Clinical outcomes after separate and composite replacement of the aortic valve and ascending aorta

Thanos Sioris, MD
Tirone E. David, MD
Joan Ivanov, PhD
Susan Armstrong, MSc
Christopher M. Feindel, MD

ACD

Objectives: We sought to compare the clinical profile and outcomes of operations for aortic valve disease and ascending aortic aneurysm in patients treated with aortic valve replacement and supracoronary replacement of the ascending aorta or composite replacement of the aortic valve and ascending aorta (Bentall operation).

Methods: From 1990 through 2001, 133 patients had aortic valve replacement and supracoronary replacement of the ascending aorta, and 452 patients had Bentall operations. Aortic valve replacement and supracoronary replacement of the ascending aorta was performed in patients who had aortic valve disease and dilation of the ascending aorta, whereas the Bentall operation was performed in patients with aortic root abnormality and ascending aortic aneurysm. Mean follow-up was 4.6 ± 3.1 years and was 100% complete.

Results: Patients who had aortic valve replacement and supracoronary replacement of the ascending aorta were older (61 ± 13 vs 52 ± 16 years, $P < .001$) and more likely to have aortic stenosis, coronary artery disease, and mitral valve disease than those who had Bentall operations. The use of mechanical valves was equal in both groups (42% for aortic valve replacement and supracoronary replacement of the ascending aorta and 43% for the Bentall operation). Operative mortality was 5% for patients undergoing aortic valve replacement and supracoronary replacement of the ascending aorta and 4% for patients undergoing the Bentall operation ($P = .45$). Survival at 10 years was $57\% \pm 8\%$ for patients undergoing aortic valve replacement and supracoronary replacement of the ascending aorta and $74\% \pm 4\%$ for patients undergoing the Bentall operation ($P = .04$), but the type of operation had no effect on survival. Older age, moderate or severe left ventricular dysfunction, active endocarditis, previous cardiac surgery, and coronary artery disease were independent predictors of death. The freedom from reoperation at 10 years was $95\% \pm 5\%$ for patients undergoing aortic valve replacement and supracoronary replacement of the ascending aorta and $94\% \pm 3\%$ for patients undergoing the Bentall operation ($P = .18$). Reoperations were mostly because of tissue valve failure or endocarditis. The risk of valve-related complications was the same in both groups. No patient required reoperation for aortic root aneurysm after having aortic valve replacement and supracoronary replacement of the ascending aorta.

Conclusions: Aortic valve replacement and supracoronary replacement of the ascending aorta and the Bentall operation provide comparable long-term results. The Bentall operation is more appropriate for patients with aortic root abnormality and a dilated ascending aorta, whereas aortic valve replacement and supracoronary replacement of the ascending aorta is a perfectly acceptable operation for patients with aortic valve disease, normal or mildly dilated aortic sinuses, and a dilated ascending aorta.

From the Division of Cardiovascular Surgery of Toronto General Hospital and the University of Toronto, Toronto, Ontario, Canada.

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Address for reprints: Tirone E. David, MD, 200 Elizabeth St, 13EN-219, Toronto, Ontario, Canada, M5G 2C4 (E-mail: tirone.david@uhn.on.ca).

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In 1968, Bentall and DeBono¹ described an operation to treat patients with aortic root aneurysms that consisted of composite replacement of the aortic valve and ascending aorta with reimplantation of the coronary arteries by using a conduit containing a mechanical valve. This procedure was modified somewhat over the years, mostly related to the techniques of reimplantation of the coronary arteries and of the distal anastomosis.² As experience with this operation increased, its indications were expanded to include patients with other pathologic processes, such as porcelain aorta and aortic root abscess, and more recently, it has been used as a technique for aortic valve replacement when a stentless biologic or bioprosthetic aortic valve is used.³⁻⁵ We have not used this approach to aortic valve replacement, except when the Ross procedure is performed.⁴ If the ascending aorta is dilated and the aortic root is normal or near normal, we replace the aortic valve and the supracoronary ascending aorta. Moreover, if the noncoronary sinus of Valsalva is dilated, we prefer to replace only the noncoronary sinus by tailoring the supracoronary graft to extend down to the aortic annulus and leave the coronary arteries undisturbed.

The purpose of this study was to compare the clinical profile and outcomes of aortic valve replacement combined with supracoronary replacement of the ascending aorta (AVR+RAA) and composite replacement of the aortic valve and ascending aorta (Bentall operation) in patients with aortic valve disease and an ascending aortic aneurysm.

Patients and Methods

From 1990 through 2001, 133 patients underwent AVR+RAA, and 452 patients underwent the Bentall operation performed by 2 surgeons (T.E.D. and C.M.F.) at Toronto General Hospital. Clinical data were entered prospectively into a computerized database. Patients who had the Ross procedure were excluded unless they had an ascending aortic aneurysm that required replacement with a tubular Dacron graft. Table 1 shows the patients' clinical profile. Table 2 shows the operative data.

Operations

AVR+RAA was performed in patients who had dilated (>45 mm) ascending aortas and normal or minimally dilated aortic sinuses. However, the noncoronary aortic sinus was dilated or damaged by dissection, infection, or a previous patch enlargement of the aortic root in 21 patients, and it was replaced along with the ascending aorta, but the left and right sinuses and the coronary arteries were left intact. In these cases the Dacron graft used to replace the ascending aorta was tailored in such a way as to create a neo-aortic sinus to replace the noncoronary aortic sinus and was secured to the aortic annulus by using the same sutures used to secure the prosthetic aortic valve. Other procedures performed in these patients are listed in Table 2.

The Bentall operation was performed in patients who had aortic root aneurysm (311 patients), active or healed aortic root abscess (33 patients), calcified aortic sinuses (32 patients), previously

TABLE 1. Clinical profile of patients

	AVR + RAA	Bentall operation	P value
No. of patients	133	452	
Age, y (mean $\pm$ SD)	61.4 $\pm$ 13.4	52.3 $\pm$ 16.3	.001
Sex			
Male	97 (73)	346 (77)	
Female	36 (27)	106 (23)	.4
NYHA functional class			.001
Class 1	6 (5)	78 (17)	
Class 2	47 (35)	151 (33)	
Class 3	51 (38)	109 (24)	
Class 4	29 (22)	114 (25)	
Left ventricular ejection fraction			.73
>59%	41 (31)	151 (34)	
40%-59%	68 (51)	205 (46)	
20%-39%	22 (17)	86 (19)	
<20%	2 (1)	6 (1)	
Aortic valve lesion			.001
Stenosis	64 (48)	105 (23)	
Insufficiency	46 (34)	230 (51)	
Mixed	22 (16)	93 (20)	
Not recorded	1 (1)	24 (5)	
Timing of operation			.17
Elective	103 (78)	312 (69)	
Urgent	27 (20)	105 (23)	
Emergency	3 (2)	34 (8)	
Endocarditis			.08
Remote	2 (2)	20 (4)	
Active	2 (2)	8 (3)	
Aortic root abscess	1 (1)	20 (4)	
Previous cardiac surgery	30 (23)	165 (37)	.003
Previous aortic valve surgery	22 (17)	136 (30)	.003
Marfan syndrome	0	23 (6)	.001
Coronary artery disease	44 (33)	95 (21)	.001
Mitral valve disease	25 (21)	34 (8)	.03
Aortic dissection			
Acute	3 (2)	26 (6)	.1
Chronic	2 (1)	13 (3)	.4
Recent myocardial infarction (<30 d)	0	5 (1)	.50
Congestive heart failure	58 (44)	56 (35)	.06
Preoperative renal failure	2 (2)	6 (1)	.88
Chronic obstructive lung disease	6 (5)	11 (2)	.24
Peripheral vascular disease	10 (8)	7 (2)	.001
Diabetes mellitus	9 (7)	26 (6)	.70
Hypertension	55 (41)	151 (34)	.17

Percentages are shown in parentheses.

AVR + RAA, Aortic valve replacement combined with supracoronary replacement of the ascending aorta; *Bentall operation*, aortic root replacement; NYHA, New York Heart Association.

replaced aortic root (28 patients), previously replaced aortic valve with patch enlargement of the aortic annulus (17 patients), need for correction of patient-prosthesis mismatch (19 patients), and complex aortic annulus-root problems (12 patients). These patients also had dilated ascending aortas. The aortic root was replaced with a biologic or prosthetic valved conduit, and the coronary arteries were reimplanted by using the button technique. In 15 patients who

TABLE 2. Operative data

	AVR + RAA	Bentall operation	P value
Aortic valve pathology			.001
Rheumatic	11 (8)	5 (1)	
Tricuspid calcific	21 (16)	24 (5)	
Bicuspid	56 (42)	175 (38)	
Other congenital	3 (2)	12 (3)	
Aortic annulus ectasia	3 (2)	58 (13)	
Aortic dissection	6 (4)	38 (8)	
Prosthetic dysfunction	20 (15)	89 (20)	
Miscellaneous	7 (5)	36 (8)	
Not recorded	11 (8)	40 (9)	
Type of heart valve implanted			.001
Mechanical	56 (42)	196 (43)	
Aortic homograft	0	49 (11)	
Pulmonary autograft	4 (3)	19 (4)	
Stentless porcine	4 (3)	145 (32)	
Stented bioprosthesis	69 (52)	43 (10)	
Coronary artery bypass	48 (36)	98 (22)	.001
Mitral valve repair-replacement	25 (21)	41 (9)	.03
Tricuspid valve repair	2 (2)	5 (1)	.65
Pulmonary valve replacement	4 (3)	19 (4)	.42
Replacement of aortic arch	13 (10)	12 (3)	.05
Circulatory arrest	45 (34)	92 (20)	.001
Aortic crossclamp time (min)*	92 ± 31	106 ± 36	.001
CPB time (min)*	120 ± 42	135 ± 49	.001
ICU stay (d)*	2.3 ± 4.3	1.9 ± 4.5	.35
Hospital stay (d)*	11.2 ± 14.6	10.7 ± 15.2	.74

Percentages are shown in parentheses.

AVR + RAA, Aortic valve replacement combined with supracoronary replacement of the ascending aorta; *Bentall operation*, aortic root replacement; CPB, cardiopulmonary bypass; ICU, intensive care unit.

*Values are expressed as means ± SD.

had a previous aortic root replacement, one or both coronary arteries had to be extended with a short segment of Dacron graft or, in cases of active endocarditis, with a saphenous vein graft before they could be connected to the valved conduit. Other procedures are listed on Table 2.

With the exception of cases of active infective endocarditis when an aortic homograft was preferentially used, patients chose the type of heart valve implanted.

Follow-up

The referring cardiologists followed the patients at annual intervals or more often if needed, and the information contained in their consultation letter was extracted and entered into our database. An annual echocardiogram was obtained for most patients. Our research personnel contacted all patients periodically through questionnaires and telephone calls. Postoperative events were compiled and analyzed according to the "Guidelines for reporting morbidity and mortality after cardiac valvular operations."⁶ The follow-up for this study was closed on December 31, 2002; extended from 0 to 13 years (mean of 4.6 ± 3.1 years); and was 100% complete. Both operations were performed throughout the period of observation, and the duration of follow-up was similar in both groups (4.9 ± 3.2 years for the AVR+RAA group and 4.4 ± 2.8 years for the Bentall group, *P* = .3).

TABLE 3. Operative mortality and morbidity

	AVR + RAA	Bentall operation	P value
Operative deaths	7 (5%)	18 (4%)	.45
Causes of operative death			
Cardiac failure	3	7	
Sudden death	0	5	
Multiorgan failure	0	2	
Sepsis	2	0	
Hemorrhage	1	0	
Respiratory failure	1	0	
Stroke	0	2	
Ruptured thoracic aneurysm	0	1	
Sternal infection	0	1	
Operative morbidity*			
Perioperative MI	1	5	
Low output syndrome	11	38	
Intra-aortic balloon pump	7	30	
Perioperative stroke	6	11	
Assisted ventilation >48 h	12	18	
Renal failure	3	8	
Re-exploration of mediastinum			
Bleeding	10	27	
Tamponade	5	8	
Wound dehiscence	0	1	
Sternal infection	3	0	
Other	1	2	

AVR + RAA, Aortic valve replacement combined with supracoronary replacement of the ascending aorta; *Bentall operation*, aortic root replacement; MI, myocardial infarction.

*Includes patients who died.

Statistical Analysis

Statistical analysis was done with SAS 8.1 software (SAS Institute, Cary, NC). Discrete patient variables were compared by using the contingency table method or the Fisher exact test. The means of continuous variables were compared by using Student *t* tests. Survival and freedom from morbid events were compared by using the Kaplan-Meier method. Independent predictors were determined by means of Cox multivariable analysis, with backward elimination of nonsignificant determinants.

Results

Table 1 shows that patients who underwent AVR+RAA were older and had more aortic stenosis, coronary artery disease, and mitral valve disease than those who underwent the Bentall operation, and those undergoing the Bentall operation, who had more aortic insufficiency, included all patients with Marfan syndrome and more patients who had previous aortic valve operations. Table 2 shows that the proportions of patients who had mechanical valves were similar between the 2 groups, but the types of bioprosthetic and biologic valves were different. The AVR+RAA group had more stented bioprostheses, whereas the Bentall group had more homografts and stentless porcine bioprostheses.

Table 3 shows the operative mortality and morbidity. The operative mortality was 5% for the AVR+RAA group

TABLE 4. Causes of death

	AVR + RAA	Bentall operation
Total no. of deaths	31	63
Operative deaths	7	18
Late deaths	24	45
Sudden death	3	4
Myocardial infarction	3	3
Congestive heart failure	5	6
Stroke	1	4
Prosthetic valve endocarditis	1	2
Anticoagulation-related bleeding	1	1
Structural valve deterioration	1	0
Ruptured aneurysm	1	2
False aneurysm of coronary button	0	1
Noncardiovascular death	8	22

AVR + RAA, Aortic valve replacement combined with replacement of the supracoronary ascending aorta; Bentall operation, aortic root replacement.

was 4% for the Bentall group ($P = .45$). The type of operation (AVR+RAA or the Bentall operation) had no effect on operative mortality. Advanced age, New York Heart Association functional class 4, urgent-emergency operations, and the need for circulatory arrest were independent predictors of operative mortality.

Late Survival

There were 24 late deaths in the AVR+RAA group and 45 in the Bentall group (Table 4). Figure 1 shows the survival at 10 years, which was lower in the AVR+RAA group than in the Bentall group ($57\% \pm 8\%$ vs $74\% \pm 4\%$, $P = .04$), but Cox regression analysis showed that the type of operation was not an independent predictor of late death (Table 5). Older age, left ventricular dysfunction (ejection fraction of $<40\%$), active endocarditis, previous cardiac surgery, and coronary artery disease were the only independent predictors of late death.

Thromboembolic Complications

There were 6 thromboembolic events in the AVR+RAA group, none of which were fatal, and 25 thromboembolic events in the Bentall group, 4 of which were fatal. The freedom from thromboembolism at 10 years was $96\% \pm 2\%$ in the AVR+RAA group and $92\% \pm 2\%$ in the Bentall group ($P = .4$). The type of prosthetic aortic valve was univariately associated with thromboembolism complications: at 10 years, the freedom from thromboembolism was $98\% \pm 2\%$ for aortic homografts, $88\% \pm 3\%$ for mechanical valves, and $97\% \pm 2\%$ for bioprosthetic valves ($P = .008$).

Prosthetic Valve Endocarditis

Nine patients had prosthetic valve endocarditis: 1 in the AVR+RAA group and 8 in the Bentall group. Five patients

Figure 1. Long-term survival.

TABLE 5. Independent predictors of death

Variable	Hazard ratio	95% Confidence limits	P value
Age by 5-y increments	1.05	1.03-1.07	.001
Ejection fraction 20%-39%	1.90	1.51-3.14	.01
Ejection fraction $<20\%$	3.50	1.07-11.37	.04
Active endocarditis	2.88	1.48-5.60	.002
Previous cardiac surgery	2.12	1.37-3.28	.001
Coronary artery disease	1.55	1.01-2.40	.049

had early (<6 months) and 4 had late infections. Four patients who had undergone the Bentall operation underwent reoperation and survived. The remaining patients were treated with antibiotics alone because they were deemed inoperable, and 3 died (1 in the AVR+RAA group and 2 in the Bentall group). The freedom from prosthetic valve endocarditis at 10 years was $86\% \pm 13\%$ in the AVR+RAA group and $96\% \pm 2\%$ in the Bentall group ($P = .5$). The type of prosthetic heart valve had no effect on the risk of endocarditis: the freedom from endocarditis at 10 years was $91\% \pm 7\%$ with aortic homografts, $94\% \pm 5\%$ with mechanical valves, and $99\% \pm 1\%$ with bioprosthetic valves ($P = .7$).

Anticoagulation-related Hemorrhage

Of 242 patients receiving oral anticoagulants (208 with mechanical valves and 34 with tissue valves), 30 patients had at least one episode of bleeding: 10 minor and 20 major. All patients with major bleeding required hospitalization, and 2 died. The freedom from bleeding at 10 years was $85\% \pm 3\%$ for all patients receiving oral anticoagulants, $94\% \pm 3\%$ for the AVR+RAA group, and $83\% \pm 4\%$ for the Bentall group ($P = .16$).

Structural Valve Failure

One patient in the AVR+RAA group had bioprosthetic structural valve failure but did not undergo reoperation

Figure 2. Freedom from reoperation.

because of advanced age and numerous comorbid conditions. Five patients in the Bentall group had structural valve failure: 4 aortic homografts and 1 xenograft. All 5 underwent successful reoperation.

Reoperations

Twelve patients underwent reoperations: 1 in the AVR+RAA group for prosthetic valve dehiscence and 11 in the Bentall group (4 for endocarditis, 5 for prosthetic valve failure, and 2 for valve-patch dehiscence in patients who had complex reconstruction of the left ventricular outflow tract). There were no operative deaths among patients who required reoperations. Figure 2 shows the freedom from reoperation. It was similar in the 2 groups.

Valve-related Mortality and Morbidity

Freedom from valve-related mortality and morbidity at 10 years was 80% in the AVR+RAA group and 83% in the Bentall group ($P = .8$).

No patient in the AVR+RAA group had aortic root aneurysm, and there were no reoperations or verified deaths caused by aortic root aneurysm in these patients.

Late Functional Class

At the last follow-up contact, 101 patients who underwent AVR+RAA were alive, and 63% were in New York Heart Association functional class 1, 25% were in class 2, 10% were in class 3, and 2% were in class 4. Of 378 patients who underwent the Bentall operation, 71% were in class 1, 19% were in class 2, and 10% were in class 3.

Discussion

This study showed that the outcomes of AVR+RAA were similar to those of the Bentall operation in patients with aortic valve disease and ascending aortic aneurysms. The fact that no patient who underwent AVR+RAA had aortic root aneurysm is an indication that the patients were correctly selected for this operation.

The clinical profiles of our patients who underwent AVR+RAA or the Bentall operation were different than those reported by Yun and colleagues⁷ from Stanford University. In that series the patients who had the Bentall operation were 10 years younger than ours; 44% had Marfan syndrome, and 34% had aortic dissection. The lower incidences of Marfan syndrome and aortic dissection in our series are likely a reflection on differences in surgical management of these diseases. Most patients with Marfan syndrome have aortic valve-sparing operations in our institution.⁸ Similarly, those with aortic dissection often have their native aortic valve preserved.⁹ These are the reasons why only 6% of patients who underwent the Bentall operation had Marfan syndrome and only 7.5% of all patients had aortic dissection in our series. The study from Stanford spanned more than 3 decades, and consequently, the operative mortality was higher than ours at 15% for AVR+RAA and 14% for the Bentall operation.⁷ For the above reasons, it might be inappropriate to compare the clinical outcomes of these 2 series. However, their conclusions were the same as ours: AVR+RAA and the Bentall operation provided similar clinical outcomes, and the type of operation had no effect on operative and long-term survival.⁷ Moreover, AVR+RAA was an appropriate operation for patients with aortic valve disease and ascending aortic aneurysm, as long as the aortic sinuses were normal or minimally dilated.⁷

In a report by Houël and colleagues¹⁰ from France, the type of operation had no effect on long-term survival, but AVR+RAA was associated with more aortic wall complications (aortic root dilation and false aneurysms) than the Bentall operation. However, AVR+RAA was performed in patients with Marfan syndrome and others with aortic root aneurysm.¹⁰ We observed none of the complications described in that report, but there was no patient with Marfan syndrome or aortic root aneurysm in the AVR+RAA group in our series.

Although the risk of development of aortic root aneurysm might be eliminated by proper patient selection for AVR+RAA, these patients, unlike those who undergo the Bentall operation, are exposed to a risk of prosthetic valve dehiscence, as we observed in one patient in our series. This risk, however, should be weighed against the hazards of coronary artery reimplantation and other problems related to aortic root replacement.^{7,11,12} Intraoperative bleeding and kinking can be difficult to manage, and late problems, such as false or true aneurysm of the arterial button, coronary artery, or both, as well as periaortic fistulas, can also occur.^{11,12} To minimize the problems related with reimplantation of the coronary arteries, Cabrol and associates¹³ described an operative procedure whereby the 2 coronary arteries were connected together by a Dacron graft, which was then sutured to the valved conduit in a side-to-side fashion. This procedure has been associated with more

problems than the arterial button technique and has been abandoned by most surgeons.¹⁴ However, in cases of aortic root rereplacement, it is not always feasible to reattach the coronary arteries directly to the valved conduit, and an extension of the coronary artery with a short segment of Dacron graft or saphenous vein might be necessary.¹⁵

Early reports indicate that prosthetic conduits containing mechanical valves were preferentially used for aortic root replacement to decrease the probability of reoperation.^{2,13,16,17} However, because of a variety of factors, such as increased experience with reoperations, development of newer bioprosthetic heart valves, and better appreciation of the problems related with anticoagulation, recent reports suggest a trend toward the use of biologic and bioprosthetic heart valves in these patients.^{3,5,7,18} The risk of reoperation has to be weighed against the risk of life-long anticoagulation with warfarin sodium and, as shown in this report, an increased risk of thromboembolic complications. In certain conditions, however, such as in aortic root abscess, the use of an aortic valve homograft might be preferable because it appears to increase the probability of cure of the infection.¹⁹ Finally, pulmonary autografts have also been used in certain patients with aortic valve disease and ascending aortic aneurysm.²⁰ This operation might be inappropriate for patients with aortic root aneurysm because the risk of dilation of the pulmonary autograft is increased when it is subjected to systemic pressures because it often has the same histologic abnormality as the aortic root.^{21,22} However, if the aortic root is not dilated and the aneurysm is limited to the ascending aorta, it might be reasonable to use a pulmonary autograft to replace the aortic root and a tubular Dacron graft to replace the ascending aorta.²⁰

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