Reexamining remodeling

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Objective: Root remodeling was proposed as valve-preserving root replacement to treat patients with aortic regurgitation and root aneurysm. The objective of this retrospective study was to review 18 years of experience with root remodeling and to identify predictors of valve durability.

Methods: Between October 1995 and December 2013, root remodeling was performed in 747 patients. The aortic valve anatomy was tricuspid in 431 patients, bicuspid in 290 patients, and unicuspid in 26 patients. Aortic aneurysm was present in 688 patients, and 59 procedures were performed for acute aortic dissection type A. The severity of aortic regurgitation ranged from grade 0 to IV (grade 0, 1%; grade 1, 8%; grade 2, 26%; grade 3, 62%; grade 4, 3%; median, 3). All patients underwent root remodeling, concomitant operations were performed in 352 patients, and cusp repair was used in 690 procedures.

Results: Hospital mortality was 2%. Overall freedom from reoperation was 92% at 10 years and 91% at 15 years. Overall freedom from reoperation was 95% for tricuspid valves at 10 and 15 years, 89% for bicuspid aortic valves at 10 years ($P = .006$), and 83% for bicuspid aortic valves at 15 years. By multivariate analysis, the strongest risk factors for failure were an aortoventricular junction 28 mm or greater (hazard ratio, 1.43) and the use of a pericardial patch as part of cusp repair (hazard ratio, 6.24).

Conclusions: Root remodeling continues to be a viable option in valve-preserving root replacement. If combined with careful assessment and, if necessary, correction of aortic valve geometry, reproducible restoration of aortic valve function can be achieved with good long term durability. (J Thorac Cardiovasc Surg 2015;149:S30-6)

Root remodeling was proposed by Sarsam and Yacoub[1] as valve-preserving root replacement to treat patients with aortic regurgitation (AR) and root aneurysm. The hypothesis was that AR was solely due to aortic dilatation, and the goal was to normalize valve function by replacing all dilated aortic root tissue.

The early results were positive, but the technique did not always yield sufficient valve competence.[2,3] Also, the late results of the original series were suboptimal, in that a relevant proportion of patients required reoperation for recurrent AR.[4] The inferior stability was related to the lack of annular stabilization in root remodeling.[5]

On the basis of initially positive results and the physiologically superior cusp motion, we started to use root remodeling for root aneurysm, initially mainly for patients without marked annular dilatation.[6] We observed that root aneurysm not infrequently coexisted with cusp prolapse,[7] and later we found that the probability of prolapse seemed to increase with increasing degree of AR.[8] In addition, we realized that cusp prolapse could be induced or aggravated through reduction of aortic diameter in root replacement.[9] We showed that the combination of root remodeling and cusp repair was safe and led to improved aortic valve function postoperatively.[10]

The finding of postoperative prolapse stimulated research on the normal configuration of aortic valve function; the introduction of the effective height concept with the possibility of intraoperative measurements helped in achieving normalized postoperative valve function irrespective of the preoperative degree of AR.[11,12] On the basis of the decreased durability of isolated aortic valve repair, we introduced the concept of suture annuloplasty as an addition to root remodeling.[13] Its use resulted in higher proportion of competent aortic valves.[14]

After initial careful exploration of root remodeling,[15] we were positively impressed by the reproducibility of achieving good aortic valve function. We extended its application to bicuspid aortic valves[16] and, more recently, unicuspid aortic valves. We hypothesized that normalized aortic valve configuration should lead to a low early failure rate, and the near-physiologic cusp motion should lead to good valve durability. More recently, we added a suture annuloplasty as quick and simple annular stabilization for individuals with large basal ring.[13] The objective of this retrospective study was to review 18 years of experience with root remodeling and to identify predictors of valve durability.

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Disclosures: Authors have nothing to disclose with regard to commercial support.

Read at The American Association for Thoracic Surgery Aortic Symposium, New York, New York, April 24-25, 2014.

Received for publication April 20, 2014; revisions received Sept 7, 2014; accepted for publication Sept 12, 2014; available ahead of print Oct 22, 2014.

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0022-5223/$36.00

http://dx.doi.org/10.1016/j.jtcvs.2014.09.048

Abbreviations and Acronyms
AR = aortic regurgitation
HR = hazard ratio

METHODS AND PATIENTS

Between October 1995 and December 2013, root remodeling was performed successfully in 747 patients at Saarland University Medical Center. One patient was excluded in whom root remodeling plus closure of several fenestrations led to unacceptable regurgitation requiring intraoperative conversion to replacement. The retrospective analysis of the data and publication in an anonymized fashion was approved by the local ethics committee.

Patients' age ranged from 3 to 86 years (mean, 54 ± 15 years), and 610 were male. The aortic valve anatomy was tricuspid in 431 patients, bicuspid in 290 patients, and unicuspid in 26 patients. Aortic aneurysm was present in 688 patients, and 59 procedures were performed for acute aortic dissection type A. A total of 29 individuals had Marfan syndrome according to Ghent criteria, and 1 patient had Loeys–Dietz syndrome.

Partial aortic arch involvement was present in 136 patients with aneurysmatic disease, and in 33 patients, the aneurysm involved the total arch. The primary indication for surgery was severe AR (n = 405), acute dissection (n = 59), or aortic aneurysm (n = 283). The severity of AR ranged from grade 0 to IV (grade 0, 1%; grade 1, 8%; grade 2, 26%; grade 3, 62%; grade 4, 3%; median, 3). Preoperative and postoperative severity of AR were quantified according to current guidelines.[17] Cardiac comorbidity included coronary artery disease (n = 112), mitral regurgitation (n = 42), tricuspid regurgitation (n = 35), and persistent atrial fibrillation (n = 42). Previous aortic or cardiac surgery had been performed in 40 patients.

The operative technique has been described in detail and has undergone only minor changes.[18] In all patients, the chest was opened by a median sternotomy, and aortic and right atrial cannulation were used; an 8-mm Dacron graft sutured to the right axillary artery was used for arterial inflow only in the presence of acute dissection. After root mobilization and excision of the sinus wall, a tubular graft was tailored to accommodate the configuration of the aortic root and sutured to the cusp insertion lines. The cusps were inspected for prolapse, and prolapse was corrected by central plication sutures on the cusp margin,[19] if necessary extending it into the belly of the cusp.

Remodeling originally was primarily used for patients with a basal diameter of less than 30 mm, and a graft size was chosen 1 to 2 mm smaller than the basal diameter. With increasing experience, all patients were included, and graft size was chosen according to the body surface area of the patient (24 mm for <1.8 m^2, 26 mm for 1.9-2.2 m^2, and 28 mm for ≥ 2.3 m^2). Since 2004, visual inspection for prolapse was replaced by measurement of effective height[11]; any effective height of less than 9 mm was considered as prolapse and corrected. Since 2009, a suture annuloplasty was added in the last 295 patients; braided polyester was used in 61 patients, and polytetrafluoroethylene was used in 234 patients.[13] Postoperative anticoagulation consisted of aspirin (100 m/d) given for 2 months unless persistent atrial fibrillation had been present preoperatively, in which case phenprocoumon (Marcumar; 3M Healthcare, Loughborough, UK) was used.

All patients were followed, and follow-up was complete in 723 patients (96.8%). Cumulative follow-up was 4582 patient-years (mean, 6.2 ± 4.4 years).

Statistical Methods

Data are expressed as means ± standard deviation, and categoric data are expressed as frequencies or ratios of patients. Demographic and baseline variables were analyzed by using the Mann–Whitney *U* test for continuous variables and the Fisher exact test for qualitative variables. Univariate associations with reoperation among clinical variables were obtained with 2 × 2 tables and the chi-square, Fisher exact, and Mann–Whitney *U* tests. End points included death and reoperations for aortic valve dysfunction. Variables that reached a *P* value less than .05 in the univariate analysis or that were considered clinically important were included in a multivariable Cox regression analysis to determine the predictors of reoperation after aortic root remodeling. The following variables were included in the Cox regression analysis: age, gender, severity of AR, nontricuspid morphology, effective height at follow-up (millimeters), use of a pericardial patch, cusp plication, large diameter of aortoventricular junction, and use of annuloplasty. Survival was analyzed using the Kaplan–Meier method. Statistical differences in Kaplan–Meier survival estimates were determined using the log-rank test. Data were analyzed using StatView 5.0 for Windows (SAS Institute Inc, Cary, NC).

RESULTS

All patients underwent root remodeling with replacement of the ascending aorta. Concomitant procedures were performed in 352 patients; these included partial (n = 195) or total (n = 33) arch replacement, coronary artery bypass grafting (n = 112), mitral repair (n = 42), tricuspid repair (n = 35), or left atrial ablation (n = 42).

Cusp repair was performed in 690 patients, with plication for prolapse correction being the most frequent maneuver (n = 664; 89%). In 69 patients, partial cusp replacement or augmentation with pericardium was performed in the setting of unicuspid (n = 26), bicuspid (n = 43), or tricuspid (n = 26) anatomy. In tricuspid aortic valves, 1 cusp was plicated in 141 patients, 2 cusps were plicated in 154 patients, and 3 cusps were plicated in 100 patients. In those with bicuspid valves, 1 cusp was plicated in 60 patients and both cusps were replicated in 209 patients. The time of extracorporeal circulation varied from 66 to 464 minutes (mean, 108 ± 34 minutes), and myocardial ischemic time ranged from 51 to 222 minutes (mean, 78 ± 19 minutes).

Fifteen patients died in the hospital, for a mortality of 2%. The causes of death were cardiac (n = 5), multiorgan failure (n = 5), sepsis (n = 2), cerebral embolism (n = 2), and pulmonary embolism (n = 1). Eighteen patients (2.4%) required reexploration for bleeding; no pacemaker implantation was required for atrioventricular conduction disturbance. In 1 patient, a pacemaker was implanted for sinus node dysfunction after atrial ablation. Actuarial survival was 93% at 5 years, 86% at 10 years, and 85% at 15 years.

A total of 42 patients underwent valve-related reoperation between 1 month and 11 years postoperatively. The aortic valve morphology was tricuspid in 15 patients, bicuspid in 25 patients, and unicuspid in 4 patients. Reasons for reoperation were secondary AR (n = 32), aortic stenosis (n = 6), and endocarditis (n = 4).

Overall freedom from reoperation was 92% at 10 years and 91% at 15 years. Overall freedom from reoperation was 95% for tricuspid valves at 10 and 15 years, 89% for bicuspid aortic valves at 10 years ($P = .006$), and 83% for bicuspid aortic valves at 15 years. At this time,