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Minimally Invasive Aortic Root Replacement

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ABSTRACT

Purpose: We retrospectively analyzed our early results with minimally invasive aortic root replacement.

Methods: Between August 1996 and April 1999, our center performed 137 aortic root replacements. Thirty-seven (27%) were accomplished through a 5 to 8 cm minimally invasive upper hemi-sternotomy incision. All minimally invasive operations were elective. The mean age for this cohort was 46 ± 12 yrs. Thirty one (84%) of the patients were male and 3 (8%) were reoperations. The average preoperative NYHA classification was 2.4 ± 0.6 and ejection fraction (EF) was 58% ± 12%. Valve pathology was congenitally bicuspid in 19 (51%), endocarditis (SBE) in 5 (14%), calcific degeneration in 4 (11%), annuloaortic ectasia in 3 (8%), rheumatic in 2 (5%) and other etiologies in 4 (11%). Nine patients (24%) had associated ascending aortic or arch aneurysms.

Results: The surgical techniques performed through mini-hemisternotomy consisted of 1) full root replacement in 31 (84%), 2) subcoronary replacement in 4 (11%), and 3) hemiroot in 2 (5%). Valve implants consisted of a homograft in 30 (81%), "Freestyle" bioprosthesis in 4 (11%) and a St Jude valved conduit in 3 (8%). Mean cardiopulmonary bypass duration was 193 ± 47 min. and aortic cross-clamp duration was 157 ± 40 min. Myocardial protection included systemic hypothermia in all (24 ± 4°C), antegrade cardioplegia (CP) in 35 (95%) with supplemental retrograde CP in 23 (62%). Three patients (8%) experienced postoperative low cardiac output syndrome (LCO). There was one operative death (3%). There was one (3%) reoperation for bleeding and 13 patients (35%) required blood transfusions. New onset atrial fibrillation occurred in 7 patients (19%) and there were 3 (8%) minor complications. Hospital length of stay (LOS) was 6.7 ± 4.3 days and LOS was less than 7 days in 29 patients (78%).

Conclusions: Minimally invasive aortic root replacement is feasible for a broad range of aortic valve pathology, can incorporate full root, hemiroot and subcoronary techniques, can be used for homografts and "Freestyle" valves as well as valved conduits, and can be accomplished with acceptable morbidity and mortality. However, the operation takes longer through the smaller incision and therefore requires more careful attention to myocardial protection.

INTRODUCTION

Aortic root replacement has traditionally been approached through a full sternotomy. This has the advantage of optimum exposure for a complex operation and ready access to the entire heart for (1) placement of a retrograde cardioplegia catheter, (2) manual decompression in the event of LV distention, (3) uniform distribution of topical hypothermia during aortic clamping, and (4) multiple options for venting and de-airing. With the recent development of minimally invasive techniques applicable to cardiac valve surgery, [Cosgrove 1996, Cohn 1997, Aklog 1998, Gundry 1998a, b] we began performing aortic root replacements through an upper hemi-sternotomy. We have generally reserved this approach for otherwise healthy patients who require elective isolated aortic root replacements. We have found that, when larger operations are preformed through smaller incisions, myocardial protection becomes more important. We report here our early experience and suggest strategies for optimal outcomes.

MATERIALS AND METHODS

Patients

Over a 32-month period between August 1996 and April 1999, we performed 137 aortic root replacements. One hundred (73%) were either non-elective, were associated with additional procedures (such as CABG) or, because of surgeon preference, underwent full sternotomy. Thirty-

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seven of the 137 patients (27%) underwent elective minimally invasive aortic root replacements as an isolated procedure and represent the patient population for this report. Patient ages for the minimally invasive cohort ranged from 27 to 71 years with a median of 43 years and a mean 46 ± 12 yrs. Thirty one (84%) were male and 3 (8%) were reoperations. NYHA Functional Class was between 2 and 4, with a median 2 and a mean 2.4 ± 0.6. Preoperative ejection fraction (EF) ranged from 15% to 78% with a median of 60% and a mean of 58% ± 12%. Valve pathology included congenitally bicuspid in 19 (51%), endocarditis in 5 (14%), calcific degeneration in 4 (11%), annuloaortic ectasia in 3 (8%), rheumatic in 2 (5%), Marfan's in 1 (3%), structural degeneration of a porcine valve in 1 (3%), perivalvar leak of a prosthetic valve in 1 (3%) and a chronic type A dissection in 1 (3%). Nine patients (24%) had associated ascending aortic or arch aneurysms.

Surgical Technique

1. Setup: An external defibrillator (R2 Stat Padz, Zoll, Inc, Burlington, MA) was placed on the patient prior to draping for subsequent defibrillation, as necessary. A Heartport® trans-jugular coronary sinus retrograde cardioplegia catheter (Heartport, Redwood City, CA) was placed in many patients later in the series by transesophageal echocardiography (TEE) guidance. An upper-hemi-sternotomy to the 3rd or 4th intercostal space, as guided by estimation of the position of the base of the heart by chest X-ray, was made and extended laterally with a narrow oscillating saw. At this point, depending on space availability in the chest, a decision was made to cannulate the arterial side either centrally (ascending or arch aorta) or peripherally (femoral or axillary) [Bichell 1997] and then the venous side either centrally (RA or innominate vein) [Zlotnick 1999] or peripherally (femoral). If the ascending aorta was particularly short or the chest cavity particularly deep, we tended to cannulate peripherally. The right pleural space was routinely opened for subsequent chest tube placement at the completion of the procedure.
2. Cardioplegia/Myocardial protection: Antegrade cardioplegia was used in all patients and a majority received a 1 liter induction dose. If significant LV hypertrophy was present, as documented by TEE, then the aortic root pressure was monitored and the cardioplegia delivered at a pressure of approximately 70-80 mmHg. A majority of the patients also received supplemental retrograde cardioplegia delivered via either a "standard" trans-atrial coronary sinus catheter positioned by TEE guidance, or more recently, via a Heartport® percutaneous trans-jugular coronary sinus catheter (Heartport, Inc, Redwood City, CA) , also positioned by TEE guidance.
3. Conduct of cardiopulmonary bypass: All patients were systemically cooled, typically to 25°C. Vacuum assistance of venous drainage was used in the majority of cases. Once the heart fibrillated, the aorta was cross-clamped and the heart protected with antegrade and/or retrograde cardioplegia. Topical hypothermia was also used but the distribution of this was felt to be unreliable. Venting was accomplished via a weighted vent placed through the aortic annulus or a right angle vent placed through the right superior pulmonary vein.
4. Valve operation: The choice of aortic valve operation and the technique used were left to the discretion of the operating surgeon.
5. De-airing: De-airing and avoidance of cerebral air embolism was accomplished by placing the patient in Trendelenberg and maintaining that position until all the air was evacuated as documented by TEE. During rewarming, while performing the distal aortic suture line, on full CPB flows, the heart was de-aired by first removing the vent and temporarily decreasing the flows on CPB and ventilating the lungs. Tilting the patient left side down also helped expel air from the LV apex. Then, after the aortic suture line was completed, and the heart regained a rhythm, a needle vent was made in the ascending aorta. If the heart did not defibrillate spontaneously, then the previously placed external defibrillator (R2 Stat Padz, Zoll, Inc, Burlington, MA) was used to obtain a rhythm. The flows on CPB were again temporarily reduced and the lungs ventilated to expel air out the aortic needle vent. The patient was then turned from side to side to help expel air. The ascending aortic needle vent was maintained open until the patient was separated from CPB and complete de-airing documented by TEE.
6. Pacing wires: The temporary epicardial pacing wires were positioned while on full CPB and before clamp removal with the heart completely decompressed to avoid the difficulty in placing the temporary wires after the heart is full off CPB. If it was not possible to place a temporary epicardial pacing wire, then either a pacing Swan-Ganz catheter or backup external pacing by use of external defibrillator/pacing pads (R2 Stat Padz, Zoll, Inc., Burlington, MA) placed on the patients prior to draping, were available.
7. Chest tubes: Typically, two 28Fr right angle chest tubes were used, both placed through right inframammary incisions. One was directed posteriorly into the right pleural cavity and the other medially into the mediastinum.
8. Closure: After a rhythm was obtained and complete de-airing was documented by TEE, the needle vent in the aorta was closed and the remainder of the closure was routine.

RESULTS

Technique and valve choice: Full root replacement with separate coronary buttons was used in 31 patients (84%), subcoronary technique in 4 (11%) and hemiroot technique in 2 (5%). Valve choice was homograft in 30 (81%), "Freestyle" (Medtronic, Inc, Minneapolis, MN) in 4 (11%) and St Jude valved conduit (St Jude Medical, Inc, Minneapolis, MN) in 3 (8%). Nine patients (24%) had

associated ascending or arch aneurysms and 3 (8%) required circulatory arrest for performance of the distal aortic anastomosis. In two of the three patients, a homograft was implanted and a Hemashield tube graft was interposed between the homograft and the distal ascending or arch aorta. The third patient had a valved conduit placed. There was no valve related complications or death.

Cardiopulmonary bypass and aortic clamp duration: Bypass duration 125 to 330 min with a median of 181 min and a mean of 193 ± 47 min. Aortic clamp duration ranged from 102 to 248 min with a median of 154 min and a mean of 157 ± 40 min. A typical aortic clamp duration for an isolated aortic root replacement performed through a full sternotomy at our insitution is approximately 90-120 min .

Myocardial protection: Systemic hypothermia was used in all patients (temperature on bypass 14°C to 28°C, mean 24 ± 4°C). Antegrade blood cardioplegia (CP) was used in 35 (95%) with supplemental retrograde blood CP in 23 (62%) and retrograde blood CP only in 2 (5%).

Low Cardiac Output Syndrome: Three patients (8%) experienced postoperative LCO syndrome. There was one operative death (3%) due to a stroke. This occurred in a 54-year-old man with rheumatic heart disease, aortic insufficiency and cardiomegally with a preoperative ejection fraction of 40%. He underwent full root replacement with a valved conduit. The aortic clamp duration was 104 min. He required conversion to a full sternotomy and BiVAD (ABIOMED) support for profound biventricular failure. The BiVADs were successfully explanted on postoperative day (POD) 7. However, he suffered a massive cerebrovascular accident (CVA) and expired on POD 40. Another patient, a 28 year old woman with endocarditis and a preoperative ejection fraction of 70% underwent full root replacement with a homograft. The aortic clamp duration was 167 min. She required conversion to a sternotomy and LVAD (ABIOMED) support for 8 days due to left ventricular failure. She had full cardiac recovery and was discharged home on POD 20. The third patient was a 55-year-old man with a preoperative ejection fraction of 15%. He underwent root replacement with a "Freestyle"® valve using subcoronary technique. The aortic clamp duration was 157 min. He experienced LCO requiring inotropic support, but also had a full recovery.

Bleeding and Transfusions: Excluding the two patients who required VAD support, there was 1 (3%) reoperation for bleeding and 13 patients (35%) required 0 to 11 units of banked blood products, with a mean of 1.3 ± 2.6 units of blood transfusion per patient. Twenty-seven patients (72%) received either epsilon aminocaproic acid (Amicar) or aprotinin.

Minor Complications: New onset atrial fibrillation occurred in 7 patients (19%), and there were 3 (8%) other minor complications (a superficial wound infection, heart block requiring a pacemaker and a urinary track infection).

Length of Stay: Hospital length of stay (LOS) ranged from 3 to 23 days with a median of 5 days and a mean of 6.7 ± 4.3 days. LOS was less than 7 days in 29 (78%).

DISCUSSION

The patients in this series were highly selected. They were generally young healthy males with good ventricles undergoing elective operations. Only 37 of the 137 patients (27%) requiring aortic root replacement at our hospital during this time period were selected for the minimally invasive approach. The majority of the remaining 100 patients either required associated procedures, such as CABG, or were non-elective, such as acute type A aortic dissections.

The principle finding in this report is that minimally invasive aortic root replacement is feasible for a broad range of aortic valve pathology, can be used for full root, hemiroot and subcoronary techniques for implantation of homografts or the newer stentless bioprostheses such as the "Freestyle" valve (Medtronic, Inc, Minneapolis, MN) valves, as well as valved conduits. These operations can be accomplished with acceptable morbidity and mortality. However, a 5% incidence of low cardiac output syndrome requiring VAD support, in an otherwise healthy population, suggests that, because the operations generally take longer through the smaller incisions (157 minutes versus less than 120 minutes), myocardial protection strategies need to be maximized. The presence of LV hypertrophy and/or aortic insufficiency may accentuate this. Several factors make the minimally invasive approach more treacherous from a myocardial protection standpoint. This includes the inability to visually detect LV distention or LV malperformance. Also, the inability to manually decompress the ventricle should distention occur, the non-uniform distribution of topical hypothermia, the relative difficulty of venting the LV, and the relative difficulty of placing the "standard" trans-atrial retrograde cardioplegia catheter through the small incision. Thus, when performing big operations through small incisions, myocardial protection becomes more important. The question therefore is not whether aortic root replacement can be performed through a small incision, but whether it can be done safely on a regular basis for most elective situations.

The two patients who suffered low cardiac output requiring VAD support were representative of the general population in that they were young and healthy with good ventricles. Both underwent elective full root replacement with a valved conduit and homograft respectively. Common features to both patients included significant aortic insufficiency (AI) as the indication for operation, systemic cooling to 28°C, and the use of antegrade CP only. Both patients had profound problems with myocardial performance after surgery, which resolved completely in both cases after one week of VAD support. The fact that the ventricles recovered fully, as documented by TEE, suggests that myocardial protection, rather than a technical problem with the coronary buttons, was the principle reason for the (reversible) myocardial failure. The significant AI likely resulted in under-appreciated LV distention. Although neither patient was vented during administration of CP via the aortic root, both were given CP via Spencer cannulae

intermittently during aortic clamping. A better approach may have been to gradually cool to 25°C and, once the heart fibrillated, clamp the ascending aorta and administer antegrade CP at the aortic root very gently. If the LV had become distended, as documented by PA pressures exceeding 20 mmHg or by TEE, then open the aorta and administer antegrade CP with Spencer cannulae down each coronary orifice and retrograde CP with the "Heartport" catheter (Heartport, Inc, Redwood City, CA). Obviously, conversion to a full sternotomy with manual decompression and topical hypothermia is another option.

The 54-year-old man died from a massive CVA likely related to clot forming on the mechanical aortic valve in the fully decompressed VAD-supported ventricle. Although we attempted to maintain LV ejection, by limiting LVAD flows, the CVA was likely from the valve because at no time was clot noted in the LVAD pump, even after explantation.

Overall, the results reported here are excellent, with no technique-related complication such as coronary button kinking or massive bleeding related to a faulty suture line. Most patients were discharged in about 5 days and patient satisfaction with the small incisions has been excellent.

Thus, if cardiac surgeons pay close and careful attention to myocardial protection, we believe that aortic root replacement can be safely performed through a minimally invasive incision. We do, however, believe that minimally invasive aortic root replacement should be reserved for good risk patients. We have found that the following principles are helpful in the performance of aortic root replacement through minimally invasive incision:

1. Routine placement of R2 Stat Padz® (Zoll, Inc., Burlington, MA) before surgery for defibrillation and/or pacing as necessary.
2. Routine cooling to 25°C or lower for myocardial protection.
3. Routine placement of "Heartport" (Heartport, Inc., Redwood City, CA) percutaneous trans-jugular retrograde CP catheter for induction and maintenance of blood CP.
4. Routine placement of a TEE probe for detection of LV distention, for monitoring of de-airing and for evaluation of LV function after surgery.
5. Routine placement of a PA catheter for detection of LV distention. If the PA pressures exceed 20 mm Hg then maneuvers to decompress the LV should be employed.
6. If venting is desired then placement of the vent through a separate stab wound in the chest wall, then through the right superior pulmonary vein and mitral valve into the LV. Placing the vent through a separate stab wound avoids congestion in the operative field.
7. In the setting of massive LV hypertrophy but no aortic insufficiency, routine use of a 12 ga angiocath for administration of 1 liter antegrade CP via the aortic root while simultaneously maintaining aortic root pressure 70-80 mm Hg, followed by maintenance retrograde CP.
8. In the setting of massive aortic regurgitation, gradual cooling to 25°C followed by aortic clamping upon fibrillation and gentle administration of antegrade CP via the aortic root. If LV distention is significant, as documented by PA pressures exceeding 20 mm Hg, or by TEE, conversion to Spencer cannulae after aortotomy followed by retrograde CP via the "Heartport" catheter.

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