Management of Aortic Root in Type A Dissection: Bentall Approach

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Abstract

Background: We analysed the results of the modified Bentall procedure in a high-risk group of patients presenting with acute type A aortic dissection (ATAAD). Methods: ATAAD patients undergoing a modified Bentall between 1996 and 2018 (n=314) were analysed. Mechanical composite conduits were used in 45%, and biological using either a bioprosthesis implanted into an aortic graft (33%) or xeno-/ homograft root conduits (22%) in the rest. Preoperative malperfusion was present in 34% of patients and cardiopulmonary resuscitation required in 9%. Results: Concomitant arch procedures consisted of hemiarch in 56% and total arch / elephant trunk in 34%, while concomitant coronary artery surgery was required in 24%. Average crossclamp and cardiopulmonary bypass times were 126 ± 43 and 210 ± 76 minutes, respectively, while average circulatory arrest times were 29 ± 17 minutes. A total of 69 patients (22%) suffered permanent neurologic deficit, while myocardial infarction occurred in 18 cases (6%) and low cardiac output syndrome in 47 (15%). In-hospital mortality rate was 17% due to intractable low cardiac output syndrome (n = 29), major brain injury (n = 16), multiorgan failure (n = 6) and sepsis (n = 2). Independent predictors of in-hospital mortality were critical preoperative state (OR, 5.6; $p < 0.001$), coronary malperfusion (OR, 3.6; $p = 0.002$), coronary artery disease (OR, 2.6; $p = 0.033$) and prior cerebrovascular accident (OR, 5.6; $p = 0.002$). Conclusions: The modified Bentall operation, along with necessary concomitant procedures, can be performed with good early results in high risk ATAAD patients presenting.

Introduction

Acute type A aortic dissection (ATAAD) is one of the most dramatic life-threatening diseases with an incidence that may be significantly higher than previously assumed based on previous retrospective studies [1-5]. This is underlined by the fact that up to one-half of ATAAD cases are detected only at autopsy [5]. Accumulation of experience, development of diagnostic tools, and improved treatment strategies have resulted in improved results of surgical treatment over time: according to International Registry of Aortic Dissection (IRAD), operative mortality dropped over time from 25 to 18% [6]. However, mortality rates remain very high in the group of patients presenting with unstable, critical conditions: about one-third of ATAAD patients present with hemodynamical instability or malperfusion of one or more organ systems [7]. The surgical options for ATAAD treatment include an impressive range of aortic interventions, depending on the extent of pathology and patient's condition. In this study, we present an overall review of results of one of the most commonly performed procedures in ATAAD patients – aortic root replacement with the Bentall procedure.

Materials and Methods

All ATAAD patients (n = 314) who underwent the modified Bentall procedure at our institution from January 1996 to December 2018 were included in our retrospective analysis (Figure 1). Perioperative patient data were prospectively collected and analyzed in our institutional database. Approval was obtained from our Institutional Research Ethics Board and individual patient consent was waived.

Operative technique

The standard surgical strategy used at our institution has been described previously and included techniques of cerebral and visceral protection [8,9]. Briefly, cardiopulmonary bypass (CPB) was established via the axillary artery in most cases (n = 247, 79%), with femoral cannulation being performed in the vast majority of remaining patients. The level of hypothermia was defined by the extent of distal aortic repair, patient's status, and surgeon's preferences. In general, moderate hypothermia ($24 - 28^{\circ}$ C) was employed for uncomplicated aortic pathologies, while deep hypothermia (20° C) was reserved for those cases where total arch replacement was required. For blood drainage, a 2-stage venous cannula was introduced into the right atrium directly or in wire-guided fashion via the femoral vein. Cardioplegia was established using antegrade (n = 241), retrograde (n = 40) or combined (n = 33) techniques. Cerebral protection was performed in the earlier years of the study by means of retrograde perfusion, which was replaced over time by antegrade cerebral perfusion. In cases of isolated ascending aortic repair with open distal anastomosis or hemiarch procedure, unilateral cerebral perfusion was frequently used. For a larger extent of repair, bilateral antegrade perfusion with or without perfusion of the left subclavian artery was performed.

Mechanical composite conduits were used in 142 patients, and biological Bentall procedures using either a biological valve implanted into an aortic graft (homemade or prefabricated, n = 102) or xeno-/ homograft root conduits (n = 70) were performed in the remaining patients. Mechanical root replacement was usually performed in the younger group of patients without contraindication to anticoagulation. Patients older than 65 years or those with contraindications for anticoagulation (including women wishing to become pregnant) were recommended to consider implantation of a biological valve. The conduit was placed by means of pledget-supported mattress sutures, reimplantation of coronary arteries was performed using the button technique in the vast majority of patients.

Outcomes and statistical analysis

We analyzed pre-, intra-, and early postoperative outcomes. Operative mortality is expressed as procedural mortality, hospital death and 30-day mortality. Neurological complications were divided into permanent and temporary, depending on their presence at discharge, and included focal (stroke), non-focal (coma) and spinal neurologic deficit (paraplegia and paraparesis). The exact definitions of these complications have been provided previously [10]. Myocardial infarction was defined as ischemia diagnosed based on clinical symptoms, new typical ECG changes, decreased local regional wall contractility and elevated biomarkers, and requiring pharmacological, percutaneous or open surgical intervention. Low cardiac output syndrome was defined as patients requiring significant pharmacological support, extracorporeal membrane oxygenation, or ventricular assist device. Pulmonary complications were classified as acute respiratory distress syndrome, pneumonia, pulmonary edema and severe atelectasis, as well as prolonged mechanical ventilation. Reexploration for bleeding included only cases with acute postoperative bleeding (diffuse or with a defined source of bleeding), requiring urgent or emergent intervention. Elective open revisions for pericardial effusion were not included in this definition. Gastrointestinal complications including prolonged ileus (>72 h) or gastric paresis, or new hepatobiliary disfunction (with metabolic acidosis or increase in lactate) were recorded [11].

Data were analyzed using GraphPad Prism Version 7.00 (GraphPad Software, La Jolla, Ca, USA). The distribution of continuous variables was evaluated using the Kolmogorov-Smirnov test and Q-Q plots. Continuous variables are expressed as mean ± standard deviation (when normally distributed) or median and range (non-normal distribution). Categorical data are reported as frequencies and percentages. Multivariable logistic regression was used to determine the independent predictors of in-hospital mortality. Clinically relevant preoperative risk factors for hospital mortality were selected using univariate analysis where p value of less than 0.05 was considered statistically significant. The variance inflation factor (VIF) was evaluated in order to exclude multicollinearity (VIF of 4.0 or more indicated intercorrelation between the analyzed variables). Multivariate logistic regression model was controlled by means of Hosmer-Lemeshow goodness-of-fit test and the area under the receiver operating characteristic curve (ROC).

Results

Preoperative patient characteristics of all 314 patients are displayed in Table 1. In 70% of cases, dissection involved all major segments of the aorta. Malperfusion of one or more end organs was observed in 107 (34%) patients, of which 45 (14%) had coronary malperfusion. Sixty-five patients (21%) required preoperative inotropic support and cardiopulmonary resuscitation was performed in 27 cases (9%). There were 24 patients (8%) with confirmed connective tissue disorders and 46 (15%) with bicuspid aortic valve.

The total number of Bentall procedures performed per year rose from 4 - 7 cases in 1996 – 2000 to 17 - 26 interventions in 2014 – 2018, due to overall increase of ATAAD cases undergoing surgical treatment at our institution. At the same time, a decrease in operative mortality was observed: from 22% mean in-hospital mortality in the earlier years (1996 – 2002), to 19% in 2003 – 2010 and 14% in 2011 – 2018.

Initially, Bentall procedures were more commonly performed using mechanical valve conduits (1996 – 2000), followed by introduction of xeno- and homograft roots (with the peak in 2008 – 2009) and biological valve conduits (used in the majority of cases since 2015) (Figure 1). For mechanical Bentall procedure we used prefabricated conduits in most of the cases: ATS Aortic Valves Graft Model 502 AG (ATS Medical, Minneapolis, MN, USA) was implanted in 80% patients and St. Jude Medical Aortic Valved Graft (St Jude Medical, Inc, St Paul, MN, USA) was used as a second option (18%) (Figure 2). BioBentall procedures were performed using intraoperative creation of a valved conduit consisting of a stented biological valve (Carpentier-Edwards Perimount Aortic Model, Edwards Lifesciences LLC, Irvine, CA, USA in the 90% of cases) and a Dacron aortic graft (Hemashield, Maquet, Wayne, NJ, USA). In several cases a prefabricated Vascutek Biovalsalva Conduit (Vascutek Terumo, Inchinnan, Scotland, UK) was used. Xenograft aortic root conduits included Medtronic Freestyle in 93% (Medtronic Inc, Minneapolis, MN, USA) and St. Jude Medical Toronto Root (St Jude Medical, Inc, St Paul, MN, USA) in 6% cases. In one patient an aortic valve conduit homograft was used.

Intraoperative characteristics are presented in Table 2. Indications for Bentall procedure included extensive dissection involving the aortic root in the majority of cases, aortic valve calcification, and failure of supracoronary aortic replacement or valve-sparing procedure (Table 2). In 20 cases root replacement strategy was chosen due to patient's age and comorbidities or based on the surgeon's experience.

The use of tissue adhesive in order to compress the separated layers of the dissected coronary buttons (n = 34) was completely abandoned in our institution in 2015. Coronary artery patch plasty or bypass grafting was required in 52 cases (17%) due to dissection or rupture of the artery; concomitant bypass grafting for coronary artery disease was performed in 11 patients.

The most commonly performed distal aortic intervention was hemiarch replacement. In more recent years, the elephant trunk (n = 55) and frozen elephant trunk (n = 22) procedures were performed more commonly in DeBakey type I aortic dissection repair. In 4 cases, open implantation of uncovered aortic stents was performed in order to open the collapsed true lumen. Among other concomitant procedures were septal myectomy (n = 3), mitral or tricuspid valve repair (n = 3) and caesarian section (n = 1).

The Table 3 summarizes the early postoperative clinical outcomes after surgical treatment. The overall 30-day mortality in this group of patients was 26%. There were 53 (17%) hospital deaths, with 13 patients who died intraoperatively. The causes of hospital death included intractable low cardiac output syndrome in half of the cases, major brain injury in 16 patients, multiorgan failure and sepsis in 6 and 2 cases, respectively. Twelve percent of patients underwent reexploration for bleeding. There were 47 (15%) cases of postoperative low cardiac output syndrome and 18 (6%) cases of myocardial infarction. A total of 69 (22%) of patients had permanent neurologic deficit: focal deficit was diagnosed in 25 and non-focal – in 30 cases; in 13 (4%) patients a newly developed permanent paraplegia or paraparesis were observed, one patient was discharged with monoparesis.

Multivariate logistic regression model revealed the following independent in-hospital death risk factors: critical preoperative state (OR, 5.6; $p < 0.001$), coronary malperfusion (OR, 3.6; $p = 0.002$), coronary artery disease (OR, 2.6; $p = 0.033$) and prior cerebrovascular accident (OR, 5.6; $p = 0.002$) (Table 4). The area under the ROC curve for this model was 79.5 (95% CI, 72.4 to 86.7) and the Hosmer-Lemeshow test was nonsignificant ($p = 0.979$) (Figure 3).

Discussion

The knowledge and experience accumulated by several generations of medical specialists and researchers have led to remarkable decreases in cardiac surgery mortality rates across a wide spectrum of pathologies. However, patients presenting with ATAAD continue to represent a major clinical challenge for cardiovascular specialists. When selecting the appropriate treatment strategy for ATAAD, the modern aortic team has a wide range of surgical techniques, protective adjuncts, and monitoring tools available for any extent of aortic dissection. For correction of the dissected ascending aorta, the most commonly performed intervention is supracoronary aortic replacement with or without concomitant aortic valve replacement [12]. In younger patients with aortic root dissection and / or dilatation combined with aortic valve insufficiency, the method of choice is a valve-sparing technique (i.e. David or Yacoub procedures), provided that the operator is experienced with performing these operations. In those cases in which the aortic valve cusps are not pliable, the operator is not experienced with valve-sparing surgery, the patient is over 60 years of age, or in which prolonged ischemic times should be avoided (eg. patients with comorbidities, malperfusion, or preoperative hemodynamic instability), the Bentall procedure should be performed. Other potential, but less commonly used, approaches to the dissected / enlarged aortic root are replacement of the noncoronary sinus and the ascending aorta (also called 1/3 or "mini" Yacoub) and Florida sleeve operation (i.e. wrapping of the aortic root from the outside).

In the last years, a growing attention to valve-sparing procedures for aortic root pathology has been observed. This approach avoids structural valve degeneration (in comparison to bioprostheses) and anticoagulation (in comparison to mechanical prostheses), and is associated with excellent long-term results when performed by experienced surgeons [13]. When managing ATAAD, however, the primary treatment goal is to save the patient's life. Valve-sparing procedures – being technically demanding and time-consuming – may be associated with increased operative risks, especially in critically ill patients. Also, these procedures require extensive preparation of the aortic root, which may increase the risk of injuring surrounding structures. Such patient- and operator-dependent issues must be weighed when considering the correct approach to the aortic root in individual ATAAD patients.

Our method of performing the modified Bentall procedure in ATAAD patients has evolved over the years. First of all, changes in types of conduits have been observed with a predominant use of biological valve conduits in recent years. While the decision about conduit type (i.e. mechanical or biological) should optimally be made by the patient and the surgeon together prior to surgery, many ATAAD patients cannot adequately participate in this decision because of neurologic or hemodynamic instability at the time of presentation. Surgeons may have therefore more frequently chosen a bioprosthesis for such patients, particularly in the current era of TAVI valve-in-valve procedures. In addition, the avoidance of postoperative coumadin is a particularly important issue to consider in those patients who will continue to have a perfused false lumen post-ATAAD repair.

We previously implanted many aortic root xenografts in ATAAD patients. However, we noted that porcine xenografts were suboptimal in regards to tissue handling. Aortic homografts (used only in 1 patient), have much better tissue handling characteristics, but are prone to heavy calcification within the first years after implantation [14-15]. Thus, our current procedure of choice for biological aortic root replacement is the use of a stented tissue valve implanted into an aortic graft prosthesis. We prefer to use an Edwards Perimount valve – because of the technical ease of securing its relatively rigid sewing ring to the aortic graft – that is sewn to a Hemashield prosthesis that is 5 mm larger than the Perimount labeled valve size. This suture line is performed with a running 3-0 Prolene (Ethicon, Bridgewater, NJ, USA), leaving a 5-8 mm skirt of Hemashield prosthesis under the sewing ring of the Perimount valve. This skirt is then secured to the native aortic annulus using pledgeted sutures that are placed in the usual fashion. Such a technique enables future redo aortic valve replacement surgery to be performed without remobilization of the coronary buttons, by simply cutting the Prolene suture and removing the stented valve.

The coronary button technique with extensive artery mobilization was used in all cases in the current series, in order to avoid tension on the anastomoses [16]. In the earlier era, dissected walls of coronary arteries were often brought together using glue injected into the false lumen, but this technique has been discontinued at our center because of the risk of tissue necrosis and embolization [17]. In case of coronary artery disruption or extensive dissection, venous graft plasty or coronary bypass surgery (with or without occlusion of the proximal ostium) was performed.

Over the analyzed time-period, we observed an improvement in operative results of aortic root replacement in ATAAD patients. This positive development is surely due to many improvements in perioperative management over time, but may also be a result of total increase of ATAAD cases treated at our institution over time. The mortality rates in the current study are similar to those reported in IRAD and GERAADA (German Registry for Acute Aortic Dissection Type A) outcomes [6, 18]. However, limited comparisons can be made to other ATAAD series for a variety of reasons. The majority of isolated Bentall studies available in the literature report the results either in a mixed aortic pathology population, or in a relatively small group of ATAAD patients with various root interventions [19, 20]. In addition, most ATAAD series include a large number of patients who underwent either very minor (eg. readaptation of the dissected noncoronary sinus layers) or absolutely no aortic root procedures. In addition, younger ATAAD patients and those without malperfusion or cardiopulmonary instability frequently undergo valve-sparing surgery at our institution. Finally, we are very aggressive with surgical management of nearly all ATAAD patients presenting at our center, regardless of age and hemodynamic status. The high-risk nature of our current Bentall patient population can be demonstrated by the fact that one-third had malperfusion of one or more organ systems, 30% were in critical preoperative state, 9% underwent preoperative cardiopulmonary resuscitation, and one-third underwent total arch or elephant trunk replacement. Nonetheless, our outcomes roughly correspond with those reported in the literature, particularly when the analysis is performed in patients with similar preoperative characteristics and distal aortic repair extent [21].

The permanent neurologic deficit rate in the current series was higher (22%) compared to our previous publications on ATAAD, (7) which could be explained by higher rates of preoperative cerebral malperfusion in the Bentall cohort of patients. In addition, one needs to consider that several patients developed permanent paraplegia/paraparesis, which is oftentimes a complication of intercostal artery malperfusion and not of the proximal aortic procedure *per se* . The rates of perioperative myocardial infarction and low cardiac output syndrome observed in the current study correspond with preoperative coronary malperfusion rates and the number of critically unstable patients. It has also been previously shown that approximately 20% of ATAAD patients have underlying coronary artery disease [22], which was an independent predictor for in-hospital mortality in our patients. This factor, together with critical preoperative state (both reported in our previous ATAAD series) [7] and coronary malperfusion (new predictor), emphasize the challenges presented by our Bentall cohort of ATAAD patients.

Conclusions

Surgical treatment of ATAAD remains one of the most challenging areas of modern cardiac surgery. The Bentall procedure is a safe and well-established surgical intervention and can be used as a standard treatment option in patients with ATAAD involving the aortic root, particularly in high-risk patients.

Conflict of interest

MAB declares speakers' honoraria and / or consulting fees from Edwards Lifesciences, Medtronic, Abbott and CryoLife. All other authors declare no conflict of interest.

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Figure Legends

Figure 1. Types of conduits used for aortic root replacement.

Figure 2. Conduits and aortic valves used for aortic root replacement.

ATS Aortic Valves Graft Model 502 AG and ATS Open Pivot valve – ATS Medical, Minneapolis, MN, USA; *Carpentier-Edwards Perimount Aortic Model and Perimount Magna Ease* – Edwards Lifesciences LLC, Irvine, CA, USA;

Carbomedics Carbo-seal – Sorin Group, Milan, Italy;

Medtronic Freestyle – Medtronic Inc, Minneapolis, MN, USA;

St Jude Medical Aortic Valved Graft, Epic Heart Valve, Trifecta Heart Valve and Toronto Root – St Jude Medical, Inc, St Paul, MN, USA;

*All the valves prostheses were used with a *Hemashield aortic graft* (Maquet, Wayne, NJ, USA).

Figure 3 . Receiver operating characteristic curve (blue line) for independent predictors of hospital death.

Tables

Table 1. Preoperative patient characteristics

Variable	n (%) or Me (range)
Age, years	59 (20 - 85)
Male	200 (64)
DeBakey Type I dissection	221 (70)
DeBakey Type II dissection	93 (30)
Iatrogenic dissection	13 (4)
Hypertension	247 (79)
History of smoking	68 (22)
Coronary artery disease	39 (12)
COPD	17 (5)
Prior cerebrovascular accident	20 (6)
Diabetes mellitus	28 (9)
Peripheral vascular disease	29 (9)
Connective tissue disorders	24 (8)
Bicuspid aortic valve	46 (15)
Prior cardiac / aortic intervention	17 (5)
Preoperative AR > moderate	277 (88)
Cardiopulmonary resuscitation	27 (9)
Inotropic support	65 (21)
Ventilation	59 (19)
Pericardial tamponade	128 (41)
Malperfusion syndrome, of them	107 (34)
Cerebral malperfusion	54 (17)
Coronary malperfusion	45 (14)
Visceral malperfusion	16 (5)

Variable	n (%) or Me (range)
Extremity malperfusion	26 (8)
Total (1996 – 2018)	**314**

Data expressed as n (%), or Median (range). AR – aortic regurgitation, COPD – chronic obstructive pulmonary disease.

Table 2. Intraoperative patient data

Variable	n (%) or mean ± SD
Indication for Bentall procedure	Indication for Bentall procedure
Dissected root and/or coronary arteries	198 (63)
Calcified aortic valve	25 (8)
Severely dilated aortic root	60 (19)
Failure of supracoronary AAR or aortic valve sparing procedure	11 (4)
Unknown	20 (6)
Types of conduits	Types of conduits
Mechanical valve conduit	142 (45)
Biological valve conduit	102 (33)
Xeno- / homograft root	70 (22)
Prosthesis size, mm	24.3 ± 1.9
Concomitant procedures	Concomitant procedures
GFR glue around the coronary buttons	34 (11)
Coronary artery patch plasty or bypass	63 (20)
CABG for coronary artery disease	11 (4)
Septal myectomy	3 (1)
MV or TV repair	3 (1)
Uncovered aortic stent implantation	4 (1)
Extent of distal aortic resection	Extent of distal aortic resection
Isolated ascending aortic replacement	32 (10)
Hemiarch	175 (56)
Total arch	26 (8)
Total arch and DTA	4 (1)
Elephant trunk	55 (18)
Frozen elephant trunk	22 (7)
Operative data	Operative data
CPB time, min	210 ± 76
Aortic crossclamp time, min	126 ± 43
Circulatory arrest time, min	29 ± 17
Operative time, min	332 ± 110
CA body temperature, °C	25 ± 4

Data expressed as n (%), or Mean ± SD. AAR – ascending aortic replacement, CA – circulatory arrest, CPB – cardiopulmonary bypass, DTA – descending thoracic aorta,MT – mitral valve, TV – tricuspid valve.

Table 3. Outcomes

Variable	n (%)
Complications	Complications

Variable	n (%)
Low cardiac output syndrome	47 (15)
Perioperative myocardial infarction	18 (6)
Permanent neurologic deficit	69 (22)
Permanent focal neurologic deficit (stroke)	25 (8)
Permanent non-focal neurologic deficit (coma)	30 (10)
Permanent spinal deficit (paraplegia and paraparesis)	13 (4)
Permanent monoparesis	1 (0.3%)
Temporary neurologic deficit	43 (14)
Reexploration for bleeding	39 (12)
Sepsis	24 (8)
Gastrointestinal complications	47 (15)
Pulmonary complications	130 (41)
Renal failure requiring dialysis	91 (29)
Death	Death
Intraoperative death	13 (4)
In-hospital mortality	53 (17)
30-day mortality	81 (26)
Causes of in-hospital mortality	Causes of in-hospital mortality
Intractable low cardiac output syndrome	26 (49)
Intractable low cardiac output syndrome and respiratory failure	3 (6)
Multiorgan failure	6 (11)
Major brain damage	16 (30)
Sepsis	2 (4)

Data expressed as n (%).

Table 4. Risk-adjusted predictive model for hospital death after the Bentall procedure for acute type A aortic dissection (n = 314)

Variable	Odds ratio	95% CI	p Value
Critical preoperative state	5.62	2.85 – 11.44	<0.001
Coronary malperfusion	3.59	1.60 – 7.96	0.002
Coronary artery disease	2.64	1.06 – 6.41	0.033
Prior cerebrovascular accident	5.56	1.84 – 16.27	0.002

CI – confidence interval

Figures

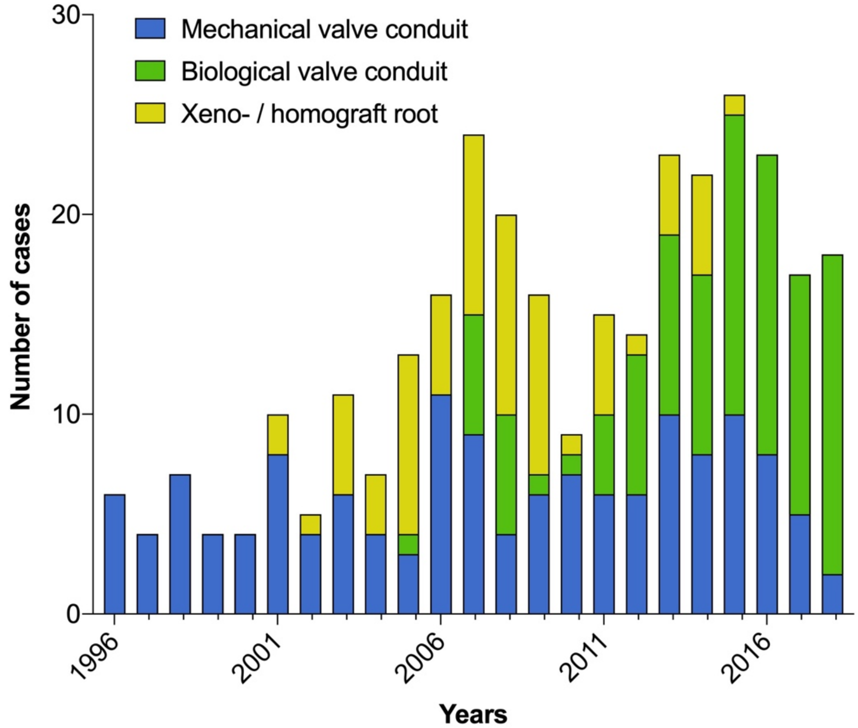
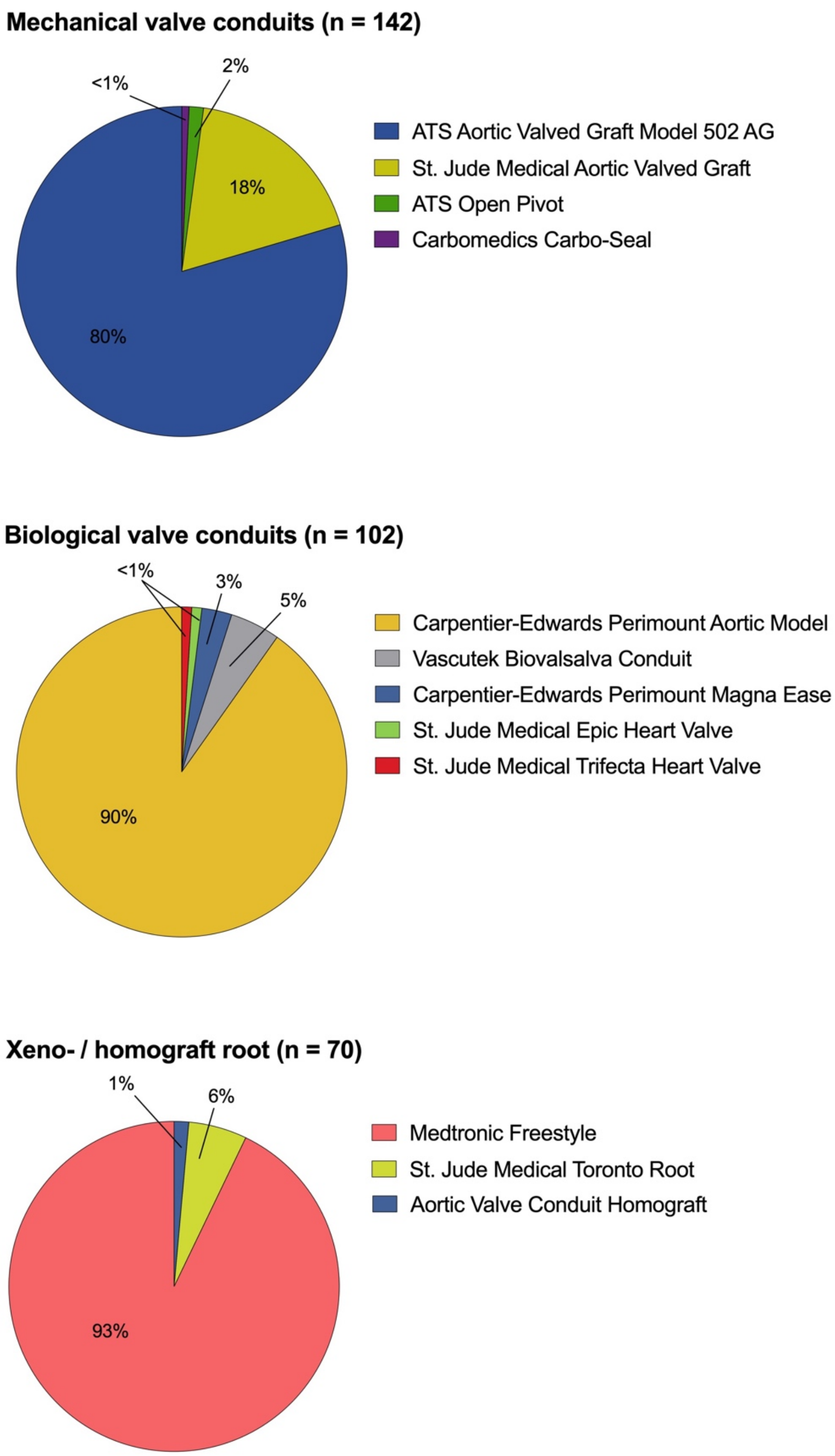


Figure 1. Types of conduits used for aortic root replacement.



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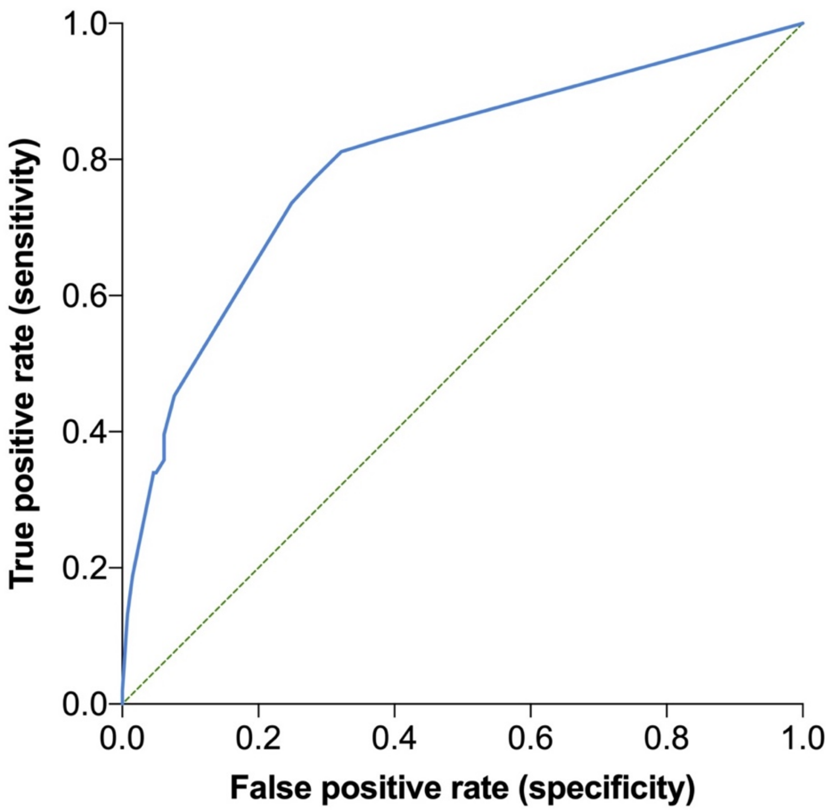

Figure 3 . Receiver operating characteristic curve (blue line) for independent predictors of hospital death.