Interactive CardioVascular and Thoracic Surgery 17 (2013) 79–84
doi:10.1093/icvts/ivt087 Advance Access publication 25 March 2013

Aortic valve bypass: experience from Denmark†

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Received 29 August 2012; received in revised form 7 January 2013; accepted 22 January 2013

Abstract

OBJECTIVES: In aortic valve bypass (AVB) a valve-containing conduit is connecting the apex of the left ventricle to the descending aorta. Candidates are patients with symptomatic aortic valve stenosis rejected for conventional aortic valve replacement (AVR) or transcatheter aortic valve implantation (TAVI). During the last one and a half year, 10 patients otherwise left for medical therapy have been offered this procedure. We present the Danish experiences with the AVB procedure with a focus on patient selection, operative procedure and short-term results.

METHODS: AVB is performed through a left thoracotomy. A 19-mm Freestyle® valve (Medtronic) is anastomosed to a vascular graft and an apex conduit. The anastomosis to the descending aorta is made prior to connecting the conduit to the apex. In 1 patient, we used an automated coring and apical connector insertion device (Correx®). The device results in a simultaneous coring and insertion of an 18-mm left ventricle connector in the apical myocardium. AVB is routinely performed without circulatory assistance.

RESULTS: Ten patients have been operated on since April 2011: eight females and 2 males with a median age of 76 (65–91) years. Seven patients had a severely calcified ascending aorta. Three of these had previously had a sternotomy, but did not have an AVR because of porcelain aorta. Six patients had a very small left ventricle outflow tract (<18 mm). The median additive EuroSCORE was 12 (10–15). Seven patients were operated on without circulatory assistance. Two patients had a re-exploration for bleeding and 1 developed a ventricle septum defect 1 month postoperatively and was treated with surgical closure. The median follow-up was 7 (2–15) months and was without mortality. New York Heart Association class was reduced from 2.5 to 2 at the follow-up, but some patients were still in the recovery period. The total valve area (native plus conduit) was 2.2 (1.9–2.5) cm^2 and 1.34 (1.03–1.46) cm^2/m^2, indexed to the body surface area. There was no AV block or stroke.

CONCLUSIONS: AVB can be performed with low mortality and acceptable results in selected patients. The procedure can be offered to patients rejected for conventional aortic valve replacement and TAVI and results in a larger total valve area than by insertion of standard bioprosthesis.

Keywords: Aortic valve stenosis • Aortic valve bypass • Apicoaortic conduit • Aortic valve replacement

INTRODUCTION

Aortic stenosis (AS) is by far the most common valvular lesion in the elderly population [1]. The most common reason for symptomatic stenosis is degeneration and calcification of a normal tricuspid aortic valve [2]. Replacement of the valve with a prosthesis (AVR) remains the standard of care and improves quality of life and extends survival in most patients [3, 4]. The procedure, however, carries a significant risk especially in the elderly and in patients who present with pre-existing comorbidities [4, 5]. The use of cardiopulmonary bypass, aortic cross-clamping, cardioplegic cardiac arrest, aortotomy and debridement of the diseased valve contributes to increased morbidity and mortality with conventional AVR. Transcatheter aortic valve implantation (TAVI) has emerged as a possible therapy in inoperable or older patients with high surgical risk, and the present results are promising [6]. However, a subgroup of patients is also not suitable for TAVI treatment because of a narrow left ventricle outflow tract (LVOT; <18 mm) or lack of appropriate admittance vessels.

In this paper, we present a treatment alternative at Rigshospitalet, University Hospital of Copenhagen, for patients with symptomatic aortic valve stenosis. Aortic valve bypass (AVB) is an option for patients with contraindications to conventional AVR and consists of the creation of a valved conduit from the apex of the left ventricle to the descending aorta. The native aortic valve is left in place, but the blood flow has an alternative route out of the heart. The technique has been known for decades, but has never gained widespread use due to the absence of a safe way to place the conduit [7]. Within the last

† Presented at the 26th Annual Meeting of the European Association for Cardio-Thoracic Surgery, Barcelona, Spain, 27–31 October 2012.

couple of years, some centres, however, have presented encouraging results in a series of AVB in high-risk patients [8, 9].

At our institution, we have operated on 10 patients with this technique since April 2011.

MATERIALS AND METHODS

Patient selection/preoperative evaluation

Patients with symptomatic aortic valve stenosis who were rejected for conventional AVR and had contraindications to TAVI were evaluated for AVB.

The reason for rejection for AVR was severe calcification of the ascending aorta in 7 patients. Three of these patients had previously had a sternotomy, but did not have an AVR because of aortic calcification. The remaining 3 patients had substantial calcification of the aortic root in addition to a very small LVOT (16, 17 and 17 mm, respectively).

The reason for rejection for TAVI was a very small LVOT in 6 patients, <18 mm. The remaining 4 patients did not have appropriate admittance vessels.

All patients underwent a thorough preoperative evaluation with respect to excluding conditions. Any chronic pulmonary disease likely to interfere either anatomically or physiologically with the surgery was assessed. A pulmonary function test and a clinical examination with blood tests were performed. A computed tomographic scan of the thorax and an echocardiography were carried out. Severe calcification of the descending aorta, moderate-to-severe aortic or mitral insufficiency and severely reduced pulmonary function were considered contraindications to the procedure just as all patients were evaluated in terms of frailty [10].

Anaesthetic technique

The day before the operation, the patient received an epidural catheter at the thoracic 6–8 interspinous space. Anaesthesia was induced and maintained with propofol, remifentanil and atracurium, and neuraxial blockade with continuous epidural marcain 0.25% with morphine 50 µg/ml. The patient was intubated with a double-lumen tube and was monitored with arterial, central venous, pulmonary pressures and transoesophageal echocardiography. In addition, cardiac output and mixed venous saturation were measured. The patient was positioned with the hips at a 45° angle and the chest in a lateral decubitus position.

Operative technique

The operation was performed through a left anterolateral thoracotomy with right-sided one-lung ventilation. Initially, a guide wire was introduced into the right atrium via the left vena femoralis under echocardiographic guidance. After inspection of the descending aorta, the apex conduit (14 mm, Medtronic) was anastomosed to a 19-mm Freestyle® valve (Medtronic) and an 18-mm vascular tube graft. On the side of the tube graft, a 10-mm side graft was connected (Fig. 1). After the administration of 5000 IU heparin, a partial occluding clamp was placed on the descending aorta above the diaphragm, and the tube graft was anastomosed to the descending aorta. AVB was usually performed without cardiopulmonary bypass, but the arterial line from the extra corporeal circulation was connected to the 10-mm side graft, so perfusion could be initiated without delay, if necessary. At this point, the patient was fully heparinized, and the venous cannula was introduced into the right atrium. The conduit position in the apex was marked with a pen, and four pledgeted sutures were placed on the circumference. The exact location of the conduit was aimed at being free of the papillary muscles, which was guided by transoesophageal echocardiography. A little stab wound was created in the middle, through which a Foley catheter was introduced. The Foley catheter with a water-filled balloon served to withdraw the heart plug when the circular cutter had cut through the apex. Finally, the conduit was put in place and sutured. In patient number 10, we used an automated coring and apical connector insertion device (Correx®) [11]. In this case, the valved conduit was first anastomosed to the descending aorta. In turn, the apical connector was inserted with the applicator. The device results in a simultaneous coring and insertion of an 18-mm left ventricle connector in the apical myocardium. Finally, the two parts were coupled and secured with an umbilical tape and a few sutures.

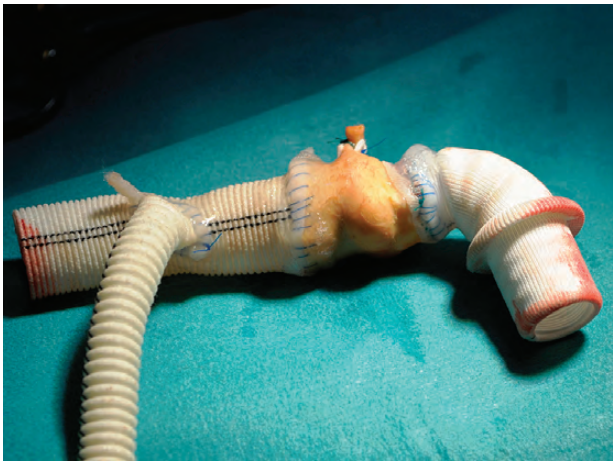

Figure 1: Freestyle bioprosthesis anastomosed to the apical connector and vascular graft. A 10-mm side graft is anastomosed to the vascular graft.

Echocardiography

Patients were examined before the treatment with a transthoracic (TTE) and a transoesophageal examination. At discharge and at 1-, 3-, 6- and 12-month follow-up, a TTE was done.

Examinations were carried out using Philips IE 33 equipped with an S5-1 transthoracic probe and an X7-2 transoesophageal probe. At baseline, grading of AS severity was done using the continuity equation [12], and peak systolic and mean transvalvular gradients were recorded using continuous-wave (CW) Doppler.

Left ventricle mass was calculated using the Devereux formula [13]. Left ventricular systolic function (LVEF) was evaluated using biplane planimetry (Simpson's method) or semiquantitatively using the wall motion index in cases of regional wall motion abnormalities. Flows through the LVOT and the conduit were calculated as the area of the left ventricular outflow tract (LVOT) or the area of the conduit times the time velocity integral of a pulsed Doppler (PW) in the LVOT or the conduit times the heart rate. When

estimating the conduit flow, PW Doppler was sampled in the conduit at the place between the freestyle valve and the descending aorta. The narrowest internal area of the conduit was 14 mm, giving a theoretical area of the conduit of 1.54 cm^2. Grading of the mitral regurgitation (MR) was done using the proximal isovelocity surface area (PISA) method [14]. The return gradient through the tricuspidal annulus was measured with the CW Doppler in systole parallel to the tricuspid return flow.

Statistics

Results are presented as median values with range. Values before and after surgery are compared using a paired *t*-test. *P*-values <0.05 were considered statistically significant.

RESULTS

Ten patients have been operated on since April 2011 (Table 1): eight females and 2 males, median age of 76 (65–91) years. The median ejection fraction was 60 ± 8.4% (40–60). The median additive EuroSCORE was 12 (10–15) and the median EuroSCORE II was 5 (3–11). The median native aortic valve area (AVA) was 0.7 (0.3–1.0) cm^2.

Eight patients had an epidural the day before the operation, 1 patient had a paravertebral catheter due to high INR (>1.5) prohibitive of the placement of an epidural catheter and the last patient had conventional treatment for pain.

The first three patients had their apex anastomosis made while on very brief perfusion. Seven patients were operated on without circulatory assistance. The last patient had his conduit put in place with the Correx® device.

The immediate postoperative courses were eventless (Table 2); all patients were extubated within the first 12 h. Their median length of stay in the intensive care unit (ICU) was 1 (1–7) days, and the median length of stay in hospital was 8 (6–15) days. Two patients had re-explorations for bleeding. Those 2 patients had a total blood loss of 1800 ml within the first 24 h. The median blood loss was 600 ml (Table 2). One month after the initial operation, 1 patient developed a ventricle septum defect (VSD). This patient was a 77-year old woman who had an LVOT of 17 mm and a severely calcified aortic root. She was admitted due to sudden onset of shortness of breath. The VSD was diagnosed by echocardiography and was located at the tip of the apical connector. She had a sternotomy and by using cardiopulmonary bypass, aortic cross-clamping and cold blood cardioplegia, the VSD was closed through an incision in the right ventricle. She was discharged 6 days postoperatively with no signs of residual VSD.

There has been no mortality; the median follow-up was 7 (2–15) months. The New York Heart Association (NYHA) class was reduced from 2.5 (2–3) to 2 (1–3) at the follow-up, but some patients were still in the recovery period. There has been no heart block or cerebral attack. None of the patients needed dialysis postoperatively, and 2 had briefly depressed renal function, which prolonged their stay in the ICU.

Echocardiography results

The results of the pre- and postoperative echocardiography can be seen in Table 3. All patients had severe aortic valve stenosis, and LVOT was <18 mm in 6 of 10 patients with a median of 17 mm. No patients had more than mild MR. LVEF was normal or moderately reduced (40%) in 2 patients. At the 3-month follow-up, the maximum gradient through the native valve was markedly reduced from 72 (40–122) to 7 (3–35) mmHg ($P < 0.01$) as a result of low flow. LV mass was found to be reduced at the follow-up from 163 (85–317) to 130 (88–257) g ($P < 0.01$), due to left ventricular remodelling. Flows through the LVOT and the AVB conduit were estimated as described in the Materials and Methods section. Flow through the LVOT was 1541 (570–2918) ml/min and through the conduit, 3590 (2331–4200) ml/min. The percentage of flow through the conduit when compared with the total cardiac output was 69 (54–86%). LVEF was unchanged. The tricuspid regurgitant gradient was reduced after the surgery, falling from 30 (29–35) to 21 (13–26) mmHg ($P = 0.01$), reflecting a reduction in systolic pulmonary pressure and hence a reduction in left ventricular filling pressure. The total output area of the left ventricle would be the native valve area plus the area supplied by the conduit (1.54 cm^2). This results in a total output area of 2.2 (1.9–2.5) cm^2. Indexed to body surface area (BSA) the total valve area was 1.34 (1.03–1.46) cm^2/m^2 BSA.

Table 1: Preoperative patient characteristics

Patient characteristics	All patients ($n = 10$)
Age median (years)	76 (65–91)
Sex (males/females)	2/8
Body surface area (m^2)	1.6 (1.4–1.9)
NYHA class, median	2.5 (2–3)
Prior stroke	2
Peripheral vascular disease	2
Previous sternotomy	3
Calcified ascending aorta	7
Aortic valve area median (cm^2)	0.7 (0.3–1.0)
Mean gradient (mmHg)	45 (18–84)
Left ventricular outflow tract median (mm)	17 (16–21)
Ejection fraction (%)	60 (40–60)
EuroSCORE median	12 (10–15)
EuroSCORE II median	5 (3–11)

Table 2: Postoperative complications and outcome

Patient characteristics	All patients ($n = 10$)
Complication all	3
Re-exploration for bleeding	2
Myocardial infarction	0
Reintubation	0
Pneumonia	0
Renal failure	0
Ventricle septum defect	1
Stroke	0
Heart block	0
Intensive care unit stay, median (days)	1 (1–7)
Hospital stay, median (days)	8 (6–15)
Mortality	0
Total blood loss (24 h), median (ml)	600 (200–1800)

Table 3: Echocardiography results before surgery and at 3-month follow-up

Parameter	Before	After	*P*-value
LVEF (%)	60 (40–60)	60 (35–60)	NS
LV mass (g)	163 (85–317)	130 (88–257)	<0.01
Aorta gradient, max (mmHg)	72 (40–122)	7 (3–35)	<0.01
Native AVA (cm^2)	0.7 (0.3–1.0)	–	–
Conduit area (cm^2)	–	1.54	–
Total output area (cm^2)	–	2.2 (1.9–2.5)	–
Total indexed valve area (cm^2/m^2)	0.4 (0.2–0.5)	1.34 (1.03–1.46)	<0.01
LVOT flow (ml/min)	–	1541 (570–2918)	–
Conduit flow (ml/min)	–	3590 (2331–4200)	–
Percentage flow through conduit (%)	–	69 (54–86)	–
TR gradient (mmHg)	30 (29–35)	21 (13–26)	0.01

LVEF: left ventricular systolic function; AVA: aortic valve area; LVOT: left ventricle outflow tract.

DISCUSSION

Owing to the growing proportion of elderly people in the Western countries, the number of patients with symptomatic AS is expected to substantially increase in the future. In the majority of these patients, AVR is considered a safe and life-extending solution [4]. Some may present with comorbidity; however, that seriously complicates the procedure. Advanced aortic atherosclerosis with calcification of the ascending aorta ('porcelain aorta'), previous sternotomy or prior coronary artery bypass graft surgery with patent critical grafts [15, 16], a narrow LVOT or a small aortic annulus, especially in combination with severe calcification of the aortic root, may significantly increase the risk of complications to AVR. TAVI may be an alternative in some patients, although this procedure also has contraindications. A narrow aortic annulus, coronary anatomy and vascular problems are well-known complicating factors [17]. Indication for AVB is severe AS in the small subset of high-risk patients with serious comorbidity and contraindications to both AVR and TAVI.

In 7 of the 10 patients, the ascending aorta was severely calcified. The remaining 3 patients had, in addition to a small LVOT, calcification of the aortic root. Patients with small calcified aortic roots are surgically challenging and require often root replacement using a stentless bioprosthesis in order to ensure the proper opening area and to avoid paravalvular leakage. This is, however, an extensive operation in elderly patients. In this series, the 3 patients were 91, 85 and 77 years, respectively. Patients with a narrow outflow tract are problematic to treat with TAVI. This procedure requires an outflow tract of minimum 18 mm, using Edwards Sapien® or the new 18-mm Corevalve® Evolut from Medtronic. In the TAVI procedure, the aortic valve prosthesis can be inserted by transfemoral, transapical, subclavian or by the direct aortic approach. With all approaches, however, balloon valvuloplasty is performed, which may predispose the patient to myocardial ischaemia from coronary occlusion and cerebral thromboembolic complications due to debridement of valvular tissue [17].

In AVB a valve-containing conduit between the apex of the left ventricle and the aorta descendens relieves left ventricular outflow obstruction by shunting blood from the apex of the left ventricle to the descending thoracic aorta. By using this technique, many of the above-mentioned potential complications are excluded due to the use of thoracotomy instead of sternotomy and omittance of extracorporeal circulation, manipulation of the valve and the ascending aorta. In the absence of debridement of calcified valvular material and manipulation of the ascending aorta, the risk of stroke is minimized. It has further been hypothesized that, in the longer run, AVB surgery confers protection from stroke because all blood flow to the brain is directed across the native valve rather than across a prosthesis, as is the case after conventional AVR or TAVI [18]. In our study, we did not see any complications related to myocardial ischaemia or cerebral embolism. Moreover, there is no risk of heart block caused by decalcification of the annulus or compression of the conduction bundle, a fairly frequent complication to TAVI [17, 19]. We did not see any conductance disturbances in any of our 10 patients.

Further advantage of AVB when compared with TAVI is that the risk of paravalvular leakage is eliminated. Patients are indeed supplied with, not just a new valve, but an additional outlet from the left ventricle, resulting in a total valve area that is much higher than could be expected with even a stentless bioprosthesis in patients with a narrow LVOT. This should completely resolve the potential problem with patient–prosthesis mismatch and resulting increased mortality [20]. It has been shown that the conduit easily provides the required flow [18, 21].

The total valve area through which the cardiac output is ejected is the sum of the native aortic area and the conduit area and is therefore higher than with AVR or TAVI alone. The effect on remodelling and regression of hypertrophy is probably substantial as suggested by our data, but has to be documented by close follow-up. A retrospective study of 47 octogenarians from 2010 found that the progression of the native AS stopped after the AVB procedure. The reason for this is suggested to be the reduction in sheer stress due to the reduction of flow through the native valve [8].

One drawback of the procedure is the thoracotomy, which may cause respiratory complications. It is crucial to manage pain and to maintain optimal pulmonary function postoperatively. Lung physiotherapy and early mobilization are key issues. Nine of the 10 patients had either an epidural or a paravertebral catheter with a continuous infusion of marcain with morphine, which to our experience offered a satisfactory pain relief. Attention to vasodilatation and blood pressure, however, is of utmost importance in order not to depress the kidney function. Six of the patients were transferred to the ward on the first postoperative day, and the reason for staying in the ICU more than 1 day was either infusion of vasopressors for sympathetic block-mediated hypotension or respiratory complications due to reoperation. It may be expected that this fragile patient population has a long recovery period after having had a thoracotomy.

One of our patients developed a VSD 1 month postoperatively and underwent a successful reoperation. This complication has not been described before, but emphasizes the importance of meticulous placement of the apical connector. The risk of septal erosion may be highest in small elderly women with hypertrophic left ventricles and small cavities.

Another theoretical risk of the AVB procedure is development of pseudoaneurysm in the area of the apical connector. This complication is not described, but would indeed be a life-threatening condition.

In this paper, we suggest that when surgical AVR or TAVI is not feasible, AVB is an option in high-risk patients.

Conflict of interest: none declared.

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APPENDIX. CONFERENCE DISCUSSION

Dr B. Osswald *(Bad Oeynhausen, Germany)*: It may be a renewal of a technique, so it's not really completely new but perhaps an alternative. However, I do have some problems with the patient selection.

You have 10 patients so far since 2011 who were neither candidates for TAVI nor for classical aortic valve replacement. There is a 65 year old patient in your group. So I wondered, why are even the younger patients not candidates for TAVI or aortic valve replacement?

Dr Arendrup: We have a young patient, I think he's 64 years old, he had severe atherosclerosis in the iliac artery, an abdominal aortic aneurysm, and he has a patent graft from the subclavian and a severely calcified aorta. Perhaps he could be a candidate for the transapical type, but at our institution we don't perform it, we only do the transfemoral axillary approach, direct approach.

Dr Osswald: And the next point: two-thirds of the blood flow is going through the bypass; is one-third enough for the brain and the upper part of the body. Do you make any tests for cognition or something like that? Did you do some diagnostics about what happens in the upper part after you've established your bypass?

Dr Arendrup: We do flow measurement during the operation, but I don't think you can do anything about that. We are routinely postoperatively doing MR scans, and the flow distribution is very consistent in all patients. Also, from the literature, one-third goes through the native aortograft, two-thirds through the conduit. I don't know why, but that's the way it is. And with the MRI you have perfect visualization and flow measurement, so you can be quite sure it is so.

Dr Osswald: Well, at least on your acute results; I'm worrying a little bit about the long-term results especially because of the impaired coronary blood supply. I don't know whether you're thinking about long-term results in these patients, but did you do any diagnostics on the coronaries?

Dr Arendrup: Of course, preoperatively we perform a coronary arteriography and we do not accept patients with coronary stenosis of more than 60%. If needed, we can do a graft to the LAD and to the circumflex during this operation, actually as an OPCAB procedure. I don't know anything about the flow through the coronaries postoperatively. But the patients have no angina, and we have patients with two years' follow-up without significant problems with the coronaries.

eComment. Aortic thrombus after aortic valve bypass surgery

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doi: 10.1093/icvts/ivt192

Conventional aortic valve replacement (AVR) carries significant operative risks, especially in the elderly, high-risk patients with severe aortic valve stenosis including porcelain ascending aorta, complex left ventricular outflow tract obstruction, previous cardiac surgery (patent coronary grafts) or prior sternal infection, and previous radiation to the mediastinum.

Transcatheter aortic valve implantation (TAVI) is an alternative therapeutic option in these complicated situations. Nevertheless, TAVI has some limitations in patients with severe aorto-iliac disease, small aortic annulus (<18 mm), and previous prosthetic valve. It is associated with an increased incidence of major stroke, an injury to atrioventricular conduction system, and major vascular complications.

Due to a higher incidence of complications of TAVI, aortic valve bypass (AVB, apicoaortic conduit) surgery may be a therapeutic means of choice in high-risk patient populations with comorbidities. We read the article by Lund *et al.* [1] with great interest. The authors have shared with us their Danish experiences regarding AVB. They are to be commended for reminding us of another alternative in the armamentarium for the treatment of severe aortic stenosis. The authors clearly stated the benefits of AVB. However, there is mention of a few serious