OBJECTIVES
This study evaluated the long-term follow-up results of balloon angioplasty (BA) in adolescent and adult patients with discrete coarctation of the aorta.

BACKGROUND
Although the immediate and intermediate term results of BA for patients with aortic coarctation (AC) have been encouraging, there is a paucity of data on long-term follow-up results.

METHODS
This basis of this study was follow-up of 49 patients (mean age, 22 ± 7 years) undergoing BA for discrete AC at median interval of 10.2 years, including cardiac catheterization, magnetic resonance imaging, and Doppler echocardiography.

RESULTS
No early or late deaths occurred. Balloon angioplasty produced a reduction in peak AC gradient from 66 ± 23 mm Hg (95% confidence interval [CI]: 59.5 to 72.7) to 10.8 ± 7 mm Hg (95% CI: 8.8 to 12.5) (p < 0.0001). Follow-up catheterization 12 months later revealed a residual gradient of 6.2 ± 6 mm Hg (95% CI: 4.4 to 7.9) (p < 0.001). Four patients (7.5%) with suboptimal initial outcome with peak gradient ≥ 20 mm Hg had successful repeat angioplasty. Aneurysm developed at the site of dilation in four patients (7.5%). Magnetic resonance imaging follow-up results revealed no new aneurysm or appreciable changes in the size of pre-existing aneurysms, and no recoarctation was observed. Also, no appreciable changes in the Doppler gradient across the AC site were noted. The blood pressure had normalized without medication in 31 (63%) of the 49 patients.

CONCLUSIONS
Long-term results of BA for discrete AC are excellent and should be considered as first option for treatment of this disease. (J Am Coll Cardiol 2004;43:1062–7) © 2004 by the American College of Cardiology Foundation

Surgery for coarctation of the aorta was first described in 1945 (1). Since that time, several surgical procedures have been advocated, each associated with a variable risk of restenosis or aneurysm formation (2–8). Balloon angioplasty (BA) has been added as a viable alternative to surgery in 1982 (9), and it is currently considered to be a safe and effective treatment option for coarctation. With encouraging immediate- and intermediate-term results (10–19), we have previously reported intermediate follow-up results at a mean 5.2 years (18), but reports on long-term results are scarce (20). The purpose of this study is to report on long-term follow-up results of up to 15 years in a sizeable series of patients with native coarctation of the aorta undergoing BA. To our knowledge, this is the longest follow-up series reported in this group of patients.

METHODS

Study subjects. Between July 1986 and July 2001, 60 consecutive adolescent and adult patients with native coarctation of the aorta were seen at King Faisal Specialist Hospital; 6 patients were referred to surgery, 3 of whom had a long tubular coarctation segment, and the remaining 3 patients had interrupted aortic arch. The remaining 54 patients with discrete coarctation underwent BA.

The indication for dilation included angiographic evidence of significant discrete coarctation or a coartation pressure gradient > 20 mm Hg or both at cardiac catheterization in addition to systemic hypertension not controlled by medical treatment. All demographic, hemodynamic, echocardiographic, and magnetic resonance imaging (MRI) follow-up data were encoded in a prospective database program.

Initial evaluation. Clinical evaluation before angioplasty included right arm blood pressure (BP) measurement, chest radiograph, 12-lead electrocardiogram, and echocardiographic examination with measurement of the Doppler gradient across the coarctation.

BA technique. The technique used for BA has been previously reported (11,18). An angioplasty balloon is selected with a diameter equal to that of the isthmus or 1 to 2 mm smaller than the diameter of the descending thoracic aorta at the level of the diaphragm. After heparin 2,000 IU was given intravenously, the angioplasty cath-
Aortic pressure above Co site, mm Hg 170/110

Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Before BA</th>
<th>Immediately After</th>
<th>p Value</th>
<th>12 Months Later</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic pressure above Co site, mm Hg</td>
<td>170 ± 21</td>
<td>132 ± 16.5</td>
<td>&lt;0.0001</td>
<td>130 ± 15.7</td>
<td>0.19</td>
</tr>
<tr>
<td>Catheter Co gradient, mm Hg</td>
<td>66 ± 23</td>
<td>10.8 ± 7</td>
<td>&lt;0.0001</td>
<td>6.2 ± 6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Doppler gradient, mm Hg</td>
<td>57.6 ± 17.7</td>
<td></td>
<td></td>
<td>16 ± 8.4</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

BA = balloon angioplasty; Co = coarctation.
gradient decreased to 5 to 15 mm Hg and remained low at repeat catheterization 12 months later. The fourth patient, in whom the morphology of coarctation in a biplane aortogram at restudy one year later was deemed unsuitable for angioplasty (Fig. 1), underwent surgical repair. This was the only patient who had single-plane aortogram at the initial dilation.

Aneurysm. The follow-up angiogram and MRI at one year after dilation were scrutinized for aneurysm at the site of BA. A total of four aneurysms were observed both on angiography and MRI, giving an incidence of 7.8%. The aneurysms were very small bulge in three patients measuring 2 to 2.3 cm in diameter. The fourth patient, who had a 4-cm aneurysm, underwent surgical repair. None of the aneurysms could be detected on chest X-ray film.

Long-term follow-up results. Two patients of the 51 underwent surgery at one year after dilation. One patient had aneurysm, and the other had suboptimal initial outcome. The remaining 49 patients were followed-up for a median of 10.2 (9.1 ± 4.4) years; 25 patients were followed-up for a median of 13.4 (mean ± SD 12.9 ± 1.4); range, 10.2 to 15.3 years.

MRI. The site of previous coarctation is shown to be well-dilated in all 49 patients (Fig. 2). No significant changes in the diameter of the aorta at the site of coarctation at one year (13.5 ± 3.1 mm [95% CI: 12.5 to 14.4]) and at the last follow-up (13.9 ± 3.3 mm [95% CI: 13.0 to 14.9]) was noted. There is agreement between these two values using the Bland and Altman method (p = 0.43) (Table 2).

Aneurysms. Follow-up MRI studies revealed no new aneurysm at the site of angioplasty or appreciable change in the size of the pre-existing aneurysms (Fig. 3).

Doppler coarctation gradient. The Doppler coarctation gradient decreased slightly at the last follow-up in comparison with the value at one year after dilation from 16.0 ± 8.4 mm Hg (95% CI: 13.6 to 18.5) to 13.0 ± 6.9 mm Hg (95% CI: 11 to 15.0) (p < 0.01) (Table 2). This was most probably due to the remodeling of the aorta after angioplasty.

Normalization of BP. The BP was normal (<140/90 mm Hg) without medication in 31 patients (63%). The remaining patients required one or two medications to control their BP.

DISCUSSION

This study has demonstrated excellent long-term results of BA in adolescents and adults with discrete native coarctation of the aorta, and we propose that it should be used as a first option for the treatment of this disease.

Coarctation restenosis. Recoarctation is a common complication after angioplasty and surgical repair in infants and children (2,4), in whom recoarctation rate after angioplasty may range from 15% to 30% (16,22,23). Recoarctation is infrequent in adults. Several investigators reported no recoarctation after angioplasty in adult patients (17,19,20). A finding that is corroborated by our study, however, we encountered suboptimal initial outcome in four patients (7.8%); in three patients, an undersized balloon catheter had been used in initial dilation. These three patients underwent repeat angioplasty with appropriate-sized balloon catheter, and results were satisfactory and have remained so. The fourth patient who had unsuitable morphology, discovered after performing biplane aortogram one year after dilation, underwent successful surgical repair. No recoarctation was observed on long-term follow-up using MRI; we previously demonstrated the accuracy of MRI in diagnosing recoarctation in comparison to angiography (24). Also, there was no change in the diameter of the coarctation site at median follow-up of 10.2 years after angioplasty compared with that at one year. The Doppler gradient at the site of coarctation decreased slightly at the last follow-up compared with one year after dilation probably due to remodeling of the aorta.
Aneurysm formation. Aneurysm formation at the dilation site has remained a long-term concern. Although early studies by Cooper et al. (25) and Brandt et al. (26) reported high incidence of aneurysm formation, most investigators have reported aneurysm formation incidence varying between 1.8% to 6% (12–14,27,28), which is consistent with our result (7.8%). No aneurysms were encountered by Koerselman et al. (17) and Walhout et al. (19). Three of the four aneurysms in the present series were small bulges, nondetectable on chest radiography and without an appreciable change in size at follow-up MRI up to 14 years.

Media tear and cystic medial necrosis have been postulated as potential causes of aneurysm formation (9,29,30). It has been suggested that aneurysm development may be caused by the use of an oversized balloon or misinterpretation of native anatomic irregularities in the aortic contour as aneurysm (31). Two of our four patients who had aneurysm were treated with larger balloon catheter. However, one patient developed a 4-cm aneurysm despite the fact that an appropriate-sized balloon catheter was used for angioplasty. Although development of aneurysm after BA is of concern, aneurysms are also known to develop after surgical repair of coarctation especially after patch aortoplasty, with incidence varying from 9% to 30% (2–8). The postsurgical aneurysms are defined as a ratio >1.5 of the repair site to the descending aorta at the level of the diaphragm (5,6). Close follow-up is required for patients with or without aneurysms, and we found that MRI is a reasonable, noninvasive imaging modality for long-term monitoring.

Figure 2. Serial magnetic resonance imaging (A) five years after balloon angioplasty, (B) 10 years after balloon angioplasty, (C) 15 years after balloon angioplasty, and (D) magnetic resonance angiography 15 years after balloon angioplasty of the same patient. Note that the site of previous coarctation (arrow) is well dilated, with no change in the diameter of the aorta at coarctation site.

Table 2. Echocardiographic and MRI Intermediate and Long-Term Results

<table>
<thead>
<tr>
<th>Parameters</th>
<th>12 Months After BA</th>
<th>Long-Term Follow-Up (Median = 10.2 Years)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of Co site measured on MRI, mm</td>
<td>13.5 ± 3.1</td>
<td>13.9 ± 3.3</td>
<td>0.43</td>
</tr>
<tr>
<td>Doppler Co gradient, mm Hg</td>
<td>16 ± 8.4</td>
<td>13 ± 6.9</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

BA = balloon angioplasty; Co = coarctation; MRI = magnetic resonance imaging.
persistent hypertension, the residual gradient was \( /H11349 \). The incidence of late hypertension after surgical repair of coarctation was long-term. Hypertension in the absence of residual coarctation angioplasty (24). Blood pressure came down to normal in 63% of our patients without medication. These findings concur with those of Schrader et al. (27) who reported a 79% rate of normalization of BP after angioplasty and Walhout et al. (19) who encountered hypertension requiring medication in six of 18 adult patients (33%). Contrary to the findings of Schrader et al. (27), we found no relation between persistence of hypertension and a residual gradient \( \leq 30 \) mm Hg. In our 18 patients with persistent hypertension, the residual gradient was \( \leq 20 \) mm Hg. We previously demonstrated that patients in whom BP became normal after angioplasty also had a normal response of BP to exercise, and regression of left ventricular hypertrophy (32). Hypertension in the absence of residual coarctation appears to be related to the duration of preangioplasty hypertension, which can be explained by insufficient resetting of the baroreceptors after angioplasty (19). The incidence of late hypertension after surgical repair of coarctation in adults varies between 33% to more than 50% (2,33,34).

**Comparison with stent implantation.** The indications for stent implantation are not clearly defined (35). Possible indications include long segment and tortuous coarctation, and recurrent aortic coarctation (AC) after surgical repair. We did not attempt balloon dilation of such patients. Recoarctation is rare in adult and adolescent patients with discrete coarctation treated by BA. The incidence of aneurysm formation after stent implantation reported by Suarez de Lezo et al. (36) at mean of 25 months follow-up was 7%, an incidence similar to that of BA. We think there is no role for stent implantation for discrete native coarctation in adolescent and adult patients.

Compared with surgery, BA offer less burden to the patient, with short in-hospital stay varying from one to two days. This also applies to the financial costs of the angioplasty that are relatively low (37).

**Conclusions.** This study demonstrated excellent long-term results of BA for native discrete coarctation in adolescent and adult patients, when compared against historical control subjects. The results of BA compare favorably with reported results of surgical repair and are associated with less morbidity and lower cost. We recommend BA as the first option for treatment of discrete coarctation in adolescent and adult patients.

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**References**