

## REVIEW ARTICLE

# Quadricuspid Aortic Valve: A Report of 12 Cases and a Review of the Literature

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Quadricuspid aortic valve (QAV) is rare and its diagnosis, clinical course, and management are less well defined relative to other aortic valve abnormalities. Advances in diagnostic imaging, notably in ultrasound, have increased clinical awareness of this anomaly and prompted this review of our experience with 12 new patients and a compilation of previously reported patients to further characterize this condition. (Echocardiography 2011;28:1035-1040)

**Key words:** aortic valve, quadricuspid, echocardiography

Quadricuspid aortic valve (QAV) is rare with an estimated prevalence of 0.013% to 0.043%.<sup>1</sup> Advances in diagnostic imaging in recent decades, notably in ultrasound, have increased awareness of QAV and allow further characterization of its diagnosis, clinical course, and management. In this review, we report our experience with 12 patients with QAV managed between 2003 and 2009, and review previously reported patients from the literature.

## Methods:

The Massachusetts General Hospital echocardiography database was interrogated for patients diagnosed with QAV (January 2003 to January 2009). Two additional patients were identified from affiliated clinical practices. Demographics, diagnostic and imaging findings, and management data was collected. QAV morphology was established in a total of 12 patients by ultrasound, and further evaluated in three of these patients by surgical examination (2 patients), and pathologic inspection (1 patient).

A literature search for QAV was conducted using PubMed, Web of Science, and Google. The reference sections of all articles were also screened.

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## Results:

Twelve patients with QAV were identified: 10 of 67,982 patients (2003–2009) undergoing cardiac ultrasound at the MGH echocardiography laboratory (0.017%). There were five females and seven males, ages ranging from newborn to 79 years (mean age at diagnosis, 49 years). Findings are summarized in Table I.

Moderate or severe aortic regurgitation (AR) was present in eight patients (75%); the newborn had mild regurgitation and the 12- and 31-year-old patients had competent valves. Severity of AR increased with age: absent or mild in four patients, ages 0, 12, 31, and 79 years, moderate AR in six patients ages 40–60 years, and severe AR in two patients ages 48 and 54 years. Two patients with severe AR underwent aortic valve replacement (AVR). The 48-year-old female patient received a 21-mm MAGNA bovine pericardial valve prosthesis and the 54-year-old man, a 23-mm St. Jude valve. Severe aortic stenosis (AS) was present in one patient who died from unrelated complications before surgical intervention. All patients had degrees of aortic valve leaflet thickening.

Aortic root and ascending aorta dimensions were within normal limits in all patients (Table I). Aortic dimensions in patients with sequential echocardiograms did not change significantly. AR increased by one class in two patients (Patient 10—newborn, 1 month interval, trace to mild; Patient 1—75-year-old, 14-year interval, mild to moderate).

In seven patients, QAV was an isolated lesion; five patients had additional structural heart lesions

**TABLE I**  
Classification, Functional Status, and Associated Conditions in 12 Patients with QAV

Patient	Age	Gender	Valve Type (H/R class) [5]	Aortic Root (mm)	Asc. Aorta (mm)	AR	AS	Normal	MR	Associated Structural Lesions
1	75	F	III (C)	32	26	3	–	–	3	MVP, AVNRT
2	48	F	I (A)	26	28	4	–	–	2	WPW
3	66	M	IV (F)	38	34	3	–	–	2	–
4	62	F	IV (F)	–	–	3	–	–	3	LV myxoma
5	12	F	III (C)	23	28	0	–	Yes	0	–
6	53	F	II (B)	28	27	3	–	–	2	–
7	79	M	III (C)	38	32	0	Yes	–	2	–
8	60	F	III (C)	26	29	3	–	–	2	–
9	48	M	III (C)	29	–	3	–	–	0	–
10	0	M	I (A)	9	12	2	–	–	0	PS
11	31	M	I (A)	34	–	0	–	Yes	0	–
12	54	M	I (A)	32	–	4	–	–	2	–

AR/MR scale: 0–2 – absent to mild, 3 – moderate, 4 – severe. AVNRT = atrioventricular nodal reentry tachycardia; WPW = Wolf-Parkinson-White Syndrome; MVP = mitral valve prolapsed; PS = pulmonary stenosis.

(Table I), one had bileaflet mitral valve prolapse, one had left ventricular myxoma, one had pulmonary valve stenosis (mild). Mild or moderate mitral regurgitation (MR) was present in eight patients. The patient with bileaflet MVP also had atrioventricular nodal reentry tachycardia (AVNRT), and one patient had ventricular preexcitation.

Valve leaflet morphology has been previously classified based on leaflet cusp size and distribution defined by Hurwitz and Roberts.<sup>2</sup> Using these criteria, the following morphologies were seen in our patients: type A (four equal cusps; three cases), type B (three large equal cusps, one smaller cusp; one case), type C (two larger equal cusps, two smaller equal cusps; five cases), type F (two large equal cusps, two smaller unequal cusps; two cases), and type G (four unequal cusps; one case). Our two patients who underwent AVR had type C and A morphologies. No patient in our group had type D (one large cusp, two intermediate cusps, one small cusp) or E (three equal cusps, one large cusp).

## Discussion:

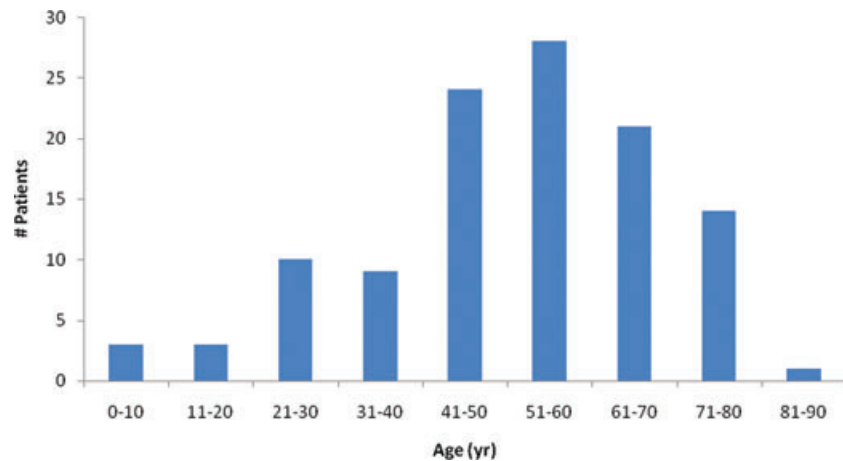
Quadricuspid aortic valve is rare; its reported incidence varies with diagnostic modality. Cardiac ultrasound reports cite a prevalence ranging from 0.013% to 0.043%, which likely underestimates, but still most closely reflects its true prevalence. Quadricuspid valve is more common in both the pulmonic valve and truncus arteriosus compared to the aortic valve.<sup>3</sup> QAV was first reported by Balington in 1862.<sup>4</sup> Embryologic studies cite both abnormal fusion of arteriopulmonary septation and abnormal mesenchymal proliferation as underlying potential explanations for QAV.<sup>5</sup>

Most often, QAV is an isolated finding although random concomitant lesions coexist. As expected in QAV, the position of the coronary artery ostia relative to the aortic sinus of Valsalva differ compared with trileaflet aortic valves, but usually is anatomically similar in the position of origin relative to the aortic root. Displacement of the coronary ostia, including common origin, has been reported but seems rare.<sup>6–10</sup> Nevertheless, delineation of the coronary artery ostia has practical importance for surgical intervention.

Tutarel published the most recent comprehensive review of QAV in 2004 citing 186 reported cases.<sup>7</sup> We found an additional 73 interim cases reported and our series adds 12 new patients (Table I). The mean age of the entire cohort of 271 patients is 50.6 years with a male to female ratio of 1.55:1 (Table II).

Cardiac ultrasound short-axis views of the aortic valve are optimal for diagnosis and delineation. The classical X-shaped commissural aortic valve pattern in diastole (Fig. 2) compared to the “Y” in the trileaflet valve is diagnostic, however QAV morphology may vary in subtypes with small leaflets and may be distorted in elderly patients with calcified valves. TEE evaluation may allow more definitive detail when not clearly evident with TTE. Ultrasound delineates the magnitude of AR, left ventricular size and contraction, coronary ostial position, presence of associated lesions, AS, and the status of the ascending aorta.<sup>11</sup>

Of note, and in contrast to patients with BAV, whose aortic valves often have associated enlargement of the ascending aorta secondary to medial disarray,<sup>5</sup> adult patients with QAV in our series did not have enlarged ascending aorta (size 26–34 mm). In addition, ascending aortic



**Figure 1.** Historical age distribution of aortic regurgitation (AR) in QAV (when reported). AR was seen in greatest frequency in the 51–60-year-old age bracket.

enlargement has only been reported three times in the literature.<sup>12–14</sup> The relative absence of associated aneurysm of the aorta has clinical and management significance, and has not been addressed previously. Histologic and clinical evaluation of the ascending aorta in QAV is thus warranted.

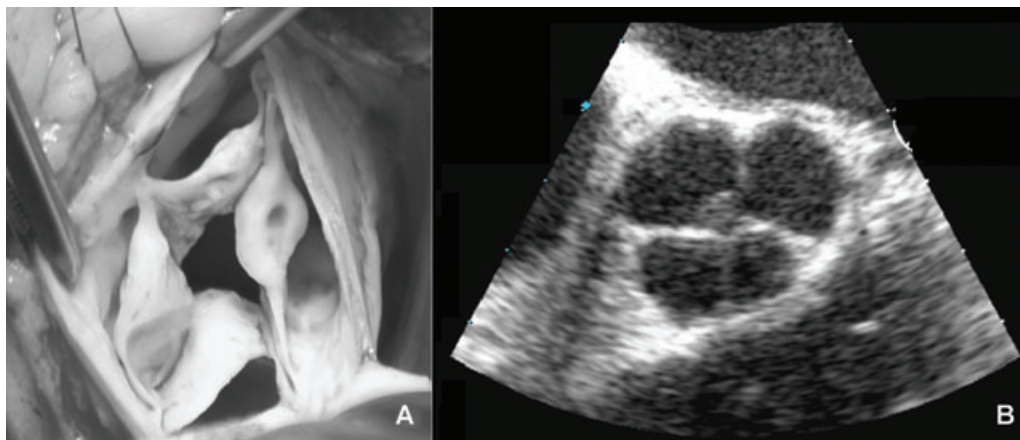
The predominant clinical findings and management issues in QAV relate to progressive AR with aging (Fig. 1), owing to progressive leaflet fibrosis and progressive failure of leaflet coaptation. The frequent association of QAV with AR is similar to patients with unicuspid aortic valves who also more frequently have AR, in contrast to those with BAV in whom AR is less common than AS. Overall, AS is uncommon in QAV and was present in only 1 of our 12 patients and reported in 19 patients from other reviews (Table II).<sup>1,7,13,15–17</sup>

Normal aortic valve function was reported in 16% of QAV patients by Tutarel, although its incidence with advanced age was not detailed.<sup>7</sup> Our review indicated the highest incidence of normal

valve function in patients under 18 years and significantly worsening function after age 40 years (Table II). Clearly, ongoing clinical and ultrasound follow up with advancing age in all patients with QAV is advisable as valve dysfunction is progressive over time.

An ejection sound (EC) in early systole is characteristic of BAV in children and young adults and is increasingly rare beyond the fourth decade. In our three younger patients (ages newborn, 16 years, and 31 years) an EC was not heard, and in our review of the literature it was not mentioned. The absence of EC might allow clinical differentiation of QAV from younger patients with BAV if indeed it is not present in QAV. Further observation in subsequent patients with QAV regarding EC presence could then be useful in clinical differentiation of younger patients with BAV and QAV.

We had no patients with subacute bacterial endocarditis (SBE), regardless we feel antibacterial coverage should be advised in QAV as several studies have reported its occurrence.<sup>2,9,18–22</sup>



**Figure 2.** Type A QAV morphology in a patient with severe aortic regurgitation (Patient 2). **A.** surgical superior view. **B.** TEE short-axis view.

**TABLE II**  
Historical Summary of All Reported Cases of QAV

Age*	Gender	Subtype H/R [5] No. Patients (%)†	Subtype I-IV # pts (%)†	Asc Aorta age (dimension)‡	AR severity No. Patients (%)†	AS No. Patients (%)†	Procedure No. Patients (%)†	Normal Function No. Patients (%)†	MR No. Patients (%)†	Associated Lesions	AVR by Subtype No. Patients (%)†
All ages (161 pts) Range: 0-84 Mean: 50.6	M - 98 F - 58	A - 47 (29.2%) B - 42 (26.1%) C - 21 (13%) D - 9 (5.6%) E - 3 (1.9%) F - 5 (3.1%) G - 4 (2.5%)	I - 47 (29%) II - 42 (26%) III - 21 (13%) IV - 21 (13%)	3 patients 10 yrs (not reported) 43 yrs (36 mm) 70 yrs (45 mm)	0 - mild - 29 (18%) moderate - 27 (16.8%) severe - 68 (42.2%)	6 (3.7%)	AVR - 79 (49.1%) Plasty - 6 (3.7%)	18 (11.2%)	25	AVNRT - 1 SBE - 7 MVP - 1 SVA - 2 SVF - 1 LV Myxoma - 1	I - 23 (48.9%) II - 24 (57.1%) III - 10 (47.6%) IV - 11 (52.3%)
Ages 0-18 (12 pts) Range: 0-17 Mean: 9.5	M - 6 F - 5	A - 2 (16.7%) B - 4 (33.3%) C - 4 (33.3%)	I - 2 (16.7%) II - 4 (33.3%) III - 4 (33.3%)	1 patient 10 yrs (not reported)	0 - mild - 9 (75%) severe - 1 (8.3%)	2 (16.7%)	AVR - 2 (16.7%)	6 (50%)	2	SBE - 1	II - 1 (50%) III - 1 (25%)
Ages 19-50 (56 pts) Range: 19-50 Mean: 37.8	M - 34 F - 22	A - 20 (35.7%) B - 15 (26.7%) C - 5 (8.9%) D - 3 (5.4%) E - 1 (1.8%) F - 2 (3.6%)	I - 20 (35.7%) II - 15 (26.7%) III - 5 (8.9%) IV - 6 (10.7%)	1 patient 43 yrs (36 mm)	0 - mild - 13 (23.2%) moderate - 10 (17.9%) severe - 26 (46.4%)	1 (1.8%)	AVR - 26 (46.4%) Plasty - 4 (7.1%)	4 (7.1%)	5	SBE - 3 SVA - 1 SVF - 1	I - 7 (35%) II - 9 (60%) III - 3 (60%) IV - 4 (66.7%)
Ages 51-84 (93 pts) Range: 51-84 Mean: 63.6	M - 58 F - 31	A - 25 (26.9%) B - 23 (24.7%) C - 12 (12.9%) D - 6 (6.5%) E - 2 (2.2%) F - 3 (3.2%) G - 4 (4.3%)	I - 25 (26.9%) II - 23 (24.7%) III - 12 (12.9%) IV - 15 (16.1%)	1 patient 70 yrs (45 mm)	0 - mild - 15 (16.1%) moderate - 17 (18.2%) severe - 41 (44.1%)	4 (4.3%)	AVR - 50 (53.8%) Plasty - 2 (2.2%)	7 (7.5%)	18	AVNRT - 1 SBE - 3 MVP - 1 LV Myxoma - 1	I - 15 (60%) II - 14 (60.9%) III - 6 (50%) IV - 10 (66.7%)

Asc Aorta = ascending aorta; AR = aortic regurgitation; AS = aortic stenosis; MR = mitral regurgitation; AVR = aortic valve replacement; AVNRT = atrioventricular nodal reentry tachycardia; SBE = subacute bacterial endocarditis; MVP = mitral valve prolapse; SVA = sinus of Valsalva aneurysm; SVF = sinus of Valsalva fistula; LV = left ventricle.

\*When age of patients was reported.

†Data and percentages are based on reported values in literature. Not all published cases reported all information.

**Table III**

Functional Status of QAV Subtypes from the Historical Report

Subtype	AR	AR + AS	AS
I	61	6	0
II	40	5	2
III	16	2	0
IV	24	2	0

Based on available data. Some reports did not indicate subtype or functional status. AR = aortic regurgitation; AS = aortic stenosis.

In 1973 Hurwitz and Roberts described seven different morphologies of QAV (types A-G) from autopsy findings. The most frequent leaflet morphology types were A and B, both of which were most frequently regurgitant (Table III).

Surgical timing for either AVR or valvuloplasty revision is similar in QAV and bicuspid aortic valve. Choice of valve replacement in this relatively young patient population would traditionally favor mechanical valves, with the resultant requirement for lifelong anticoagulation, making repair, when possible an attractive option.

In principle, repair aims to either achieve a functioning bicuspid or tricuspid valve by “eliminating” one (tricuspid repair) or two leaflets (bicuspid result) and bringing together the associated commissures. This requires a combination of techniques as described by several case reports.<sup>8,11,23–26</sup> Elimination of an “abnormal commissure,” and its associated leaflet is accomplished by resection and sewing together the free edges of adjacent leaflet to create a large single leaflet. Often the commissure itself is resected to provide a more normal leaflet attachment to the neo-annulus. Rarely, additional leaflet length requires use of tissue patch material, either native or bovine pericardium.

Several reports of tricuspidization of the QAV have shown promising short-term relief from AR but long-term data is still needed. Schmidt et al report surgical plasty repair via tricuspidization in two cases with two normal sized leaflets and two smaller leaflets using a combination of leaflet fusion, resection of the interposed commissure, and, in one patient, patch augmentation.<sup>26</sup> A similar approach was used by Jeanmart et al. in two patients.<sup>24</sup> This type of “fusion” repair to create a tricuspid valve would seem to be most applicable when there are either two “normal” or near normal appearing leaflets with two smaller leaflets, Hurwitz and Roberts type F, and G, or in the case of three large leaflets and a smaller “accessory” leaflet (Type B). Simple exclusion of a small accessory leaflet would also seem logical in Type B.

Bicuspidization would appear attractive when two principle leaflets are accompanied by two smaller leaflets and would involve similar techniques of combining adjacent leaflets. Bicuspid repairs should thus be considered in subtypes C, F, and G.

The current seven-type classification system can be challenging in practice from a surgical and echocardiographic perspective and lacks close correlation to patient management. Therefore a simplification of classification might be appropriate. We found the following subtyping to be more user-friendly:

- (1) Type I – valve with four equal cusps
- (2) Type II – valve with three larger cusps and one small accessory cusp
- (3) Type III – valve with two larger cusps and two small accessory cusps
- (4) Type IV – valves with other variations in leaflet size distribution

This proposed system separates the morphologies most prone to severe AR (Table III) from other leaflet configurations, and hence might assist cardiologists and surgeons in following patients and planning a repair or replacement intervention strategy. With Type II and III valves, a tricuspid or bicuspid repair using the techniques previously described might be considered. For Type IV valves, additional information, such as the relative leaflet arch length (all would be 90° in Type I) might provide the surgeon with helpful planning information.

### Conclusion:

Quadricuspid aortic valve is rare and single-center clinical experiences with these patients are small with a number of clinical aspects and management guidelines still ill-defined. We add our 12-patient experience to the previously reported 259 patients to further elucidate principles of significance in diagnosis, natural history, and management.

In contrast to bicuspid aortic valves, aortic aneurysm seems to be uncommon in quadricuspid aortic valves. Most quadricuspid valves are difficult to identify clinically as they have minimal dysfunction in younger patients, and often lack the identifying heart sounds heard in bicuspid patients in the last three decades of life. However, it is reasonably clear that the natural history of QAV is described by progressive aortic valve insufficiency which suggests that regardless of function at time of diagnosis, progressive regurgitation, presumably due to free edge fibrosis of the leaflets, warrants long term periodic echocardiography follow-up, particularly in Hurwitz and Roberts types A and B. Additional

management once the diagnosis is made should include consideration of valve prophylaxis—SBE incidence is low but not uncommon in this population (2%).

Surgical management involving replacement or repair (via tricuspidization or bicuspidization) is possible in certain patients depending on leaflet morphology. We propose a revised four-part classification system to improve communication and clinical and surgical decision making.

## References

1. Feldman BJ, Khandheria BK, Warnes CA, et al: Incidence, description and functional assessment of isolated quadricuspid aortic valves. *Am J Cardiol* 1990;65:937–938.
2. Hurwitz LE, Roberts WC: Quadricuspid semilunar valve. *Am J Cardiol* 1973;31:623–626.
3. Timperley J, Milner R, Marshall JA, et al: Quadricuspid aortic valves. A review. *Clin Cardiol*. 2002;25:548–552.
4. Balington J. London Medical Gazette. 1862.
5. Fernandez B, Duran AC, Thiene G, et al: Embryological evidence for the formation of a quadricuspid aortic-valve in the Syrian-Hamster. *Cardiovasc Pathol* 1994;3:287–291.
6. Formica F, Sangalli F, Ferro O, et al: A rare cause of severe aortic regurgitation: Quadricuspid aortic valve. *Interact Cardiovasc Thorac Surg* 2004;3:672–674.
7. Tutarel O: The quadricuspid aortic valve: A comprehensive review. *J Heart Valve Dis* 2004;13:534–537.
8. Godefroid O, Colles P, Vercauteren S, et al: Quadricuspid aortic valve: A rare etiology of aortic regurgitation. *Eur J Echocardiogr* 2006;7:168–170.
9. Kawanishi Y, Tanaka H, Nakagiri K, et al: Congenital quadricuspid aortic valve associated with severe regurgitation. *Asian Cardiovasc Thorac Ann* 2008;16:e40–e41.
10. Scrofani R, Pettinari M, Vanelli P, et al: Type F quadricuspid aortic valve: Surgical treatment of a rare cause of aortic valve disease. *J Cardiovasc Med* 2008;9:311–313.
11. Kawanishi Y, Tanaka H, Nakagiri K, et al: Congenital quadricuspid aortic valve associated with severe regurgitation. *Asian Cardiovasc Thorac Ann* 2008;16:e40–e41.
12. Naito K, Ohteki H, Yunoki J, et al: Aortic valve repair for quadricuspid aortic valve associated with aortic regurgitation and ascending aortic aneurysm. *J Thoracic Cardiovasc Surg* 2004;128:759–760.
13. Yildirim SV, Gumus A, Coskun I, et al: Quadricuspid aortic valve: A rare cause of aortic regurgitation and stenosis. *Turk J Pediatr* 2008;50:500–502.
14. Attaran RR, Habibzadeh MR, Baweja G, et al: Quadricuspid Aortic valve with ascending aortic aneurysm: Report of a case and discussion of embryological mechanisms. *Cardiovasc Pathol* 2009;18:49–52.
15. Sasahashi N, Ando F, Okamoto F, et al: A case of quadricuspid aortic valve associated with aortic steno-insufficiency. *Nippon Kyobu Geka Gakkai Zasshi* 1997;45:1055–1060.
16. Mecozzi G, Pratali S, Milano A, et al: Severe quadricuspid aortic valve stenosis after mediastinal irradiation. *J Thoracic Cardiovasc Surg* 2003;126:1198–1199.
17. Yotsumoto G, Iguro Y, Kinjo T, et al: Congenital Quadricuspid Aortic Valve: Report of Nine Surgical Cases. *Ann Thoracic Cardiovasc Surg* 2003;9:134–137.
18. Matsukawa T, Yoshii S, Hashimoto R, et al: Quadricuspid aortic-valve perforation resulting from bacterial-endocarditis—2-d echographic and angiographic diagnosis and its surgical-treatment. *Jpn Circ J-Engl Ed* 1988;52:437–440.
19. Asami H, Asano H, Handa N, et al: A surgical case of quadricuspid aortic valve associated aortic regurgitation and severe mitral regurgitation due to infective endocarditis. *Kyobu Geka* 1998;51:216–219.
20. Takeda N, Ohtaki E, Kasegawa H, et al: Infective endocarditis associated with quadricuspid aortic valve. *Jpn Heart J* 2003;44:441–445.
21. Pirundini PA, Balaguer JM, Lilly KJ, et al: Replacement of the quadricuspid aortic valve: Strategy to avoid complete heart block. *Ann Thorac Surg* 2006;81:2306–2308.
22. Bauer F, Litzler P, Tabley A, et al: Endocarditis complicating a congenital quadricuspid aortic valve. *Eur J Echocardiogr* 2008;9:386–387.
23. Iglesias A, Oliver J, Munoz JE, et al: Quadricuspid aortic-valve associated with fibromuscular sub-aortic stenosis and aortic regurgitation treated by conservative surgery. *Chest* 1981;80:327–328.
24. Jeanmart H, de Kerchove L, El Bitar F, et al: Tricuspidation of quadricuspid aortic valve: Case reports. *J Heart Valve Dis* 2007;16:148–150.
25. Pouleur AC, de Waroux JBL, Pasquet A, et al: Successful repair of a quadricuspid aortic valve illustrated by transoesophageal echocardiography, 64-slice multidetector computed tomography, and cardiac magnetic resonance. *Eur Heart J* 2007;28:2769.
26. Schmidt KI, Jeserich M, Aicher D, et al: Tricuspidization of the quadricuspid aortic valve. *Ann Thoracic Surg* 2008;85:1087–1089.