Congenital Mitral Stenosis With or Without Associated Defects
An Evolving Surgical Strategy

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Background—Congenital mitral stenosis (CMS) remains a surgical challenge, particularly when it is associated with other heart defects. As in other groups of heart defects, there is a trend toward early single-stage complete repair, but the optimal surgical approach remains unanswered.

Methods and Results—This study was designed to analyze the evolution of surgical strategies in patients with CMS and associated defects through single-stage and staged repair. Between 1980 and 1999, 72 children were operated on for congenital heart defects, including CMS. Preoperative transmitral gradient was 12.6 ± 7 mm Hg. Preoperatively, all the patients were NYHA class III to IV. Thirteen patients had an isolated CMS; in 59, it was associated with other heart defects, mainly ventricular septal defect (n = 28) or multilevel left ventricular obstruction (n = 41). In this group of patients, 33 had a staged approach, and 26 had a single-stage approach. Early mortality was 12.5% (9 patients). There were no deaths in the isolated CMS and single-stage repair groups. Logistic regression revealed that early mortality was influenced by association with left ventricular outflow tract obstruction (P < 0.001) and by use of a staged approach (P < 0.01). There was no late mortality in isolated CMS; there were 2 late deaths in the group of single-stage repair and 6 late deaths in the staged approach group (P < 0.01). Reoperation was required in 24 patients, mainly for residual mitral valve dysfunction or residual left ventricular outflow tract obstruction. Including the reoperations, 10 patients received a prosthetic mitral valve. At 15 years after surgery, survival was 69.6 ± 7.5%, freedom from reoperation was 70.8 ± 6.3%, and freedom from mitral valve replacement was 69 ± 6%.

Conclusions—Surgery for isolated CMS gives excellent early and long-term results. In patients with associated heart defects, a single-stage operation seems superior to a staged approach. Mitral valve replacement in this category of patients should be reserved as a salvage procedure. (Circulation. 2000;102[suppl III]:III-166-III-171.)

Key words: mitral valve n stenosis n surgery n pediatrics

Infants with symptomatic congenital mitral stenosis (CMS) remain a therapeutic challenge.1-3 From a surgical point of view, CMS presents particular technical problems because of a wide spectrum of malformations, a high prevalence of associated lesions, and the relatively limited experience in each institution.4,5 On the other hand, the use of prosthetic valves has been disappointing in children; therefore, all efforts had to be focused on a conservative approach.6 When symptomatology occurred early in life, the early policy was to treat the assumed cause of disability, namely the mitral valve stenosis, and to delay complete repair of eventual associated heart defects. In young children, because exposure of the mitral valve apparatus might be difficult, the reparative procedure is oriented more toward increasing surface valve area rather than reconstructing an anatomic mitral valve. This approach, although palliative, is thought to increase the flow in the left ventricle and therefore to improve cardiac output.

In the recent era, with the evolution of diagnostic tools and the considerable improvements in perioperative management, single-stage complete biventricular repair has been proposed as feasible for most congenital heart defects having 2 suitable ventricles. Because in patients with CMS and associated lesions it is still very difficult to define which of the cardiac lesion is the cause of the symptoms, we switched our strategy to single-stage repair in this cohort of patients in an attempt to correct all the cardiac lesions and to restore a normal cardiac output. Although comparison between 2 surgical strategies that are nonsynchronous and nonrandomized is impossible, this retrospective study tries to analyze the different outcomes of the switch in surgical strategy for infants having surgery for congenital heart defects, including CMS, by either staged or single-stage complete repair.

Methods

Between January 1980 and September 1999, 72 infants were referred to our institution for surgery of heart defects, including CMS. Left AV valve stenosis associated with AV septal defects, class IV hypoplastic left ventricle, univentricular AV connection, and ac-
quired mitral valve stenosis was excluded from this study. This study analyzes only the patients who underwent surgical mitral stenosis relief.

CMS was diagnosed when a small, abnormal-appearing mitral valve apparatus was demonstrated on 2-dimensional echocardiography.\textsuperscript{7,8} The mitral valve anteroposterior diameter was obtained from the parasternal long-axis view. The observed mitral valve diameter was then standardized to the Z value by this equation:\textsuperscript{9} \( Z = \log (\text{observed dimension}) - \log (\text{mean normal dimension})/\text{SD of the mean normal dimension} \), where the normal dimension was obtained from previously published work normalized to body surface area.\textsuperscript{10} Surgical intervention was considered when the peak instantaneous transmitral gradient was >10 mm Hg at echo Doppler. Because of the frequent association of an atrial septal defect, the transmitral gradient alone was not the single criterion for judgment of the severity of the CMS; therefore, all patient files were reviewed for clinical condition, hemodynamic investigation if any, and echocardiographic records.

There were 38 boys and 52 girls. The median age at surgery was 18 months (range, 1 to 228 months), and the median weight was 8.25 kg (range, 3 to 60 kg). Twenty patients were <3 months of age, 32 were <1 year, 17 were between 1 and 2 years, 11 were between 2 and 5 years, and 12 were >5 years. Preoperative status was significantly impaired in most patients with pulmonary edema and failure to thrive: 12 were in NYHA class II, 37 were in class III, and 23 were in class IV. Only 1 patient was already under ventilatory support, but all patients were treated by antifailure therapy. Previous catheterization was performed in 41 patients; the mean pulmonary artery pressure was 48.8 ± 16.5 mm Hg, mean capillary pressure was 21 ± 0.5 mm Hg, and mean pulmonary arterial resistance was 5.1 ± 3.35 U/l/m\textsuperscript{2}.

Echocardiographic evaluation was performed through the parasternal and subxiphoid views to assess the mitral valve and associated defects. The mean anteroposterior mitral valve diameter was 11.6 ± 4.3 mm, and the mean Z value was −0.94 ± 0.8. Thirteen patients had isolated CMS, and 59 had associated heart defects. Anatomic description according to the Ruckman–Van Praagh\textsuperscript{11} classification was difficult mainly because several mitral valve apparatus lesions were associated in each patient. Therefore, the Chauvaud et al\textsuperscript{12} classification was preferred because it is based on both anatomy and function. Thirty-three patients presented with mitral stenosis and normal papillary muscles. It consisted of commissural, chordal, and papillary muscular fusion, 29 of whom had also a supravalvular ring originating from the atrial surface of the mitral leaflets (Figures 1 and 2). Within this group, 21 patients had the typical mitral stenosis of Ruckman–Van Praagh,\textsuperscript{11} and 4 patients had a double-orifice mitral valve with 2 separate mitral orifices. Thirty-nine patients had mitral stenosis with abnormal papillary muscles. The main pathological finding in this group was a parachute mitral valve in 32 with either a single papillary muscle or an asymmetrical parachute mitral valve associated with hypoplasia of 1 muscle and hypertrophy of the other papillary muscle, with most of the chordae inserting on the top of the latter. Seven patients presented with hammock mitral valve. In the whole group of patients, only 4 had a severe hypoplastic mitral valve annulus with a Z value below −2. At echo Doppler, the mean transmirtal gradient was 12.6 ± 7 mm Hg.

Associated lesions were demonstrated in 59 patients (the Table). A ventricular septal defect (VSD) was present in 28 patients, and 41 had multilevel left heart obstruction with aortic stenosis in 23, subaortic stenosis either membrane or tunnel in 23, and coarctation of the aorta in 32. Twenty-five patients were categorized as having Shone’s syndrome.\textsuperscript{13} Left ventricular dimensions were initially assessed by measurement of the end-diastolic left ventricular diameter and more recently by end-diastolic left ventricular volume. Seventeen patients had a non–apex-forming small left ventricle with an end-diastolic LV diameter <13 mm or an end-diastolic LV volume <20 mL/m\textsuperscript{2}.

Surgery
The goal in mitral valve repair was to restore a widely patent and competent pathway between the inflow and outflow tracts of the left ventricle. Intraoperative exploration of the valve allowed recognition of the different components causing obstruction.\textsuperscript{12} A supravalvular ring was resected in 29 patients; papillary fusion was treated by fenestration and splitting. Short chordae were also treated by splitting incisions in the papillary muscle. Parachute mitral valve was treated by splitting of the single papillary muscle as far as possible into the left ventricular cavity. It was associated with fenestration of chordae in most cases. In 1 patient, splitting of the papillary muscle was performed through an apical left ventriculotomy. Hammock valve was one of the most difficult lesions to repair. Here again, splitting the subvalvular muscle was performed to individualize 2 papillary muscles and chordae. All repairs were assessed by use of a matched Hegar dilator and by evaluation of iatrogenic mitral insufficiency. More recently, all repairs are assessed by intraoperative transesophageal echocardiography. Seven patients had at first procedure a mitral valve replacement, and 1 had a valved conduit inserted between the left atrial appendage and the apex of the left ventricle.\textsuperscript{14,15} (Figure 3). In patients with associated heart defects, the staged approach was defined when several intracardiac defects were necessary to eventually obtain complete repair. This was achieved through a first operation that addressed aortic and/or subaortic stenosis through either closure of intracardiac shunts or mitral stenosis relief; the remaining cardiac defects were then treated in a second operation.

**Figure 1.** Transesophageal echocardiographic view of mitral supravalvular ring causing inlet obstruction. Mean transmirtal gradient was 18 mm Hg. LA indicates left atrium; RA, right atrium, MV, mitral valve; LV, left ventricle; and RV, right ventricle.
Single-stage operation was defined when all intracardiac defects were treated in a single operative session. Before mitral valve stenosis repair, 26 patients received different types of cardiovascular procedures. Twenty had coarctation repair either alone through a left thoracotomy or in association with VSD closure in 1 or with aortic commissurotomy in 1. Three patients had previous VSD closure, and 3 had aortic commissurotomy. Two additional patients underwent previous pulmonary artery banding. Finally, 7 patients had a “palliative mitral stenosis relief” that left the other defects untouched.

Seventeen patients had associated left ventricular outflow tract obstruction (LVOTO) relief by means of subaortic membrane resection in 11, septal myotomy in 8, aortic commissurotomy in 11, or associated coarctation repair in 8. Eighteen patients had also associated VSD closure. Altogether 26 patients with associated defects other than mitral valve stenosis received a single-stage repair, 33 received a staged approach.

Follow-Up
All the survivors were regularly reviewed by their referring cardiologist, achieving a median follow-up of 93 months (range, 3 to 220 months). Particular attention was given to the function of the mitral valves and left ventricular outflow tract.

Statistical Analysis
Data are expressed as mean values ±70% CLs. Time-related events were examined by Kaplan-Meier actuarial methods. Comparisons between these curves were performed by the log-rank test. Risk factors for early and overall mortality, as well as for recurrent mitral stenosis and reoperation, were assessed by univariate analysis. Student’s t test was used for continuous variables, and the χ² test was used for dichotomous variables. Multivariate logistic regression was used to assess independent factors affecting early mortality. Cox regression model was used to assess independent factors affecting long-term survival and reoperation.

Results
Mortality
There were 9 early deaths (12.5%; 70% CL, 8.1 to 17.9). In 2 patients, death was due to severe residual mitral stenosis. Both patients presented with multilevel left ventricular obstruction and small mitral valve annulus. Five patients died in the postoperative course of intractable paroxysmal pulmonary hypertensive crisis. These deaths occurred before the era of nitric oxide. Finally, 2 patients died of low cardiac output without apparent residual anatomic lesions. Among the patients who did not survive, endocardial fibroelastosis was found in 4. Within the group of patients with isolated CMS, early postoperative mortality was 0% (70% CL, 0 to 13.7), whereas in the group with CMS associated with other heart defects, postoperative mortality was 15.25% (70% CL, 10 to 21.6; P=NS). Within the latter group of patients, 26 patients received a single-stage repair with a postoperative mortality of 0% (70% CL, 0 to 7.15), and 33 did not with a postoperative mortality of 24.2% (70% CL, 15 to 34; P<0.05). Univariate analysis revealed that association with LVOTO (P<0.0001), Shone’s syndrome (P<0.005) and age <3 months (P<0.005) were significant risk factors for early mortality. In addition, nonsurvivors tended to have higher
levels of preoperative pulmonary hypertension ($P=0.05$) and smaller mitral valve annular diameters ($P=0.009$). Finally, single-stage repair was associated with better outcome ($P=0.008$). At multivariate logistic regression, only associated LVOTO ($P=0.001$) and staged repair ($P=0.03$) were independent risk factors for early mortality.

**Late Mortality**

There were 8 late deaths, giving an overall mortality of 23.6% (70% CL, 18 to 30). Of the 8 late deaths, 6 were related to either residual mitral stenosis or previous mitral valve mechanical prosthesis replacement. It is noteworthy that 2 of these patients had also endocardial fibroelastosis. One patient died after reoperation for Swiss cheese form of multiple VSDs, 1 died 10 years after reoperation for residual subaortic stenosis, and the other died of an unknown cause. In the group with isolated CMS, there were no late deaths; in the group with single-stage repair, there were 2 late deaths; and in the group with the staged approach, there were 6 late deaths. Actuarial survival rates at 5, 10, and 15 years after surgery were 78.3±5.2%, 78.3±5.2%, and 69.6±7.5%, respectively. Survival curves were constructed for each group of surgical strategy. At 15 years after surgery, survival rates were 100%, 85.7±10%, and 41.5±14.3% for isolated CMS single-stage repair and staged repair, respectively ($P<0.01$, 1-stage versus staged repair) (Figure 4). The Cox model was applied to analyze the potential risk factors for long-term survival. Again, staged approach repair was recognized as an independent risk factor for long-term mortality. There were, however, no independent risk factors for reoperation.

**Reoperations**

Twenty-four patients underwent 34 reoperations, 19 of which were related to a residual mitral valve dysfunction. Ten had residual or recurrent isolated mitral stenosis, 3 had mitral insufficiency, 4 had combined mitral stenosis and LVOTO, 5 had isolated LVOTO, and 2 had mechanical mitral valve prosthesis displacement or thrombosis. Second mitral valve repair was performed in 10 patients; 9 patients had a mechanical mitral valve replacement. Residual or recurrent LVOTO was treated by myectomy in 4 patients, by a Ross-Konno procedure in 2, and by an aortic valve replacement in 1. Finally, 1 patient had a reoperation for multiple VSDs. A second reoperation was necessary in 8 patients for residual mitral valve stenosis in 1 or insufficiency in 1, for dysfunction of mitral valve prosthesis in 3, for residual subaortic stenosis in 1, for an aortic insufficiency in 1, and for prosthetic endocarditis in 1. At the second operation, a mechanical mitral valve prosthesis was inserted in 5, a Ross-Konno procedure was performed in 1, an aortic root replacement with aortic valve replacement was performed in 1, and aortic valve replacement was done in 1 patient. Two patients required a third reoperation for thrombosed mitral valve prosthesis and aortic prosthetic endocarditis. Overall mortality at first and second reoperation was 25% (6 patients). Actuarial freedom from reoperation at 5 and 10 years was 77.2±5.5% and 70.8±6.3%, respectively. Again, actuarial curves of freedom from reoperation were constructed for each group; however, no difference was observed between groups (Figure 5). Actuarial freedom from mitral reoperation at 10 years was 58±7%, and freedom from prosthetic mitral valve replacement was 69±6%.

**Follow-Up**

A median follow-up of 93 months (range, 3 to 220 months) was achieved in all survivors. The majority (90%) were in NYHA class I to II. The mean transmural gradient at echo Doppler was 2.16±3 mm Hg. Twenty-two patients had mild mitral regurgitation, and 3 had a residual transmural gradient >8 mm Hg. One patient with a valved conduit between the left atrial appendage and the apex of the left ventricle had...
conduit stenosis and progressively developed an anterograde flow through the native mitral valve. This patient is awaiting reoperation.

Discussion
From this study, it can be suggested that progressing from a multiple-stage to a 1-stage surgical approach in infants born with CMS and associated defects has considerably improved results in terms of early mortality and morbidity and long-term outcome. Although tempting, statistical comparison between these 2 surgical strategies is a source of bias, and the results should not be misinterpreted.

Initially, because of a lack of understanding of the physiology of left ventricular performance and a lack of appropriate diagnostic tools and surgical techniques, palliative procedures were generally used to treat infants with complex congenital heart defects. Although these approaches gave satisfactory results for several heart lesions, some particular situations seem not to hold to this concept. Patients with left ventricular inlet obstruction through a mitral stenosis present 2 basic pathophysiological mechanisms: an unloaded left ventricle with inadequate cardiac output and post-capillary pulmonary hypertension. The latter is also responsible for right ventricular enlargement, which can also jeopardize left ventricular function.

When this lesion is isolated, restoration of a widely patent and competent left ventricular inlet by means of mitral valve repair generally allows the left ventricle to sustain postoperative systemic cardiac output with normalization of pulmonary pressures. However, when it is associated with other heart defects, either obstructive lesion to the left ventricular outflow or a shunting lesion, correction of only 1 lesion does not permit the left ventricle to work at its optimal condition. Indeed, closure of a ventricular left-to-right shunt leaving a mitral stenosis untouched is associated with a potential reduction in pulmonary artery pressure but also a drastic volume reduction in the left ventricle. Relief of an LVOTO without relief of an inlet left ventricular obstruction is associated with an increase in inadequate loading conditions of the left ventricle. On the other hand, relief of a mitral stenosis without closure of a VSD or without relief of an LVOTO will be associated with either an increased Qp/Qs or an increased preload to the left ventricle. All these conditions are far from the expected postoperative physiology, which tends to normalize the Qp/Qs and the loading conditions of the left ventricle. From these considerations, the single-stage approach in which all lesions are addressed in a single operative session was developed and has proved to be effective in our patient population. This trend in improved early results continued even in the long-term follow-up in terms of survival, and the single-stage approach also has proved to have a significant positive effect on long-term survival. However, in terms of reoperation, we were not able to find any difference between the staged approach group and the single-stage group. Indeed, we have found in several patients that relief of mitral valve stenosis can unravel staged obstruction within the left ventricular outflow tract.

There was, however, a bias in our population. Only patients who received mitral surgery at any stage of their disease were selected, which excludes those having some degree of mitral stenosis but for whom the transmural gradient was not considered high enough to indicate surgery. In this category of patients, we still propose a conservative approach, meaning no mitral surgery, but with very close follow-up to allow intervention when the transmural gradient rises to >10 mm Hg or when pulmonary hypertension appears.

Surgical techniques allowing relief of mitral stenosis have been very well established by Chauvaud and colleagues. Very early in this series, these techniques were not followed closely because it was assumed that a small increase in mitral valve diameter would considerably increase the effective surface valve area. Therefore, at that time, the main objective was to increase mitral valve diameter and to avoid significant mitral insufficiency. Although this technique gave satisfactory results, with the recent improvements in diagnostic echocardiography and surgical exposure, the lesions can be addressed directly, and surgery can attempt to restore a nearly normal anatomy of the mitral valve apparatus. We were not able in this series to compare the different types of mitral surgery and to find out whether one is statistically associated with higher morbidity than the other. Because these techniques evolved with time, the time effect on the results was also analyzed and was not recognized as an independent risk factor. On the other hand, the reoperation rate and late mortality were associated with a high degree of residual mitral stenosis, particularly at the beginning of the experience, and we believe that although not statistically proved, these results are associated with less-than-optimal repair of the mitral valve apparatus. We would therefore propose even in very young patients an approach that will attempt to reconstruct an anatomic mitral valve apparatus as closely as possible. In only 1 recent 2-month-old patient with a parachute mitral valve, the transatrial exposure to the mitral valve was very difficult; therefore, an apical left ventriculotomy as described by Barbero-Marcial et al was used to divide the single papillary muscle. However, even this approach did not give satisfactory results, with a residual transmural gradient >15 mm Hg. A valved conduit between the left atrial appendage and the apex of the left ventricle was therefore used to bypass the mitral stenosis.

In the whole series, several parameters were significant risk factors for early mortality at univariate analysis: Shone’s complex, early presentation and surgery, and a smaller mitral valve annular diameter. Although we were not able to find a clear cutoff size for mitral valve diameter, we intuitively believe that in patients with spontaneous or maintained ductal patency by prostaglandin E1 and multiple left heart obstruction, if the Z value of the mitral annulus is between −3 and −2, they would be better managed by a Norwood stage I operation.

Balloon dilatation was not performed in our patients because early surgical results gave initial satisfaction and mainly because during direct vision of the valvular and subvalvular lesions, none were believed to be an anatomic substrate for improvement after dilatation.

Finally, mitral valve replacement, as in other series, was associated with higher morbidity rates, but this event remains relatively rare, with a freedom of prosthetic valve insertion of
70% at 15 years after surgery. Most valve replacements were performed in a cohort of patients with very complex valve anomaly, namely a hammock mitral valve, which remains a challenging lesion to repair.

In conclusion, patients with isolated CMS can be managed by a conservative surgical repair, which allows excellent early and long-term results. In patients with associated heart defects, a single-stage operation treating all the lesions in a single operative session gives better early and late results than a staged approach. The reoperation rate remains high in this group of patients mainly because of residual mitral valve dysfunction or because mitral stenosis relief reveals a downward left ventricular obstruction that was not obvious before mitral surgery. Finally, mitral valve replacement in this category of patients should be reserved as a salvage procedure.

References
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