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_Circulation_ 2005;111;920-925; originally published online Feb 14, 2005;
DOI: 10.1161/01.CIR.0000155623.48408.C5

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Frequency by Decades of Unicuspid, Bicuspid, and Tricuspid Aortic Valves in Adults Having Isolated Aortic Valve Replacement for Aortic Stenosis, With or Without Associated Aortic Regurgitation

William C. Roberts, MD; Jong M. Ko, BA

Background—Aortic valve stenosis (with or without aortic regurgitation and without associated mitral stenosis) in adults in the Western world has been considered in recent years to most commonly be the result of degenerative or atherosclerotic disease.

Methods and Results—We examined operatively excised, stenotic aortic valves from 932 patients aged 26 to 91 years (mean ± SD, 70 ± 12), and none had associated mitral valve replacement or evidence of mitral stenosis: A total of 504 (54%) had congenitally malformed valves (unicuspid in 46 [unicommissural in 42; acommissural in 4] and bicuspid in 458); 417 (45%) had tricuspid valves (either absent or minimal commissural fusion); and 11 (1%) had valves of undetermined type. It is likely that the latter 11 valves also had been congenitally malformed. Of the 584 men, 343 (59%) had either a unicuspid or a bicuspid valve; of the 348 women, 161 (46%) had either a unicuspid or a bicuspid aortic valve.

Conclusions—The data from this large study of adults having isolated aortic valve replacement for aortic stenosis (with or without associated aortic regurgitation) and without associated mitral stenosis or mitral valve replacement strongly suggest that an underlying congenitally malformed valve, at least in men, is more common than a tricuspid aortic valve. (Circulation. 2005;111:920-925.)

Key Words: aorta ▪ heart defects, congenital ▪ valves ▪ regurgitation

The most common cardiac operation today, of course, is coronary artery bypass grafting. The second most common is aortic valve replacement for aortic valve stenosis. During the past 11 years, we have examined 932 operatively excised, stenotic aortic valves from adults. This study describes the frequency of the various aortic valve structures (unicuspid, bicuspid, and tricuspid) in each of 8 decades of life in a group of patients who had isolated aortic valve replacement. This study differs from previously reported similar analyses in that children and patients with concomitant mitral valve replacement or associated mitral stenosis were excluded. The hypothesis was that if cases of rheumatic heart disease could be excluded, then the frequency of an underlying congenital heart disease of those undergoing aortic valve replacement would be higher than previously realized.

See p 832

Methods
From January 1993 through June 2004, every cardiac valve operatively excised at Baylor University Medical Center and submitted to the surgical pathology department of the same medical center has been examined by one of us (W.C.R.). Among the valves examined during this >11-year period were 932 aortic valves that had some degree of stenosis (a peak left ventricular to aortic systolic pressure gradient ≥10 mm Hg or clear anatomic evidence of aortic valve stenosis) with or without some degree of aortic regurgitation. Excluded from this study were patients having combined aortic and mitral valve replacement, patients with mitral stenosis whether or not the mitral valve was excised or the patient had a mitral valvuloplasty, patients 20 years of age at the time of aortic valve replacement, patients who had had a previous aortic valvulotomy; and patients who also had hypertrophic cardiomyopathy. Thus, patients included herein were those in whom only the aortic valve was excised and the aortic valve had some degree of stenosis.

Each stenotic aortic valve was received in the surgical pathology department in a container of formaldehyde. The valve structure in all cases was determined by one of us (W.C.R.). Among the valves examined during this >11-year period were 932 aortic valves that had some degree of stenosis (a peak left ventricular to aortic systolic pressure gradient ≥10 mm Hg or clear anatomic evidence of aortic valve stenosis) with or without some degree of aortic regurgitation. Excluded from this study were patients having combined aortic and mitral valve replacement, patients with mitral stenosis whether or not the mitral valve was excised or the patient had a mitral valvuloplasty, patients 20 years of age at the time of aortic valve replacement, patients who had had a previous aortic valvulotomy; and patients who also had hypertrophic cardiomyopathy. Thus, patients included herein were those in whom only the aortic valve was excised and the aortic valve had some degree of stenosis.

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gradients between 10 and 20 mm Hg. Nearly all of the remaining 243 patients also had undergone cardiac catheterization, but those studies were performed before the patient was referred to Baylor University Medical Center, and the data were not available to us. Another 111 patients had echocardiographic data available but no cardiac catheterization data available. Thus, for 800 (86%) of the 932 patients, either cardiac catheterization data or echocardiographic data before aortic valve replacement were available. The transvalvular peak systolic pressure gradients ranged from 10 to 141 mm Hg (mean SD, 53 SD, 25); in the patients not having simultaneous coronary bypass surgery, the peak gradients ranged from 10 to 141 mm Hg (mean SD, 57 SD, 26), and in those patients having coronary bypass surgery at the time of aortic valve replacement, from 10 to 133 mm Hg (mean SD, 49 SD, 24; P 0.001). Aortic valve areas (637 patients) ranged from 0.18 to 1.90 cm² (mean SD, 0.74 SD, 0.25) and were significantly different in those having versus those not having simultaneous coronary bypass surgery (mean SD, 0.72 SD, 0.25 versus 0.76 SD, 0.25; P =0.037). All 932 patients had structurally abnormal aortic valves including calcific deposits, including those patients with peak transvalvular pressure gradients as low as 10 mm Hg.

Statistical analysis was performed with SigmaStat version 2.0 software (SPSS Inc). To compare the percentages in 2 different groups, the z test was used. To compare the mean transvalvular peak systolic pressure gradients and the mean aortic valve areas in patients with and without simultaneous coronary bypass surgery, the nonparametric Mann-Whitney rank-sum test was used instead of a parametric test because the data to be analyzed did not pass the normality and equal-variance assumption tests. To compare the mean ages among patient groups with unicuspid, bicuspid, and tricuspid valves, the nonparametric Kruskal-Wallis 1-way ANOVA on ranks test was used. A probability value <0.05 was considered statistically significant. The institutional review board of Baylor University Medical Center approved the study protocol.

**Results**

The numbers and percentages of patients in each of the 8 decades subdivided by aortic valve structure and sex are shown in Table 1. Among the 932 patients, 46 (5%) had unicuspid unicommissural valves, 458 (49%) had bicuspid valves, 417 (45%) had 3-cuspid aortic valves, and 11 (1%) had valves excised in several pieces, such that the underlying valve structure was not clearly discernible. (We believe that these 11 valves with uncertain structure were also congenitally malformed because they all contained a very large amount of calcific deposits.) More men than women had congenitally malformed valves (59% versus 46%, P=0.008; Table 1), and fewer men than women had tricuspid aortic valves (40% versus 53%, P=0.011; Table 1).

The unicuspid aortic valves were all heavily calcified, and their cusps were rigid. Of these 46 valves, 42 had a single, unfused commissure, and the valve orifice was linear (similar to an exclamation point), eccentrically triangular, or oval (Figure 1); the other 4 had triangular, more central orifices, and 3 “undeveloped commissures” (Figure 2).

The bicuspid aortic valves were of 2 types (Figure 3). All had been excised in 2 pieces. In 432, the free margins of both cusps were relatively linear in appearance, or the margins of one of the 2 cusps had a V-shaped configuration, with the apex of the V pointing toward a raphe (false commissure). In
the latter situation, the free margins of the raphe cusp were concave, and the free margins of the nonraphe cusp were convex, such that the valvular orifices were nevertheless usually competent. The ventricular aspect of the valve beneath the raphe in all instances was flat or nearly so. Furthermore, on the aortic aspect at the site of the raphe, the V-shaped cuspal margins were not visible in the raphe. The cephalad extension of the raphe was always less than that of the 2 true commissures. In the remaining 26 valves classified as bicuspid, the cusps were fused at one commissure, and the length of the fusion was ≥4 mm and usually =10 mm. In these circumstances, the free margins were visible cephalad to the cuspal fusion, which was located caudal to the margins. The fused cusps beneath the visible free margins (which extended to the aortic wall) were either flat or not. Additionally, the cephalad extension of the fused commissure appeared to be on the same horizontal plane as the other 2 commissures.
The tricuspid aortic valves were of 2 types (Figure 4). None of the 3 commissures were fused, such that each cusp was excised separately (340 cases), or there was slight (≤3 mm) fusion of one or more commissures (77 cases); in nearly all cases, the fusion extended for only 1 or 2 mm.

The fewer the number of aortic valve cusps, the younger was the patient. Patients with 3-cuspid aortic valves had higher mean ages than did patients with fewer cusps. The ages of the 46 patients with unicuspid valves ranged from 26 to 75 years (mean ± SD, 51 ± 14); that of the 458 patients with bicuspid valves, from 27 to 91 years (mean ± SD, 67 ± 11); and that of the 417 patients with tricuspid valves, from 45 to 91 years (mean ± SD, 74 ± 8; P < 0.001). Of the 932 patients, 176 (19%) were in the 4 younger decades (21 to 60 years), and 756 (81%) were in the 4 older decades (61 to 100 years). Nearly two thirds (66%) of the 932 patients were aged 61 to 80 years at the time of aortic valve replacement. Of the 46 patients with unicuspid valves, 33 (72%) were in the 4 younger decades, and the other 13 were in the next 2 older decades (61 to 80 years). Of the 458 patients with bicuspid valves, 115 (25%) were in the 4 younger decades (21 to 60 years), and 343 (75%) were in the 4 older decades (61 to 100 years). Of the 417 patients with tricuspid aortic valves, 27 (6%) were in the 4 younger decades (21 to 60 years; 25 of the 27 in the sixth decade); the other 390 (94%) were in the 4 older decades (61 to 100 years). Of the 176 patients in the 4 younger decades, the aortic valves in 33 (19%) were unicuspid; in 115 (65%), bicuspid; and in 27 (15%), tricuspid. In contrast, of the 756 patients in the 4 older decades (61 to 100 years), the aortic valves were unicuspid in 13 (2%); bicuspid in 343 (45%); and tricuspid in 390 (52%).

The age range of the 932 patients was 26 to 91 years (mean ± SD, 70 ± 12). The 584 men ranged in age from 26 to 91 years (mean ± SD, 69 ± 11), and the 348 women, from 27 to 91 years (mean ± SD, 71 ± 11). Of the 584 men, 119 (20%) were in the 4 younger decades (21 to 60 years), and 465 (80%) were in the 4 older decades (61 to 100 years); of the 348 women, 57 (16%) were in the 4 younger decades, and 291 (84%) were in the 4 older decades.

Of the 932 patients, 490 (53%) also had coronary artery bypass grafting at the time of aortic valve replacement (Table 2). Coronary artery bypass grafting was performed in 7 (15%) of the 46 patients with unicuspid valves, in 211 (46%) of the 458 patients with bicuspid valves, in 268 (64%) of the 417 patients with tricuspid aortic valves, and in 4 (36%) of the 11 with undetermined valve structure. Of the 176 patients in the 4 younger decades (21 to 60 years), 59 (34%) had concomitant coronary bypass surgery; of the 756 patients in the 4

### Table 2. Aortic Valve Structure in Patients With Isolated Aortic Stenosis Subdivided Into Those With and Without Concomitant Coronary Artery Bypass Grafting

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<td>10 (2)</td>
<td>48 (10)</td>
<td>135 (28)</td>
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Values in parentheses are percentages.
older decades, 431 (57%) had concomitant coronary bypass surgery.

**Discussion**

The present study of 932 stenotic aortic valves operatively excised from 1993 to 2004 in patients >20 years of age has demonstrated that slightly more patients had congenitally malformed aortic valves (either unicuspid or bicuspid) than tricuspid aortic valves (54% versus 45%; indeterminate structure 1%). Among the 46 patients with unicuspid aortic valve, 42 (91%) had valves with 2 rudimentary commissures and 1 true commissure (Figure 1): Four had valves with 3 rudimentary commissures and no true commissures (Figure 2). We classify these latter 4 cases as unicuspid acommissural aortic valves. These latter 4 cases in the past would have been classified by most investigators, we suspect, as rheumatic in origin. We, however, searched the medical records thoroughly for evidence of mitral valve disease in these 4 cases and found none. It is possible, of course, in rheumatic heart disease for aortic valve disease to be clinically apparent before the appearance of clinical evidence of mitral disease, and that could be the situation in these 4 cases. It is also possible that the cuspal fusion at each of the 3 rudimentary commissures was present at the time of birth, and therefore, this multifusion represents congenital heart disease. Lack of separation of each of 3 cusps before birth appears to us a more reasonable explanation of the valve disease in these 4 cases than rheumatic heart disease manifesting itself clinically as isolated aortic valve disease.

Although the patients with unicuspid or bicuspid aortic valves clearly had congenital heart disease underlying their aortic stenosis, the cause of the aortic stenosis in the patients with 3-cuspid aortic valves is almost certainly acquired in origin. Although stenosis involving a 3-cuspid aortic valve unassociated with mitral valve disease has in the past most commonly been called "degenerative" in origin—a consequence of aging—we prefer to call these stenotic, 3-cuspid aortic valves (unassociated with mitral disease) "atherosclerotic" in origin. The evidence for attributing the calcific and other deposits on the aortic aspects of the 3 cusps in these patients to atherosclerosis is the following: (1) Patients with homozygous familial hypercholesterolemia (individuals with serum total cholesterol levels >800 mg/dL from the time of birth) develop aortic stenosis by the teenage years (without lipid-lowering therapy); (2) patients >65 years of age with aortic stenosis involving a 3-cuspid aortic valve unassociated with mitral valve disease usually have extensive atherosclerosis involving the major epicardial coronary arteries and usually other arterial systems; (3) serum total cholesterol levels tend to be higher in patients with aortic stenosis involving a 3-cuspid aortic valve (unassociated with mitral valve disease) than in patients of similar age and sex without aortic stenosis; (4) the use of lipid-lowering therapy (statins) has been demonstrated to slow the progression of aortic valve stenosis; and (5) histological study of 3-cuspid, stenotic aortic valves has demonstrated that

### Table 3. Data in Patients Whose Stenotic Aortic Valves Are Shown in Figures 1–4

<table>
<thead>
<tr>
<th>Aortic Valve Structure</th>
<th>Age, y</th>
<th>Sex</th>
<th>LV-Aorta PSG (S/D), mm Hg</th>
<th>LV-Aorta Mean Gradient (S/D), mm Hg</th>
<th>Aortic Valve Area, cm²</th>
<th>Aortic Valve Weight, g</th>
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<td>Figure 1a</td>
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LV indicates left ventricular; PSG, peak systolic gradient; and S/D, peak systole/end diastole.
these valves have features similar to those in arterial athero-
sclerotic plaques. It has been demonstrated that the cusps of
congenitally bicuspid, stenotic valves are usually of unequal
dimension; ie, that they differ in weight.6 Likewise, the cusps of
3-cuspid, stenotic aortic valves also often differ in weight.
Roberts and Ko7 weighed 260 operatively excised, stenotic
3-cuspid aortic valves from patients having no evidence of
mural valve disease and found that all 3 cusps differed (by
>0.1 g) in weight in 69 patients (26%), that one cusp differed
in weight from the other 2 in 158 patients (61%), and that in
only 33 patients (13%) were all 3 cusps of similar weight.

The first institution where a large number of operatively
excised stenotic aortic valves were examined was the Mayo
Clinic. Subramanian and colleagues8 in 1984 described 374
valves with “pure aortic stenosis” (no associated aortic
regurgitation or only mild regurgitation); Passik and col-
leagues9 in 1987 examined another group of operatively excised
valves with “pure aortic stenosis”; and Subramanian et al10 in
1985 examined another group of operatively excised valves
with “combined aortic stenosis and insufficiency.” The diffi-
culty in comparing their findings with those in the present
study is that the former also included patients with coexistent
mitral disease and children. Combining the findings of the 3
studies from the Mayo Clinic together indicated that 44 (4%)
of their 1219 patients with operatively excised, stenotic aortic
valves had unicuspid valves, 459 (38%) had bicuspid valves,
431 (35%) had “postinflammatory” valves, 257 (21%) had
degenerative valves, and 28 (2%) had valves of indetermi-
nate structure. Their inclusion of children appeared to in-
crease the likelihood of congenitally malformed valves. These
authors also intermixed etiology with structure, a
process that prevented us from being entirely clear about
valve structure in their cases. Their patients as a group were
younger than those included in the present study because the
earlier studies included both children and patients with
unambiguous rheumatic heart disease. The present study, in
contrast, made every reasonable attempt to exclude patients
whose valve disease was of rheumatic etiology.

Turri and colleagues11 in 1990 described operatively ex-
cised aortic valves from 602 patients having valve replace-
ment in the 1980s: A total of 787 valves had some degree of
stenosis, but there was no attempt to describe valve structure.
These authors also included patients with associated mural
valve disease, and indeed, rheumatic heart disease was the
most common etiology of the aortic valve stenosis (573 of
787 [73%]). “Degenerative calcification” was the explanation
for the stenosis in the other 214 patients (27%). These authors
also included children in their study. The mean ages of their
patients with aortic stenosis was 47 years.

Several features of the present study make it different from
previous studies on operatively excised, stenotic aortic
valves. First, the study was limited to adults >20 years of age
and excluded those patients who had had a previous aortic
valvulotomy. Second, it excluded patients with associated
mitral stenosis, which in adults is virtually always of rheu-
matic origin, and it also excluded patients having mural valve
replacement for any reason. Third, it included only patients
whose stenotic aortic valve was excised in the last decade of
the 20th century or the first decade of the 21st century.
Fourth, the structure of the operatively excised stenotic aortic
valve was determined by a single physician (W.C.R.), who
has studied the aortic valve for >40 years. Fifth, it made no
attempt to separate stenotic valves into those that were purely
stenotic versus those that were both stenotic and regurgitant,
a division that is fraught with error unless an aortogram or
echocardiogram has been used for this determination.

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