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Serial Doppler Echocardiographic Evaluation of Bioprosthetic Valves in the Tricuspid Position

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Objectives. **This study sought to evaluate bioprosthetic valve dysfunction in the tricuspid position by serial Doppler echocardiography.**

Background. **Few reports on the long-term results of tricuspid valve replacement with bioprosthetic valves are evaluated by serial Doppler echocardiography.**

Methods. **Between September 1979 and December 1993, 95 patients underwent tricuspid valve replacement with bioprosthetic valves at our facility. Sixty patients who underwent serial Doppler echocardiographic examination at intervals of at least 2 years after operation were included in the final analysis. These patients were followed up from 1.5 to 13.0 years (mean 5.8 ± 2.5).**

Results. **The actuarial rates of freedom from bioprosthetic valve stenosis and regurgitation at 10 years were 46% and 51%, respectively. The prevalence of bioprosthetic valve stenosis and regurgitation increased progressively in a linear manner beginning 1 or 2 years after tricuspid valve replacement. Right heart failure developed during follow-up in 20 of the 25 patients with bioprosthetic valve dysfunction.**

Conclusions. **The long-term durability of bioprosthetic valves in the tricuspid position was substantially lower in our study than that reported in previous studies. Tricuspid bioprosthetic valve dysfunction increased progressively in a linear manner beginning 1 to 2 years after tricuspid valve replacement.**

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Bioprosthetic valve has been considered the valve of choice for tricuspid valve replacement because the risk of valve thrombosis is highest in the tricuspid position owing to the lower pressures and velocity of blood flow (1). Although durability of bioprosthetic valve in either the mitral or aortic position is a major problem (2–4), several studies reported good durability of bioprosthetic valves in the tricuspid position (5–7). However, long-term follow-up and assessment of patients after tricuspid valve operations are difficult because inevitable associated mitral or aortic valve disease tends to dominate the clinical picture.

Doppler echocardiography is a noninvasive method of assessing prosthetic valve hemodynamic condition in either the mitral or aortic position (8–10). However, only few reports on long-term results of tricuspid valve replacement with bioprosthetic valves are evaluated by serial Doppler echocardiography. This study evaluated bioprosthetic valve dysfunction in the tricuspid position by serial Doppler echocardiography.

Methods

Study patients. Between September 1979 and December 1993, 95 patients underwent tricuspid valve replacement with bioprosthetic valves at our facility. Thirteen patients who died postoperatively were excluded from analysis. Nineteen patients who did not undergo serial Doppler echocardiographic examination were also excluded. Color Doppler echocardiography was routinely initiated in 1984. Three patients who underwent tricuspid valve replacement before 1984 and showed bioprosthetic valve dysfunction on color Doppler echocardiography in 1984 were also excluded. Six patients who underwent tricuspid valve replacement before 1984 were included in this study. Therefore, 60 patients were included in the final analysis. All 60 patients underwent Doppler echocardiographic examination within 1 month after the valve operation. However, six patients who received tricuspid valve replacement before 1984 also first underwent color Doppler echocardiography in 1984. There were 34 female and 26 male patients, with a mean age 49 ± 11 years (range 8 to 74). These patients were followed up from 1.5 to 13.0 years (mean 5.8 ± 2.5), with a total follow-up of 350 patient-years.

Indications for tricuspid valve replacement were rheumatic heart disease (n = 23), Ebstein's anomaly (n = 12), tricuspid regurgitation secondary to other congenital heart diseases (n = 9), prosthetic valve dysfunction (n = 4), infective endocarditis (n = 3), congenital tricuspid valve regurgitation (n = 2), constrictive pericarditis (n = 2), ruptured chordae tendineae (n = 2), mitral regurgitation (n = 2) and restrictive cardiomyopathy (n = 1). Some patients received multiple valve replacement together with tricuspid valve replacement. In addition to the tricuspid bioprosthetic valve, 8 patients had a mitral prosthetic valve, 1 had an aortic prosthetic valve, 7 had mitral

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and aortic prosthetic valves, 3 had pulmonary prosthetic valve and 2 had mitral valve repair. Isolated tricuspid valve replacement was performed on 39 patients. Nine patients also had repair of congenital heart disease. Previous operations had been performed on 34 patients. Nineteen patients had previous tricuspid valve surgery, including 14 with annuloplasty and 5 with tricuspid valve replacement. Predominant valvular lesion was regurgitation in 48 patients, stenosis in 3 and stenosis/insufficiency in 9. There were 15 patients with sinus rhythm and 45 patients with atrial fibrillation.

The annular size of the bioprosthetic valve was 33 mm in 16 patients, 31 mm in 36, 29 mm in 6 and 27 mm in 2. The bioprosthetic valves used were 41 Carpentier-Edwards pericardial, 3 Carpentier-Edwards supraannular, 14 Ionescu-Shiley, 1 Hancock, and 1 Mitroflow.

Doppler echocardiography. Routine two-dimensional and Doppler echocardiographic examinations using a commercially available, real-time, two-dimensional, Doppler color flow imaging system with a 2.5-MHz transducer were performed at intervals of at least 2 years after the operation. Continuous wave Doppler recordings across the tricuspid bioprosthetic valve were made. Doppler examinations were reviewed at an off-line station from videotapes or Doppler strip charts. The outer edge of the velocity profile of the tricuspid inflow was traced, and the mean gradient was automatically calculated by computer using a simplified Bernoulli equation.

Doppler color flow studies were performed using the gain to maximize the tricuspid regurgitation jet signal with minimal background noise. Regurgitant flow of the bioprosthetic valve in the tricuspid position was graded on an apical four-chamber or parasternal long- or short-axis view as described previously (mild: regurgitant flow visualized in less than half the diameter of the right atrium; moderate: regurgitant flow visualized in approximately half the diameter of the right atrium; severe: regurgitant flow visualized across the entire right atrial cavity) (11). Regurgitation was considered transvalvular if its origin was observed within the orifice (as defined by the forward flow pattern) in at least two different views. Periprosthetic regurgitation was recognized by detection of regurgitant jets originating from the junction between the prosthetic ring and annulus.

The calculations were based on an average of five sequential cardiac cycles in patients with normal sinus rhythm and of 10 sequential cycles in those with atrial fibrillation because the pattern of the spread of tricuspid inflow and tricuspid regurgitant jet varied with respiration and because they varied from beat to beat in cases with atrial fibrillation. Bioprosthetic valve stenosis was defined as a mean gradient of tricuspid inflow ≥5 mm Hg because the mean gradient across the normal heterograft in the tricuspid position estimated by Doppler echocardiography has been previously found to be 3.2 ± 1.1 mm Hg (12). Reduced excursion of the bioprosthetic valve leaflets in the tricuspid position was also evaluated by two-dimensional echocardiography as bioprosthetic valve stenosis to exclude the influence of prosthetic valve regurgitation on the mean gradient across the bioprosthetic valve. Bioprosthetic valve regurgitation due to bioprosthetic valve dysfunction was defined as moderate or severe transvalvular regurgitation.

Table 1. Mean Gradient Across Bioprosthetic Valve

Mean Gradient (mm Hg)	Within 1 mo (no. of pts)	Latest (no. of pts)
<5	60	42
5–8	0	11
8–11	0	3
>11	0	4

Latest = most recent Doppler echocardiographic examination; pts = patients; within 1 mo = within 1 month after tricuspid valve replacement.

Statistical analysis. The event rates were calculated by linearized analysis. Actuarial analyses were calculated by the Kaplan-Meier method (13). The actuarial rates were expressed as a percentage of the patient's event-free rate, and survival curves were compared by the log rank statistics.

Results

Bioprosthetic valve stenosis in the tricuspid position. No patient had greater than mild degree of pulmonary stenosis or regurgitation. During follow-up, left heart failure developed in one patient with perivalvular regurgitation in the mitral mechanical valve. One patient had prosthetic valve endocarditis 2 years after the procedure. However, this patient had tricuspid bioprosthetic valve stenosis (mean gradient 5 mm Hg) before prosthetic valve endocarditis developed. She died of right heart failure due to tricuspid bioprosthetic valve stenosis (mean gradient 13 mm Hg) 2 years after prosthetic valve endocarditis was diagnosed.

The mean gradients of bioprosthetic valve in the tricuspid position were less than 5 mm Hg within 1 month after tricuspid valve surgery. Bioprosthetic valve stenosis in the tricuspid position was observed in 18 patients during follow-up. In these patients, reduced excursion of one or more leaflets of the tricuspid bioprosthetic valve was also observed on two-dimensional echocardiography. The mean gradient on the most recent Doppler echocardiographic examination was 5 to 8 mm Hg in 11 patients, 8 to 11 mm Hg in 3, >11 mm Hg in 4 (Table 1). The linearized rate of bioprosthetic valve stenosis was 5.5% per patient-year. The actuarial rates of freedom from bioprosthetic valve stenosis was 87% at 5 years, and 46% at 10 years (Fig. 1). The prevalence of bioprosthetic valve stenosis increased progressively in a linear manner beginning a few years after the operation. Because most of the patients underwent tricuspid valve replacement using Ionescu-Shiley or Carpentier-Edwards pericardial valve, we compared these two groups. Although bioprosthetic valve stenosis was observed in patients with either bioprosthetic valve, it occurred earlier in patients with Carpentier-Edwards pericardial valve than in those with Ionescu-Shiley pericardial valve ($p < 0.01$).

Bioprosthetic valve regurgitation in the tricuspid position. One patient showed moderate transvalvular regurgitation of the tricuspid bioprosthetic valve within 1 month after the

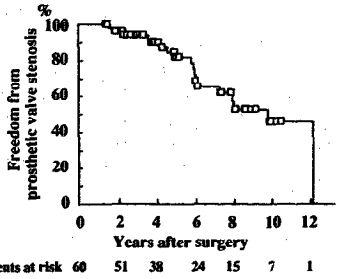


Figure 1. Actuarial analysis of bioprosthetic valve stenosis in the tricuspid position. **Numbers** below the graph are number of patients at risk after each year of follow-up.

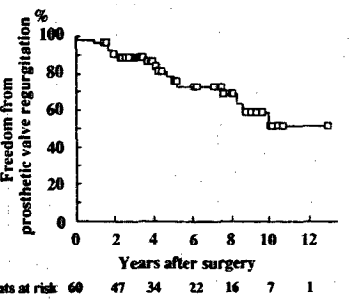


Figure 2. Actuarial analysis of moderate or severe bioprosthetic valve regurgitation in the tricuspid position. **Numbers** below graph are number of patients at risk after each year of follow-up.

procedure. Bioprosthetic valve regurgitation became severe and bioprosthetic valve stenosis (mean gradient: 12 mm Hg) also developed during follow-up. This patient underwent a second tricuspid valve replacement. Moderate or greater transvalvular bioprosthetic regurgitation was observed in 18 patients during follow-up. On the most recent Doppler echocardiographic examination, bioprosthetic valve regurgitation was moderate in 11 patients and severe in 7 (Table 2). The linearized rate of transvalvular bioprosthetic regurgitation was 5.8%/patient-year. The actuarial rates of freedom from transvalvular bioprosthetic regurgitation was 76% at 5 years, and 51% at 10 years (Fig. 2). The prevalence of bioprosthetic valve regurgitation also increased progressively in a linear manner beginning a few years after the operation. Although transvalvular bioprosthetic regurgitation was observed in patients with either Ionescu-Shiley or Carpentier-Edwards pericardial valve, it occurred earlier in patients with Carpentier-Edwards pericardial valve than in those with Ionescu-Shiley pericardial valve ($p < 0.01$). Both bioprosthetic valve stenosis and moderate or severe regurgitation developed in 11 patients. Tricuspid bioprosthetic valve dysfunction due to bioprosthetic valve stenosis and moderate or severe regurgitation was observed in 25 patients. The linearized rate of bioprosthetic valve dysfunction was 9.3%/patient-year. The actuarial rates of freedom from bioprosthetic valve dysfunction on Doppler echocardiography was 66% at 5 years and 37% at 10 years (Fig. 3). Bioprosthetic valve dysfunction occurred earlier in patients with Carpentier-Edwards pericardial valve than in those with Ionescu-Shiley pericardial valve ($p < 0.01$).

Table 2. Bioprosthetic Valve Regurgitation

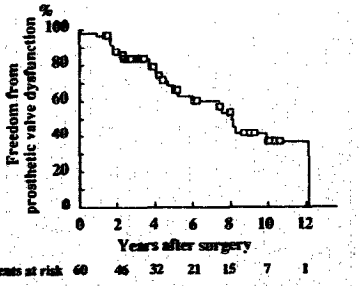
Regurgitation	Within 1 mo* (no. of pts)	Latest (no. of pts)
None or mild	53	42
Moderate	1	11
Severe	0	7

*Six patients who underwent tricuspid valve replacement were excluded before color Doppler echocardiography was available. Abbreviations as in Table 1.

Clinical outcome of tricuspid bioprosthetic valve dysfunction. Right heart failure developed in 20 of the 25 patients with bioprosthetic valve dysfunction because of tricuspid bioprosthetic valve dysfunction during follow-up. One patient died of right heart failure. A second tricuspid valve replacement was performed in four patients. Another patient is currently waiting for a second tricuspid valve replacement. The remaining 14 patients are treated with medication rather than an operation. Another two patients with moderate tricuspid regurgitation received a second tricuspid valve replacement at the time of repair of perivalvular regurgitation in the mitral mechanical valve or the Maze procedure for atrial fibrillation. Right heart failure developed in one of these patients that could be treated with medication before the second tricuspid valve replacement. The other patient did not have any symptoms of right heart failure. The linearized rate of additional procedure due to bioprosthetic valve dysfunction was 1.2%/patient-year. The actuarial rates of freedom from additional procedure due to bioprosthetic valve dysfunction was 98% at 5 years and 78% at 10 years (Fig. 4).

Five of the 25 patients with bioprosthetic valve dysfunction did not have right heart failure. However, all five patients received medication such as diuretics after their initial tricuspid valve replacement.

Figure 3. Actuarial analysis of bioprosthetic valve dysfunction in the tricuspid position by Doppler echocardiography. **Numbers** below graph are number of patients at risk after each year of follow-up.



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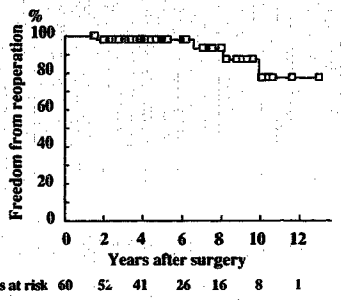

Figure 4. Actuarial analysis of additional operation due to tricuspid bioprosthetic valve dysfunction. **Numbers** below graph are number of patients at risk after each year of follow-up.

Discussion

In the present study, the long-term durability of bioprosthetic valves in the tricuspid position was substantially less than that reported in previous studies. Although few reports show the incidence of bioprosthetic valve dysfunction in the tricuspid position, the tricuspid bioprosthetic valves appear to be more durable than those on the left side of the heart (5–7). The remaining event-free rate from structural valve failure in bioprosthetic valves in the tricuspid position was reported to be 94% at 10 years by Kawachi et al. (5) and 68% at 14 years by Guerra et al. (6). Although patients were children, Dunn (7) showed that the durability of bioprosthetic valves in the tricuspid position at 9 years was 100%. Our Doppler echocardiographic findings showed a poorer durability than those in other studies. In addition to this finding, although it is well known that aortic and mitral bioprosthetic valves increase the rate of bioprosthetic valve dysfunction in a nonlinear manner ≥6 years after implantation, the present study using Doppler echocardiography has shown that the prevalence of bioprosthetic valve dysfunction of tricuspid bioprosthetic valves increased progressively in a linear manner beginning a few years after the operation.

Doppler echocardiographic evaluation. The long-term follow-up and assessment of patients after tricuspid valve surgery are difficult because the inevitable associated mitral or aortic valve disease tends to dominate the clinical picture. Doppler echocardiography is a valuable tool in evaluating prosthetic heart valves noninvasively (8–10), and Doppler hemodynamic conditions have been validated by comparison with invasive hemodynamic conditions in severe studies that included a small number of patients with prosthetic valves in the tricuspid position in the study group (14,15). Previous studies demonstrated that prosthetic valve stenosis or insufficiency in the tricuspid position could be detected by echocardiography even though patients were asymptomatic (16,17). In the present study, although 20 of the 25 patients with bioprosthetic valve dysfunction had symptoms of right heart failure, 14 patients were treatable with medication. The present study, compared with previous studies, demonstrated poorer durability of the tricuspid bioprosthetic valves. This might be due to greater sensitivity of Doppler echocardiography, compared with the clinical examination, for detecting bioprosthetic valve dysfunction. Such patients should be followed up carefully because right heart failure may develop due to systemic infection, atrial fibrillation, dietary excess of sodium and so on.

Mechanism of bioprosthetic valve dysfunction. Bioprosthetic valve dysfunction as a result of structural deterioration in either the mitral or aortic position has been seen as cusp disruption and leaflet calcification, either isolated or associated with fibrous tissue overgrowth (18–20). From a comparison of gross inspections of simultaneously implanted and explanted bioprosthetic valves in the tricuspid and mitral position, degenerative changes were found to be more extensive in the mitral than in the tricuspid bioprosthetic valve (6,19). This finding is explained by the fact that the closing pressure on the bioprosthetic valve in the mitral position is higher than that of the bioprosthetic valve in the tricuspid position. According to this finding, the bioprosthetic valve in the tricuspid position would be more durable than that in the mitral position. Therefore, in addition to cusp disruption, leaflet calcification and fibrous tissue overgrowth, other mechanisms might play a role in bioprosthetic valve dysfunction in the tricuspid position. This might be the reason that tricuspid bioprosthetic valve dysfunction increased progressively in a linear manner beginning a few years after the operation. However, no alternative mechanisms of bioprosthetic valve dysfunction were elucidated by the present study, and we could not also find the reason why bioprosthetic valve dysfunction occurred earlier in patients with Carpentier-Edwards pericardial valve than in those with Ionescu-Shiley pericardial valve. Guerra et al. (6) observed that fibrous pannus on the ventricular side grew into one or more sinuses and also observed impaired pliability of the corresponding cusp in explants from the tricuspid position but not in those from the mitral position. Another report mentioned that the particular configuration of the right ventricle was thought to be detrimental to ideal functioning of the bioprosthetic valve in the tricuspid position (21). However, no alternative mechanisms of bioprosthetic valve dysfunction were elucidated by the present study.

Study limitations. First, this Doppler echocardiographic study was a retrospective and actuarial analysis performed in 60 patients representing 73% of all patients who underwent tricuspid valve replacement. Second, the Doppler echocardiographic images obtained from patients after valve replacement were sometimes unclear because of acoustic shadowing from the bioprosthetic valve. Considering this effect, bioprosthetic valve dysfunction in the tricuspid position might occur more often than indicated in the present study. Third, although some patients had both bioprosthetic valve stenosis and regurgitation in the tricuspid position, bioprosthetic valve regurgitation may influence the mean gradient across the bioprosthetic valve. However, patients with bioprosthetic valve stenosis by our Doppler echocardiographic criteria also showed reduced excursion of the bioprosthetic valve leaflets in the tricuspid position on two-dimensional echocardiography. Fourth,

poorer durability of Carpentier-Edwards pericardial valve, compared with Ionescu-Shiley pericardial valve, in the tricuspid position might influence the result as an entire group although bioprosthetic valve dysfunction were observed in patients with either Ionescu-Shiley or Carpentier-Edwards pericardial valve. Fifth, we did not use transesophageal echocardiography to assess any of these bioprosthetic valves. Transesophageal echocardiography would be particularly useful for defining the mechanism of tricuspid bioprosthetic valve dysfunction.

Conclusions. In the present study, the long-term durability of bioprosthetic valves in the tricuspid position was substantially less than that reported in previous studies. Tricuspid bioprosthetic valve dysfunction increased progressively in a linear manner beginning a few years after tricuspid valve replacement. Doppler echocardiography is very useful in detecting bioprosthetic valve dysfunction in the tricuspid position.

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