SURGERY FOR CONGENITAL HEART DISEASE

MOBILIZATION OF THE LEFT AND RIGHT FIBROUS TRIGONES FOR RELIEF OF SEVERE LEFT VENTRICULAR OUTFLOW OBSTRUCTION

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Background: There is still no agreement about the optimal method of surgical relief of fixed subaortic stenosis, particularly the severe forms. **Objectives:** The purpose of this study was to describe a new technique for the relief of subaortic stenosis based on analysis of the functional anatomy of the left ventricular outflow tract and pathophysiologic features of subaortic stenosis. **Methods and patients:** We propose that one of the basic abnormalities in subaortic stenosis is interference with the hinge mechanism provided by the 2 fibrous trigones with progressive deposition of fibrous tissue in these angles. The technique described in this paper consists of excision of all components of the fibrous "ring," with mobilization of the left and right fibrous trigones. This results in the restoration of the normal dynamic behavior of the left ventricular outflow tract with maximal widening of the outflow tract as the result of backward displacement of the subaortic curtain and anterior leaflet of the mitral valve. This technique has been used in 57 consecutive patients who ranged in age between 5 months and 56 years (mean, 15.5 ± 10.6 years). Gradients across the left ventricular outflow tract were between 45 and 200 mm Hg (mean, 86.7 mm Hg). Additional lesions were present in 10 patients, and 7 patients had had 8 previous operations on the left ventricular outflow tract. At operation, in addition to resection of subaortic stenosis, 3 patients had aortic valvotomy, 2 patients had homograft replacement of the aortic valve, 7 patients had patch closure of a ventricular septal defect, and 1 patient had open mitral valvotomy. **Results:** There were 2 early deaths and 1 late sudden death during the follow-up period that ranged from 1 month to 25 years (mean, 15.2 years). One patient experienced the development of endocarditis on the aortic valve 7 years after operation, which was successfully treated by homograft replacement. Postoperative gradients across the left ventricular outflow tract varied from no gradient to 30 mm Hg (mean, 8 mm Hg). There were no instances of recurrence of a gradient across the left ventricular outflow tract. **Conclusion:** It is concluded that mobilization of the left and right fibrous trigones results in durable relief of subaortic stenosis. (J Thorac Cardiovasc Surg 1999;117:126-33)

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Fig 1. The diagram shows the position of inflow and outflow valves, which share the same orifice in ventricle (A) in contrast to the arrangement in right ventricle, where the 2 valves are located at 2 ends of muscular tube (B).

Obstructive lesions of the left ventricular outflow tract (LVOT) below the aortic valve encompass a group of varied complex conditions that continue to constitute a management challenge.¹⁻⁵ To date there is no standardized approach to surgical relief of these lesions, with a relatively high incidence of reported incomplete relief or recurrence of obstruction. This has led to the application of more radical procedures such as aortoventriculoplasty,^{6,7} which has several potential disadvantages. We believe that the “ideal” operation should result in predictable durable relief of LVOT obstruction while preserving the anatomic integrity of the LVOT and, whenever possible, conserving the aortic valve. Achieving these goals depends on thorough understanding of the anatomic features of the LVOT, the pathophysiologic features of subaortic stenosis, and the factors involved in its evolution and/or recurrence. In this article, we describe specific anatomic features of the LVOT relevant to the development and/or relief of obstructive lesions and review our experience with a new technique, which relies on these anatomic principles.

Surgical and functional anatomy of LVOT

The LVOT has unique features because, unlike the right ventricular outflow tract, it shares the same orifice with the inflow valve (the mitral valve; Fig 1) within the fibrous framework of the heart. This is thought to enable the flask-shaped left ventricular myocardium to deliver a bolus of blood under high pressure to the systemic circulation. This anatomic arrangement results in a complex interaction between the left ventricular inflow and outflow tracts during different stages of the cardiac cycle (Fig 2, B and C) and in several key intracardiac structures acting as boundaries to the LVOT (Fig 2, A).

Fig 2. The diagrams show (B and C) the interaction between the mitral and aortic orifices, with the 2 fibrous trigones acting as a hinge mechanism for the movement of the subaortic curtain and anterior leaflet of the mitral valve during different phases of the cardiac cycle and (A) the structures surrounding the LVOT.

These include the anterior leaflet of the mitral valve, the subaortic curtain, the 2 fibrous trigones, and the muscular and membranous interventricular septa. In the long axis, the LVOT extends from the level of the

Fig 3. A-D, The diagrams show the anatomic location of the different types of fixed subaortic stenosis.

Fig 4. Photograph of the LVOT in a patient with subaortic stenosis shows the relationship between the fibrous shelf and the fibrous trigone.

tip of the anterior leaflet of the mitral valve to the level of the attachment of the aortic cusps and is bound posteriorly by the subaortic curtain and anterior leaflet of the mitral valve. Anteriorly the LVOT is related to the muscular septum below the right coronary cusp of the aortic valve. In the short axis, the anterior leaflet of the mitral valve and the subaortic curtain are fixed to the right and left fibrous trigones (Fig 2). The former is continuous anteriorly with the membranous interventricular septum and is closely related to the penetrating part of

the bundle of His; the left fibrous trigone serves to attach the subaortic curtain posteriorly to the muscular interventricular septum anteriorly (Fig 2). The right and left fibrous trigones¹⁴ act as hinge mechanisms, allowing the subaortic curtain and anterior leaflet of the mitral valve to move backward and forward during different phases of the cardiac cycle (Fig 2, B and C). This movement allows the LVOT to enlarge during ventricular systole. We believe that the dynamic nature of the LVOT is important for its proper function, that the fibrous trigones play a crucial role in this regard, and that malfunction of this mechanism plays an important part in subaortic stenosis.

Anatomy of fixed subaortic obstruction

This is usually due to a complete ring that can be situated at different levels in the LVOT (Figs 3 and 4) and can have several components (anterior, posterior, right and left lateral). The anterior component is usually firmly attached to the endocardial surface of the muscular septum and extends from the membranous septum on the right to the left fibrous trigone on the left and is situated below the right coronary cusp and intercoronary commissure (Figs 3, A and D, and 4).

The right and left lateral components consist of fibrous tissue that fills the angles between mitral valve and subaortic curtain posteriorly and the interventricu-

Fig 5. Echocardiogram shows (A) the anterior component of the subaortic stenosis, (B) postoperative transesophageal echocardiogram of the LVOT during systole and diastolic, and (C) the mobilized hinge mechanism of the right and left fibrous trigones. RV, Right ventricle; LV, left ventricle; Ao, aorta; MV, mitral valve; LA, left atrium.

lar septum anteriorly (Fig 4) and thus interferes with the hinge mechanism function of the fibrous trigones, resulting in anteroposterior narrowing of the LVOT. Unlike the anterior component, the lateral components are difficult to visualize echocardiographically (Fig 5, A and B) and during operation and therefore are likely to be missed.

Pathogenesis of fixed subaortic stenosis

The exact mechanisms responsible for the development, progression, and/or recurrence of subaortic stenosis remain poorly understood. Several factors are thought to be responsible, or to play a part; these include developmental abnormalities resulting in small and/or long aortic root,^{8,9} displacement of the ventricular septum, malalignment between the muscular and

membranous parts of the interventricular septum,¹⁰ persistence of endocardial cushion tissue in this region, displacement of the mitral valve apparatus forward into the LVOT, or presence of accessory fibrous bands, which could be related to the mitral valve. In addition, turbulence produced by one or more of these factors may produce intimal fibrous proliferation, which can be progressive.^{11,12} The exact molecular mechanisms involved are not known, but endothelial injury, resulting in platelet deposition and scarring caused by the release of a variety of growth factors through a process analogous to that responsible for stenosis after balloon angioplasty or atherosclerosis, may be responsible. Davis and Tripathi¹³ have shown that turbulent fluid increases vascular endothelial cell turnover in vitro. We propose that abnormalities of the right and left fibrous

Fig 6. A photocopy of an excised specimen of subaortic stenosis shows the different components, including the fibrous tissue adjacent to the right and left fibrous trigones, and the resected wedges from the muscular interventricular septum.

trigones and malfunction of the hinge mechanism created by these structures play an important role in subaortic stenosis by creating areas of stasis adjacent to the fibrous trigones, which together with turbulence can favor tissue proliferation or deposition.

Dynamic subaortic obstruction

This is usually due to hypertrophy of the interventricular septum, resulting in a "localized" bulge extending from the membranous septum on the right to the left fibrous trigone on the left. In the long axis plane, the bulge extends from just below the aortic valve to a level below the tip of the papillary muscle. Although initially the obstruction is entirely muscular, during the later stages, secondary subendocardial fibrous proliferation can result in different degrees of additional fixed obstruction as the result of a fibrous ring similar to that described under isolated fixed obstruction, particularly in the region of the fibrous trigones possibly because of interference with the hinge mechanism. Conversely, secondary hypertrophy of the interventricular septum in patients with fixed subaortic stenosis can result in additional obstruction. There is therefore a strong interaction between the dynamic and fixed forms of subaortic obstruction.

Patients and methods

Surgical technique. Optimal relief of LVOT depends on complete excision of all the components of the subaortic fibrous ring, mobilization of the fibrous trigones and radical wedge excision of the hypertrophied muscular interventricular

septum (Fig 6) in an attempt to restore the functional characteristics of the LVOT. After cardiopulmonary bypass is established, cold antegrade crystalloid or blood cardioplegia is used for myocardial protection. The aortic valve is then exposed through a long hockey-stick incision that extends into the base of the noncoronary sinus of Valsalva. The aortic valve is inspected, and any commissural fusion is sharply divided without jeopardizing the suspensory function of the commissures. The subvalvular region is exposed by retracting the aortic leaflets. In patients with a high subaortic membrane, this is peeled off the undersurface of the aortic cusps, with care taken not to buttonhole the affected leaflets. The main part of the anterior component of the fibrous ring is then excised by making a vertical incision in the interventricular septum, starting just below the right and middle thirds of the base of the right coronary cusp (Fig 7, A) and extending deep into the ventricle to a level just below the tip of the anterior papillary muscle. A wedge of fibromuscular tissue is excised starting from the vertical incision and extending toward the left fibrous trigone (Fig 7, C). The latter is carefully mobilized by extending the incision laterally into the fibrous trigone (Fig 7, D), thus opening the hinge mechanism between the muscular interventricular septum and the subaortic curtain. The incision is gradually and slowly deepened until the free lateral border of the anterior leaflet of the mitral valve can be clearly seen. Any bridging tissue between the mitral leaflet and muscular interventricular septum is excised; care should be taken not to buttonhole the mitral leaflet or open the outflow tract to the exterior, noting that the left main coronary is very close to this region. Attention is then directed toward the posterior component of the obstructing ring. This is excised by developing the tissue plane between the well-defined abnormal ridge and the subaortic curtain with a blunt instrument (Fig 7, F). The abnormal tissue is peeled from the subaortic curtain and mitral valve. This process is continued laterally toward the right fibrous trigone. The latter is mobilized by the excision of the wedge of abnormal tissue in the angle between the membranous septum and subaortic curtain. This opens the hinge mechanism between these structures. Minimal extension of the incision laterally into the fibrous trigone is then made (Fig 7, G), avoiding injury to the bundle of His. Finally, the excision of the obstructing ring is completed by removing the abnormal tissue from the membranous septum and its junction with the muscular septum with blunt dissection. This technique is applicable to all types of fixed subaortic stenosis, including tunnel obstruction and these associated with hypertrophic obstructive cardiomyopathy.

Clinical experience. Between 1973 and 1998, 57 consecutive patients underwent an operation for subaortic obstruction. During this period all patients with subaortic stenosis were treated by this technique. The ages of the patients were between 5 months and 56 years (mean, 15.5 ± 10.6 years). There were 34 male patients and 23 female patients. Before the operation, 49 patients were investigated by cardiac catheterization that included left and right heart catheteriza-

Fig 7. A-G, Diagrams show the different steps of surgical relief of fixed subaortic stenosis with mobilization of the fibrous trigones (see text for details).

tion and left ventricular and aortic angiography to rule out additional lesions. Late in the experience, patients were investigated by 2-dimensional echocardiography and echocardiographic Doppler alone. Gradients across the LVOT were between 45 and 200 mm Hg (mean, 86.7 mm Hg). Additional lesions were present in 10 patients. A ventricular septal defect (VSD) was present in 7 patients, between the aortic valve and the ring (proximal) in 3 patients and the left ventricular side of the subaortic obstruction (distal) in 4 patients. Coarctation of the aorta, persistent ductus arteriosus, and congenital mitral stenosis were present in 3 patients, respectively. Four patients had a bicuspid nonstenotic aortic valve. One patient had endocarditis on a normal aortic valve, and 1 patient had aortic regurgitation as the result of damage from a previous operation. Seven patients had had 8 previous operations on the outflow tract. These included attempts at removal of the ring in 6 patients, a punch dilation in 1 patient, and repair of atrioventricular septal defect in infancy in 2 patients. At the operation, in addition to resection of the subaortic obstruc-

tion, 3 patients had an aortic valvotomy, 2 patients had a homograft replacement of the aortic valve, 7 patients had patch closure of the VSD, and 1 patient had an open mitral valvotomy. Postoperatively, patients were followed up either at our hospital or by mail at regular intervals. The evaluation included clinical examination, electrocardiography, and 2-dimensional echocardiography.

Results

Two patients, both early in the experience, died after the operation. One patient, aged 18 months, had a proximal VSD; and the other patient, aged 7 years, had extremely poor left ventricular function. With a follow-up of between 1 month and 25 years (mean, 15.2 years), there has been 1 late death 16 years after operation. This was a sudden death in an otherwise well young man and is presumed to be due to an arrhythmia. None of the patients experienced complete or partial heart block.

One patient experienced the development of endocarditis on her aortic valve 7 years after the operation and required an operation for this. No other patient has required reoperation. The remaining patients are well and leading normal lives. At last follow-up, 7 patients had mild to moderate aortic regurgitation on clinical examination. Although trivial aortic regurgitation was common on echocardiography, no other patients had aortic diastolic murmurs. The gradient across the LVOT on echocardiographic Doppler was between 0 and 30 mm Hg in all patients, with a mean gradient of 8 mm Hg. The gradient has not changed with time.

Discussion

We describe a technique of radical relief of subaortic stenosis designed to restore the functional and anatomic integrity of the LVOT. The technique is based on the characterization of the functional anatomy of the normal and diseased LVOT and the proposition that the right and left fibrous trigones play a crucial role in this regard. We also describe our experience with this technique over a period of 25 years.

Although the LVOT is a very short connecting channel between the left ventricular cavity and aortic valve, it is situated in a strategic position, surrounded by very important structures, and has a complex structure best suited for its sophisticated function with an important dynamic element, which needs to be preserved or restored. This could have important implications to durability of surgical relief of obstruction, as suggested by the extremely low rate of recurrence in our series. It is hoped that the findings described in this article will help in improving the overall management of subaortic stenosis.

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Discussion

Dr Frank L. Hanley (*San Francisco, Calif*). I would like to congratulate the authors for an innovative technique that, at the very least, will cause us to rethink how we assess the obstructed LVOT.

I note from your presentation that you have limited application of this technique to fixed LVOT obstruction. Have you applied this technique in any way to more dynamic LVOT obstruction, specifically idiopathic hypertrophic subaortic stenosis (IHSS)? In this regard, we have had experience with 6 pediatric patients with severe IHSS over the past 7 years. All of these patients had varying degrees of systolic anterior motion of the mitral valve. The approach that we have developed in these patients with hypertrophic dynamic obstruction has been somewhat similar, in fact very similar to your technique.

Our observations in these pediatric patients with severe IHSS is that there is an important amount of encroachment of fibrous and fibromuscular hypertrophic tissue onto the trigones at the hinge point of the mitral valve. It is our contention that this, in essence, causes an incomplete subaortic conus, which, with dynamic contraction, is responsible for so-called systolic anterior motion. We believe that this is a much better explanation than that involving a Bernoulli effect, pulling the mitral valve into the outflow tract in some mysterious way.

The results of these 6 patients have been dramatic. With aggressive relief of the fibromuscular adhesions from the mitral valve hinge point and from the 2 trigones, in essence, releasing the trigones, we have seen complete relief of obstruction, short term and medium term, and relief of systolic anterior motion on follow-up studies.

Have you applied your technique in this subgroup of patients and, if so, with what results?

The right trigone area is very close to the conduction sys-

tem. Have you seen heart block? The left trigone is in the area of the posterior root of the aortic valve, and aggressive resection in this area can lead to either aneurysm formation in the transverse sinus or frank rupture in the early postoperative period. Have you seen either of these 2 problems, and if you have not, have you taken specific measures to avoid them?

In cross section, the LVOT is a circular ring. I would be interested in your thoughts as to why these incisions in the posterolateral regions at the trigones are better than the more standard aortoventriculoplasty with the anterior incision in the septum. Both techniques enlarge the ring.

Dr Yacoub. Thank you, Dr Hanley, for your excellent questions, the first relating to application of this technique to patients with hypertrophic obstructive cardiomyopathy. We believe that there is an interaction between those 2 conditions and that there is fibrosis in the trigones. We applied this technique to this condition, particularly more recently; and we

think that is superior to injecting, for example, alcohol down the first septal perforator, which will not touch any of the fibrous tissue. We make a point about that.

With regard to your second question regarding the fibrous trigone, we believe that although there is a massive amount of tissue there, once you get to the angle between the free border of the mitral valve and subaortic curtain, there is a thin area that separates it from the outside where the left coronary artery is situated, and this could be dangerous. We have been particularly aware of that, and we have not had a rupture and/or aneurysms in this area.

Concerning the right fibrous trigone, we do believe that incisions in the right fibrous trigone have to be limited because of the penetrating part of the bundle of His, which would limit it; and indeed, any fibrous tissue in front of that toward the membranous septum should be removed bluntly and not by sharp dissection.