Calf Aortic Valve Heterograft Replacement for Aortic Valvular Disease*


The calf aortic valve heterograft was used to replace the damaged aortic valves in 15 patients. There were two deaths which occurred in the immediate postoperative period. The first seven of the 13 surviving patients were studied six months postoperatively. Results showed that the heterograft valves were working effectively. There was no systolic pressure gradient across the new valve. Clinical competence of the valves has been confirmed by retrograde aortograms. Heart size has decreased in all cases. All the patients have shown marked improvement. It is obviously too short a time to draw any definite conclusions regarding the eventual fate of the implanted heterograft. However, our early clinical and laboratory results have shown that the calf aortic valve heterograft placed in the subcoronary position functions effectively and is well tolerated by the human host. This is most encouraging and it is felt that in view of these results further clinical application of this technique is warranted.

The homologous aortic valve segment interposed in the proximal descending thoracic aorta was successfully used in the treatment of aortic valvular insufficiency.1-3 This procedure, however, did not gain wide acceptance. More recently, Ross,4 Duran and Gunning5 and subsequently Barratt-Boyes6 replaced diseased aortic valves with homograft aortic valves implanted in the subcoronary position. Their results after more than three years of follow-up have been good.7,8 There is still, however, reluctance on the part of most cardiac surgeons to utilize this method because as Beall and Cooley9 stated, “the logistical problems associated with obtaining sufficient numbers of satisfactory aortic valve homografts, should their use become commonplace, appear insurmountable.” Furthermore, a number of patients who have undergone homograft valve replacement have developed aortic insufficiency subsequent to the operation.7,10-12 The problem of supply, however, has remained. Awareness of this latter problem has led to the use of heterologous aortic valves.14,15 Since aortic valve heterografts are easily obtainable in various sizes and in sufficient quantity, there should be no logistical problems associated with their use.

If it can be shown that (1) the human host will tolerate the heterograft as well as the homograft, and (2) the heterograft will function as efficiently when placed in the subcoronary position, then it can be used as a good substitute for the homograft aortic valve. To answer these questions, a clinical study was undertaken using the calf aortic valve. This article is a report of our experience.

**CLINICAL MATERIAL**

From May to December, 1967, 15 patients underwent calf aortic heterograft replacement at Deborah Hospital (Table 1). There were nine men and six women, ranging in age from 14 to 59 years with an average age of 40 years. Eight patients were in the fifth decade of life. Four patients had pure aortic stenosis. Two patients had major stenosis and minor aortic regurgitation. The remaining seven patients had multiple valve involvement. Four of these patients had aortic regurgitation associated with major mitral regurgitation. One patient had aortic regurgitation associated with major mitral stenosis and minor mitral regurgitation. One patient had aortic regurgitation, major tricuspid stenosis and minor mitral stenosis. One patient had aortic stenosis associated with major mitral stenosis, minor aortic regurgitation and minor tricuspid regurgitation.

Four patients had operations performed before the aortic heterograft valve replacement. One patient had had a single Bahnsen aortic leaflet replacement four years ago. One patient had had a closed mitral commissurotomy nine...
years ago and subsequent replacement of the mitral valve with a Starr-Edwards mitral valve prosthesis three years ago. One patient had an open mitral and aortic commissurotomy six years before. The fourth patient had a permanent transvenous pacemaker inserted eight months before aortic valve replacement.

**SURGICAL PROCEDURES**

Eight patients had only aortic valve replacement. Two patients had aortic replacement and concomitant mitral valve commissurotomy. Two patients had aortic replacement and mitral valve replacement using the Beall mitral valve prosthesis. Two patients had aortic replacement and mitral annulus cross polar plication. One patient had aortic valve replacement and tricuspid commissurotomy.

Intentional hemodilution was used on all patients. The rotating disc oxygenator with an internal heat exchanger was primed with one to four day-old acid citrate dextrose blood and 15 percent Rheotran. The chest was entered through a median sternotomy incision. After the patient was placed on cardiopulmonary bypass, the left ventricle was decompressed by inserting in its apex a plastic catheter connected to a low pressure cardiotomy suction line. If the corrective procedure was to be performed for both the mitral and aortic valves, the aortic valve was exposed first through a hockey stick aortotomy. The coronary cannulas were inserted and coronary perfusion started. The mitral valve was then approached either through an incision in the left atrium parallel and posterior to the interatrial groove or through a Dubost transverse incision crossing the right atrial wall and interatrial septum. After completion of the repair of the mitral valve, the atrial incisions were closed. The aortic valve was excised and the aortic root measured. The appropriate size calf valve heterograft was then chosen and carefully sutured in the subcoronary position as previously described.

**RESULTS**

Thirteen of the 15 patients are alive and vastly improved. Two patients died in the immediate post-

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**Table 1—Aortic Valve Replacement with Calf Aortic Valve Heterograft**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age</th>
<th>Sex</th>
<th>Diagnosis</th>
<th>Classification</th>
<th>Operation Performed</th>
<th>Amer. Heart Association Classification</th>
<th>Current Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.P.</td>
<td>50</td>
<td>M</td>
<td>Aortic Regurgitation Mitral Stenosis (major) Aortic Regurgitation (minor)</td>
<td>New York 3C</td>
<td>Aortic replacement, No. 11 Mitral commissurotomy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.M.</td>
<td>40</td>
<td>F</td>
<td>Aortic Regurgitation Mitral Stenosis (minor)</td>
<td>New York 3C</td>
<td>Aortic replacement Tricuspid commissurotomy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.C.</td>
<td>37</td>
<td>M</td>
<td>Aortic Stenosis Aortic Regurgitation (minor)</td>
<td>New York 3C</td>
<td>Aortic replacement No. 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.P.</td>
<td>50</td>
<td>F</td>
<td>Aortic Regurgitation</td>
<td>New York 3C</td>
<td>Aortic replacement, No. 11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.F.</td>
<td>54</td>
<td>M</td>
<td>Aortic Stenosis Complete A-V Block</td>
<td>New York 2C</td>
<td>Aortic replacement, No. 11 Mitral valve pllication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.R.</td>
<td>55</td>
<td>M</td>
<td>Aortic Regurgitation Mitral Regurgitation</td>
<td>New York 3C</td>
<td>Aortic replacement No. 8 Mitral valve pllication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J.P.</td>
<td>51</td>
<td>F</td>
<td>Aortic Stenosis (minor) Aortic Regurgitation (minor)</td>
<td>New York 2B</td>
<td>Aortic replacement, No. 8 Mitral commissurotomy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.N.</td>
<td>54</td>
<td>F</td>
<td>Aortic Regurgitation Mitral Regurgitation with S-E mitral prosthesis</td>
<td>New York 3C</td>
<td>Mitral commissurotomy Aortic replacement, No. 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.F.</td>
<td>44</td>
<td>M</td>
<td>Aortic Stenosis Aortic Regurgitation</td>
<td>New York 2B</td>
<td>Aortic replacement, No. 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J.R.</td>
<td>36</td>
<td>M</td>
<td>Aortic Regurgitation Ruptured Chordae Diabetes Mellitus Mitral Regurgitation</td>
<td>New York 3C</td>
<td>Aortic replacement, No. 10 Mitral replacement with large size Beall mitral valve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R.R.</td>
<td>21</td>
<td>F</td>
<td>Aortic Regurgitation Mitral Regurgitation</td>
<td>New York 2B</td>
<td>Aortic replacement, No. 8 Plication mitral valve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P.M.</td>
<td>31</td>
<td>F</td>
<td>Aortic Regurgitation Mitral Regurgitation Aortic Stenosis Mitral Stenosis</td>
<td>New York 2B</td>
<td>Aortic replacement, No. 9 Mitral replacement Beall medium-size valve</td>
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<td></td>
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<tr>
<td>J.L.</td>
<td>59</td>
<td>M</td>
<td>Aortic Stenosis Coronary artery disease</td>
<td>New York 2B</td>
<td>Aortic replacement, No. 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.G.</td>
<td>50</td>
<td>F</td>
<td>Aortic Regurgitation</td>
<td>New York 2B</td>
<td>Aortic replacement, No. 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V.M.</td>
<td>14</td>
<td>M</td>
<td>Aortic Regurgitation Thalassemia (minor)</td>
<td>New York 3C</td>
<td>Aortic replacement, No. 9</td>
<td></td>
<td></td>
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</table>

operative period. One patient who was a diabetic had both aortic and mitral regurgitation. The mitral regurgitation was due to ruptured chordae tendineae. The mitral valve was replaced with a Beall mitral valve prosthesis. During the rewarming period the patient developed ventricular tachycardia which persisted up to the time he was returned to the recovery room. Drugs were first tried to correct his arrhythmia. When these failed to produce results, direct current countershock was applied. His cardiac rhythm reverted to nodal rhythm. Vital signs stabilized, but after five hours he suddenly went into cardiac arrest from which he could not be resuscitated. Postmortem examination showed massive subendocardial infarction. The other patient had aortic stenosis associated with coronary artery disease. There was difficulty in getting him

**FIGURE 1.** Preoperative and postoperative phonocardiograms of a patient with aortic stenosis and complete heart block.

**FIGURE 2A** (left). Preoperative and postoperative simultaneous left ventricular and brachial artery pressure tracings in a patient with aortic stenosis. **FIGURE 2B** (right). Patient with aortic regurgitation.

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off the pump at the completion of valve implantation. Cardiac contractions were weak and could hardly produce an adequate blood pressure without the support of partial cardiopulmonary bypass. Post-operatively he was sustained with epinephrine (Adrenalin) intravenous drip but despite this measure he showed signs of the low cardiac output syndrome. He subsequently became anuric. On the

Table 2—Hemodynamic Data of Seven Patients

<table>
<thead>
<tr>
<th>Patient</th>
<th>Diagnosis</th>
<th>Cardiac Output L/min Preop</th>
<th>Cardiac Index L/M/MBSA Preop</th>
<th>Stroke Index cc/m/MBSA Preop</th>
<th>LVEDP* mm Hg Preop</th>
<th>LVEDP* mm Hg Postop</th>
<th>HR**</th>
<th>HR**</th>
<th>Brachial Artery Pressure mm Hg Preop</th>
<th>Brachial Artery Pressure mm Hg Postop</th>
<th>LV-BA Pressure mm Hg Preop</th>
<th>LV-BA Pressure mm Hg Postop</th>
<th>Aortogram 1+—4+</th>
<th>Aortogram 1+—4+</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.P.</td>
<td>AI</td>
<td>3.23</td>
<td>4.1</td>
<td>1.85</td>
<td>2.3</td>
<td>19.9</td>
<td>4</td>
<td>4</td>
<td>110 (58)</td>
<td>130 (74)</td>
<td>11</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>M.M.</td>
<td>MS mi</td>
<td>3.3</td>
<td>3.68</td>
<td>2.1</td>
<td>2.35</td>
<td>17.2</td>
<td>122</td>
<td>5</td>
<td>2</td>
<td>94 (68)</td>
<td>114 (76)</td>
<td>11</td>
<td>0</td>
<td>4+</td>
</tr>
<tr>
<td>M.C.</td>
<td>AS si</td>
<td>4.7</td>
<td>4.8</td>
<td>2.3</td>
<td>2.4</td>
<td>32.4</td>
<td>71</td>
<td>9</td>
<td>5</td>
<td>95 (90)</td>
<td>140 (87)</td>
<td>73</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A.F.</td>
<td>AS Complete heart block</td>
<td>3.2</td>
<td>3.3</td>
<td>1.8</td>
<td>26.9</td>
<td>67</td>
<td>4</td>
<td>1+</td>
<td>185 (76)</td>
<td>185 (112)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>M.R.</td>
<td>AI MI</td>
<td>2.0</td>
<td>3.56</td>
<td>1.1</td>
<td>2.20</td>
<td>16.9</td>
<td>95</td>
<td>10</td>
<td>145 (84)</td>
<td>140 (71)</td>
<td>131</td>
<td>0</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>L.P.</td>
<td>AI</td>
<td>4.9</td>
<td>4.0</td>
<td>3.0</td>
<td>3.49</td>
<td>80</td>
<td>6</td>
<td>1+</td>
<td>131 (72)</td>
<td>131 (72)</td>
<td>131</td>
<td>0</td>
<td>4+</td>
<td>0</td>
</tr>
<tr>
<td>M.P.</td>
<td>AS si</td>
<td>4.0</td>
<td>4.0</td>
<td>2.47</td>
<td>7.5</td>
<td>110</td>
<td>10</td>
<td>4</td>
<td>119 (74)</td>
<td>119 (73)</td>
<td>46</td>
<td>0</td>
<td>2 to 3+</td>
<td>3</td>
</tr>
</tbody>
</table>

*Left ventricular end-diastolic pressure.

**Heart Rate.

AI — major aortic insufficiency  
MS — major mitral stenosis  
mi — minor mitral insufficiency  
AI — minor aortic insufficiency  
ms — minor mitral stenosis  
AS — major aortic stenosis  
T5 — major tricuspid stenosis  
MI — major mitral insufficiency

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third postoperative day he was transferred to another hospital for possible dialysis but he died before this could be accomplished. Postmortem examination showed severe coronary atherosclerosis and massive left ventricular myocardial infarction.

Six months after valve replacement, each surviving patient was subjected to hemodynamic studies and aortography. There are now seven patients in this group (Table 2). Cardiac output, cardiac index and stroke index have all improved over preoperative values and in most cases are near normal limits. In all patients a soft aortic systolic murmur could be heard at the time of discharge from the hospital. Six months later, however, this murmur has become either very slight or has completely disappeared (Fig 1). There was no pressure gradient across the heterograft valve in any case (Fig 2A and 2B). Brachial artery pressure curve measurement showed a normal range of diastolic pressure. On only one patient did the retrograde aortogram show slight aortic incompetence. The rest of the studied patients showed competent heterograft valves (Fig 3).

All the patients showed marked clinical improvement. Chest roentgenograms showed decrease in heart size. The most dramatic improvement was seen in the patients in whom only the aortic valve was diseased (Fig 4). Except for those patients in whom the mitral valve was replaced with a mitral valve prosthesis, none was placed on anticoagulant therapy postoperatively. No incidence of thromboembolism was seen.

DISCUSSION

The calf valves used in this study were obtained from freshly slaughtered three to six month-old
calves. Meticulous trimming of excess tissues was performed under a magnifying glass. Even with
great care, a rough surface is left on the areas where myocardium is attached to the undersurface
of the cusps (Fig 5). This surface, exposed to the rapid aortic ejection stream may be the cause of
the systolic murmur heard in the immediate post-operative period and at the time of discharge from
the hospital. The disappearance of the same murmur after six months may be due to the formation
of pseudo-intima over the rough surface. The complete absence of valvular obstruction is shown by
the absence of any systolic pressure gradient across the heterograft at the time of postoperative cardiac
catheterization.

The fully trimmed preserved heterograft valve is a virtual prosthesis. The cusps are the only essen-
tial moving parts. Therefore, excess aortic wall tissue and muscle were removed from the ventricular
aspect as close to the line of cusp attachment as is possible. On the aortic aspect, only 2 to 3 mm of
aortic wall is retained as a sewing rim. A No. 5
braided Dacron is sutured with a whip stitch of
No. 6-0 Polydek* to the scalloped aortic rim (Fig
6). This was done for two reasons: to reinforce the
sewing rim of the graft and to promote capture of
the braided material by the recipient. It was hoped
that tissues would grow into this area to firmly an-
chor the heterograft valve in place.

The finished fully trimmed heterograft is stored
in 4 percent formaldehyde solution buffered to a
pH of 5.6 as recommended by O'Brien.\textsuperscript{19} This
serves the twofold purpose of sterilization and pres-
ervation. No valve is used after four months from
the day of final trimming.

In the process of establishing the calf aortic het-
terograft bank, it became obvious that although va-
rious sizes were available, the largest obtainable
calf valve was comparable to only a No. 11 or at
most a No. 12 Starr-Edwards aortic valve prosthesis. This posed a problem for the patient who would
require a valve larger than these sizes. This prob-
lem was solved by a modification in the technique
of insertion (Fig 7).

In patients with aortic insufficiency, the aortic
root is also invariably large. Their aortic cusps are
seldom severely calcified. The leaflets are either
fibrotic and curled at the edges or of uneven length
which results in at least one sagging cusp. After
excision of the deformed leaflets, the aortic root can
be narrowed to conform to the size of the largest
available heterograft valve. This is accomplished by
uplicating adjacent cusp remnants in the commissu-

\*Deknatel, Queens Village, L. I., New York.

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eral areas. Interrupted sutures of No. 2-0 Tevdek are used. Bites are taken to include not only the cusp remnant but also the tough tissues at the attachment of the cusp to the aortic wall. Usually three sutures 2 to 3 mm apart at each angle suffice to narrow the aortic opening to the desired size. Valve implantation is then carried out by the usual technique.

The human host apparently can tolerate the calf aortic valve heterograft as well as it tolerates the homograft valve. In the subcoronary position, it functions as effectively, if not better than the homograft valve. This is shown by our postoperative studies performed six months following valve implantation. Since calf valves of varying sizes can be easily procured in any number, there is no logistical problem such as is anticipated with the homograft valve. A heterograft valve bank can therefore be established in a very short period of time even if the preparation of the valve is meticulous and time consuming.

Regardless of the good results seen in this study, however, the period of follow-up is still short. And as McGoon stated in a recent symposium, the important parameter, the element of time, is inadequate thus far in studies involving either the homograft valve or the heterograft valve. The patients in this series will be carefully followed in the hope that we can help supply the answer to the last remaining question of whether the heterograft valve will continue to function as efficiently for an indefinite period of time.

References

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