 (3.2) years (median 3.5, IQR 2.1–7.3 years).

The dimensions of the aortic root at the study intervals are summarized in Supplementary Material, Table S3 and Fig. 2. The size of the aortic root significantly changed during the study intervals. Still, the instrumental variable estimation of aortic root growth from the early postoperative imaging examination to the last was 0.22 mm/year (95% CI 0.03–0.40) in diameter, 7.19 mm^2/year (95% CI -5.02–19.57) in area and 0.43 mm/year (95% CI -0.25–1.11) in perimeter. The mean linear growth rate of the aortic root diameter was 0.23 (0.90) mm/year (median 0.13 mm/year, IQR -0.13–0.61), of its area 9.58 ± 50.29 mm^2/year (median 13.30 mm^2/year, IQR -5.82–27.62) and of its perimeter 0.50 (2.99) mm/year (median 0.78 mm/year, IQR -0.36–1.49). During the follow-up period, the aortic root reached a diameter >55 mm (range 56–64 mm) in 7 (6.9%) patients. Their aortic diameter ranged from 49 to 58 mm at the time of surgery and at the early postoperative follow-up, it ranged from 47 to 60 mm. Preoperative and early postoperative dimensions of the aortic root did not affect the aortic root growth in multivariate analysis (Supplementary Material, Table S4).

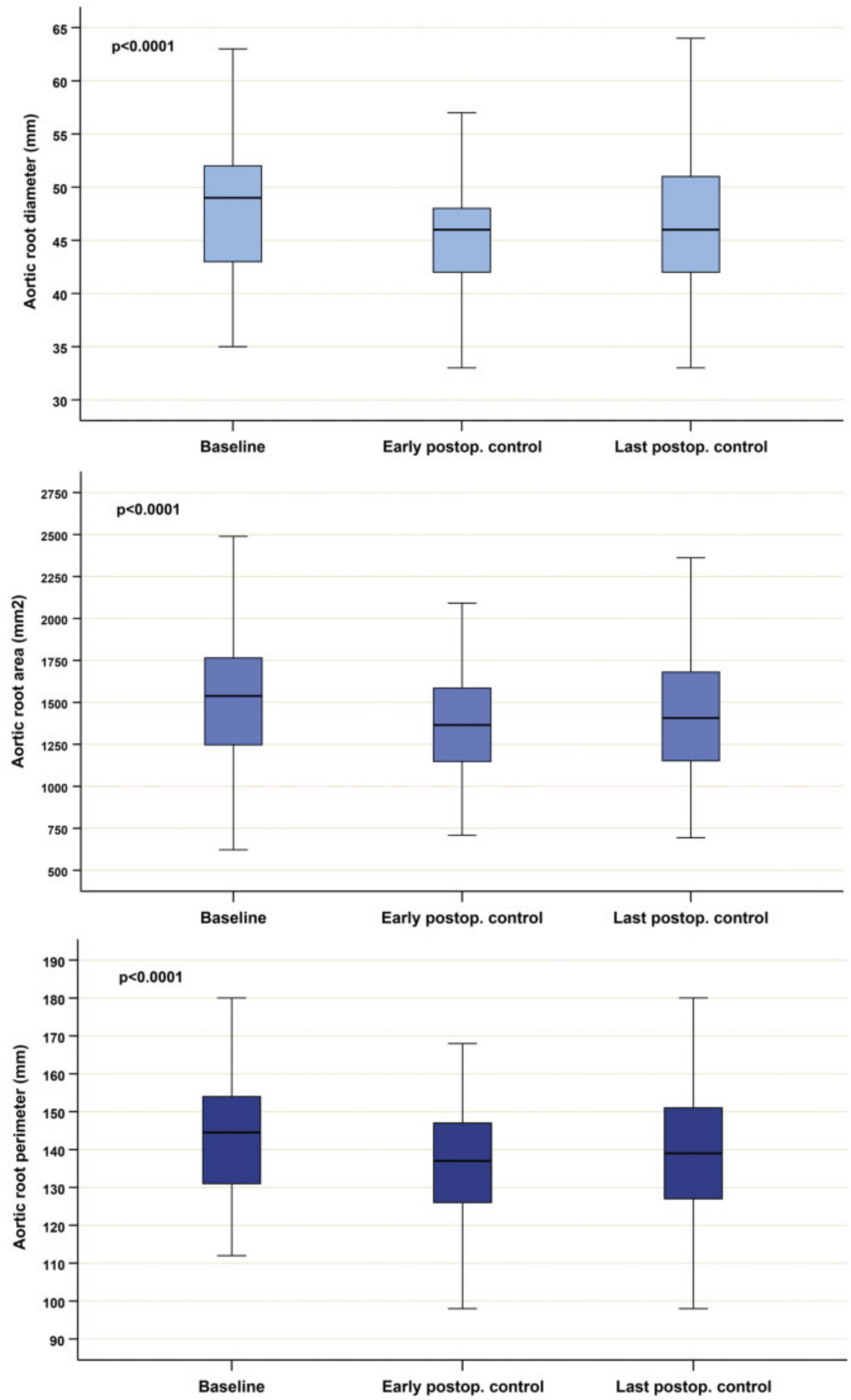

Figure 2: Changes in aortic root diameter area and perimeter at preoperative, early postoperative and late postoperative imaging examinations in 102 patients. *P*-values are from the test of within-subjects effects.

The all-cause mortality of hospital survivors with complete imaging data was 19.1% at 10 years. The cumulative incidence of proximal aortic reoperation at 10 years was 10.1% (95% CI 4.3–18.8).

DISCUSSION

The main findings of the present study are as follows: (i) Replacement of the ascending aorta achieved similar early and late survival compared to aortic root replacement for acute TAAD. (ii) A proximal aortic reoperation was uncommon after ascending aortic replacement. (iii) In a subset of patients who underwent CT follow-up examinations, the aortic root growth rate after supracoronary ascending aortic replacement was negligible.

The present results suggest that supracoronary ascending aortic replacement is a durable treatment for acute TAAD when the aortic root is not dilated or severely dissected. This finding is dependent on the specific nature and extent of the aortic dissection. Supracoronary replacement of the ascending aorta is a straightforward procedure with a shorter period of myocardial ischaemia compared to a more complex aortic root replacement procedure, and it can be successfully performed in an emergency setting by less experienced surgeons. These results can be interpreted as non-inferiority performance of aortic root replacement compared to ascending aortic replacement in terms of early adverse events. However, the experience of the individual surgeon might have introduced bias in the choice of surgical treatment and the outcome of these patients. Indeed, we expect that surgeons with more experience in aortic root surgery and/or surgical treatment of TAAD might have performed more extensive operations, still with favourable results. The relatively large number of surgeons who operated on these patients and the limited size of the present series do not allow a reliable analysis of the individual surgeon's impact on clinical choices and outcomes.

Results from the present analysis and previous studies showed a certain risk of the development of a pseudoaneurysm, aortic valve regurgitation and endocarditis after ascending aortic replacement. Geirsson *et al.* [7] reported that, out of 11 proximal reoperations, pseudoaneurysm was one of the indications for repeat surgery in 5 cases, aortic valve insufficiency in 5 cases, aortic valve endocarditis in 2 cases and aortic prosthesis infection in 1 case. The authors did not report any reoperation performed for aortic root dilatation. Westby *et al.* [8] reported 2 reoperations for aortic valve regurgitation (1 was associated with aortic root dilatation) in a series of 89 patients with TAAD treated with ascending aorta replacement. Ikeno *et al.* [10] recently reported their results with supracoronary aortic replacement in patients with TAAD. The authors reported a cumulative incidence of aortic root-related reoperations of 8.8% at 10 years [10], a figure which is comparable to our results. The Nordic Consortium for Acute Type A Aortic Dissection (NORCAAD) Investigators [15] reported the outcome of 832 (73.7%) supracoronary aortic replacement and 285 (25.2%) aortic root replacement procedures. At 8 years, the rate of proximal aortic reoperation did not differ between the aortic root replacement group and the ascending aortic replacement group (2.6% vs 6.2%; $P = 0.84$). The risk of proximal aortic reoperation was significantly increased in patients with connective tissue diseases. The International Registry of Acute Dissection Investigators [16] reported the results of aortic root replacement (699 patients) and ascending aortic replacement (1296 patients) for TAAD. In this large multicentre registry, patients who underwent root replacement had 3-year mortality (28.8% vs 26.4%) and proximal aortic reoperation (0.8% vs 0.7%; $P = 0.770$) rates comparable to those of patients who underwent ascending aorta replacement. Nishida *et al.* [17] reported a significantly increased risk of combined aortic root adverse events (defined as proximal aortic operation, aortic valve insufficiency moderate or higher or pseudoaneurysm or dilatation of the Valsalva sinus) after ascending aortic replacement for TAAD. However, only 3 out of 276 patients required a proximal aortic reoperation after ascending aorta replacement, and their 5-year survival was higher than that of patients who underwent aortic root replacement. Qiu *et al.* [18] reported the outcome of 95 patients who underwent ascending aorta replacement for TAAD with a mean follow-up of 3.0 years. At 5 years, freedom from grade 2+ aortic valve regurgitation was 97.2%, and none of these patients required proximal aortic reoperation. Our findings confirm a certain increased risk of proximal aortic pseudoaneurysm and severe aortic regurgitation after isolated replacement of the ascending aorta (Table 2). Development of a pseudoaneurysm might have been related to the extent of aortic dissection and/or characteristics of the aortic wall as well as failure to adequately reinforce the aortic anastomosis with double strips of pericardium or Teflon felts. Regarding the 3 cases of late aortic valve replacement for aortic regurgitation, none of these patients had more than mild aortic regurgitation before surgery. Still, the retrospective nature of this study does not allow a full elucidation of whether the characteristics of the aortic valve or the surgical technique of supracoronary aortic repair might have contributed to severe aortic valve regurgitation.

In this study, we did not observe an increased risk of early mortality with aortic root replacement compared to ascending aortic replacement. The International Registry of Acute Dissection Investigators [18] documented comparable hospital mortality with these 2 treatment methods (21.3% vs 18.0%, respectively; $P = 0.073$). Still, Geirsson *et al.* [7] documented increased in-hospital mortality when the aortic root was repaired (23.1% vs 8.1%; $P = 0.004$). Similarly, Nishida *et al.* [17] reported a higher operative mortality after aortic root replacement (12.5% vs 4.7%; $P = 0.05$) with a trend towards poorer 5-year survival compared to ascending aorta replacement in patients with TAAD. Hsu *et al.* [4] observed that aortic root replacement was an independent predictor of in-hospital mortality in these patients. A meta-analysis by Wu *et al.* [19] confirmed the significantly increased risk of early mortality in patients undergoing a composite aortic grafting compared to an ascending aortic replacement for TAAD. However, these results were not adjusted for potential confounders, which might have had an important impact on the choice of procedure. Furthermore, suboptimal meta-analysis methods prevented conclusive results on the potential benefits of aortic root replacement in preventing late cardiovascular events and the need for a proximal aortic reoperation.

Qiu *et al.* [18] estimated an aortic root growth rate of 0.50 mm/year after ascending aorta replacement based on a 3-year follow-up study. Ikeno *et al.* [10] estimated a sinus of Valsalva growth rate of 0.65 mm/year for a baseline aortic root diameter of 40.2 mm. In the present study, the aortic root growth was 0.23 mm/year based on a mean follow-up of almost 5 years. It is worth noting that, in the Ikeno series [10], the baseline Valsalva diameter was 40.5 mm, whereas in our series it was 42.8 mm. Only 7.1% of patients in the Ikeno series [10] underwent aortic root replacement, and the outcome of these patients was not described. Instead, in our series, 30.1% of patients with TAAD underwent aortic root replacement. This finding suggests possible differences in the characteristics of patients as well as the severity of aortic dissection, which might have indicated a more extensive surgical repair in our patients. These factors might have influenced the estimated aortic root growth rate of our series, which can be considered negligible.

Finally, the present study documented a 10-year mortality of 35.9%, which is lower than those of previous studies, which ranged from 40% to 56% [3, 7, 9, 10], despite similar age and early postoperative deaths among the study populations. This finding further confirms the long-term durability of our treatment strategy.

Limitations

The retrospective nature of this study is the major limitation. Second, one must consider a policy of primary surgical repair of extensively dissected and/or aneurysmatic aortic root when viewing the outcomes after ascending aorta replacement. Third, we did not consider aortic-related death as a study outcome because the declining rate of post-mortem examinations might have prevented a reliable evaluation of this adverse event. Fourth, the sample size might not be large enough for a reliable comparative analysis of these treatment methods. *Post hoc* analysis showed that 1362 patients in each study group are needed to detect a 5% increase in 10-year survival (from the observed rate of 36.0% in the ascending aortic replacement group to 41.0%) with a power of 80%, using a 2-sided log-rank test at the 5% significance level, whereas 1777 patients in each study group are needed to detect a decrease in the observed 10-year aortic root reoperation rate from 17.0% to 9.0% (ignoring the competing risk, in the present study, the 10-year reoperation rate on the aortic root was 9.4% in the ascending aortic replacement group and 16.7% in the aortic root replacement group). Fifth, the experience of the individual surgeon might have introduced bias both in the choice of surgical treatment and the outcome of these patients. Indeed, surgeons with more experience in aortic root surgery and/or the surgical treatment of TAAD might have tended to perform more extensive repairs, still with favourable results. The large number of surgeons and the limited size of the present series prevented an analysis of the impact of an individual surgeon on clinical outcomes. Sixth, the small number of patients with connective tissue disease did not allow an analysis of the durability of these treatment methods in this patient population. Finally, aortic root growth rate was assessed in a limited number of patients whose imaging follow-up was performed at our institution. In view of this limitation, we performed an analysis of the clinical results of the entire series, whose strength is the completeness of data on late mortality and proximal aortic reoperations.

CONCLUSIONS

The present study showed that, when stringent selection criteria were used to determine the extent of proximal aortic reconstruction, aortic root replacement and ascending aorta replacement for TAAD achieved comparable clinical outcomes. This finding is dependent on the specific nature and extent of the aortic dissection. Ascending aorta replacement was associated with a limited risk of proximal aortic reoperation and a negligible aortic root growth rate. Further studies with longer follow-up are needed to investigate the durability of ascending aorta replacement in patients with long life expectancy.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *ICVTS* online.

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Author contributions

Mikko Jormalainen: Conceptualization; Data curation; Investigation; Methodology; Supervision; Validation; Writing—original draft; Writing—review & editing. **Risto Kesävuori:** Conceptualization; Data curation; Investigation; Methodology; Validation; Writing—review & editing. **Peter Raivio:** Conceptualization; Investigation; Methodology; Supervision; Writing—original draft; Writing—review & editing. **Antti Vento:** Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Supervision; Validation; Writing—review & editing. **Caius Mustonen:** Conceptualization; Data curation; Validation; Writing—review & editing. **Hannu-Pekka Honkanen:** Conceptualization; Data curation; Validation; Writing—review & editing. **Stefano Rosato:** Formal analysis; Investigation; Methodology; Validation; Writing—review & editing. **Jarmo Simpanen:** Conceptualization; Investigation; Methodology; Writing—review & editing. **Kari Teittinen:** Conceptualization; Investigation; Methodology; Writing—review & editing. **Fausto Biancari:** Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Supervision; Validation; Writing—original draft; Writing—review & editing. **Tatu Juvonen:** Conceptualization; Investigation; Methodology; Supervision; Validation; Writing—original draft; Writing—review & editing).

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