Correction of Mitral Insufficiency under Direct Vision

By EARLE B. KAY, M.D., CID NOGUEIRA, M.D., AND H. A. ZIMMERMAN, M.D.

MANY ingenious closed or blind technics have been devised and enthusiastically advocated in the recent past for the surgical correction of mitral regurgitation. Invariably, success was transitory and such operations were short lived, to be replaced similarly by others. During the past 3 years we have operated upon 82 patients with varying degrees of mitral insufficiency by the open-heart technic. During this period there have been modifications and improvements in the technics, although the principles involved have remained essentially unchanged. For the first time, postoperative results have continued to warrant our initial enthusiasm.

Pathology

In 25 patients pure mitral regurgitation was found (table 1). There was generalized dilatation of the annulus fibrosus. The regurgitant jet was most pronounced through the posteromedial half of the valve orifice but also occurred in varying degrees throughout the valve. In only 1 patient was there a flail anterior leaflet from rupture of the chordae tendineae. More than adequate valvular tissue was present in all instances, even though in the majority there was some thickening of the leaflets with rolling of their edges.

Seventeen patients had predominant mitral regurgitation but with significant degrees of mitral stenosis. The valve rings for the most part were fairly normal in size. The leaflets and chordopapillary structures showed greater degrees of thickening, although adequate valvular tissue remained. The residual orifice was either centrally located and patulous or eccentrically located and of the tear-drop variety.

Twenty-one patients had predominant mitral stenosis but also had varying degrees of mitral regurgitation. The annulus in these patients appeared for the most part smaller in size. There was further thickening and absorption of the leaflets and chordopapillary structures. The majority also had varying degrees of subvalvular stenosis. For the most part these were rigid, incompetent valves. Four additional patients might be referred to as having destroyed valves from the viewpoint of significant valvular function. A rigid tunnel remained as a result of the fusion of contracted leaflets to scarred and fused papillary muscles.

In 8 patients the valve was destroyed by extensive calcification that extended in 3 instances into the papillary muscles and ventricular endocardium. Two patients had traumatic regurgitation resulting from previous attempts to relieve their mitral stenosis by means of the comissurotomy knife, and 1 patient had a hole in the anterior leaflet resulting from a previous subacute bacterial endocarditis. Four additional patients had incompetent mitral valves as part of congenital atrioventricularis communis. Knowledge of the etiology of the regurgitation is important, for it determines the type of surgical correction to be employed.

Advisability of Cardiac Arrest

The first 7 patients had their mitral valvular correction during elective cardiac arrest in the belief that there would be less risk of air embolism. It soon became apparent that the surgeon must have a knowledge not only of the structural changes but also of the relation between structural changes and functional changes. Functional changes in the case of valvular disease mean motion—the proper opening and closing of the valve. Nothing short of observing the valve mechanism in the beating heart gives the surgeon information of the pathologic physiology of that patient’s valvular mechanism. The factors contributing to the regurgitation, the site of the regurgita-
tion, and the effectiveness of the correction can all be assessed better with the heart beating.

The greater improvement in the results has borne out these observations, so that routinely all patients with mitral regurgitation are now operated upon with the heart beating. There are also additional advantages in maintaining cardiac action in that the myocardium is kept well oxygenated; the operation need not be hurried; the need to restart the heart is obviated; and there have been no associated arrhythmias in our series.

In the presence of combined lesions, particularly aortic regurgitation, the aortic valve is corrected first. Usually this has been done with direct coronary artery cannulation and perfusion, so that the beating heart is maintained. With the coronary cannulae still in place, and with the heart beating, correction of the mitral valve is then performed. In instances of subclinical aortic valvular involvement considerable regurgitation through the aortic valve and into the operative field may take place, particularly if there is undue traction against the aorta by the mitral retractors. As long as regurgitation is insufficient to influence arterial perfusion pressure, this excess blood is aspirated back to the oxygenator by means of the sump. In extreme cases, intermittent aortic occlusion for 2-minute periods is employed.

Recent advances in localized cardiac hypothermia in the range of 7 to 10 C. appear attractive and have been used in several instances in the presence of combined lesions. In the future this technic may be further employed during the insertion of complete mitral valvular prosthesis, when it is important to have a dry field and a quiet heart while the artificial chordae tendineae are sewed to the papillary muscles.

Selection of Patients

In the recent past, prior to an effective technic for the surgical correction of mitral regurgitation, considerable effort was exerted in the selection of patients for valvular surgery, directed at excluding patients with mitral regurgitation or multivalvular disease. Many diagnostic tests were employed to aid in this differentiation, including left-sided cardiac catheterization, Evans blue dye-dilution curves, and Diodrast studies. Now that we can successfully correct patients with mitral regurgitation it makes little difference whether this differentiation is made preoperatively. Furthermore, although these examinations in skilled hands are not associated with many complications, they are still formidable and frequently exhausting to the sick cardiac patient, in addition to which they frequently do not provide sufficient additional information. The need for the more precise preoperative information is less important, since it can be readily obtained at the time of surgical exploration by pressure studies and direct examination.

Preoperative Evaluation

The history, clinical course, and physical examination still remain very important aspects of the appraisal. The electrocardiogram and roentgen examinations give valuable information of chamber hypertrophy and dilatation. It is particularly valuable to have earlier studies available for comparison to determine whether significant change or progression of the disease has occurred. Phonocardiograms are employed for comparison with postoperative studies. A definite im-

Table 1

<table>
<thead>
<tr>
<th>Type</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Pure regurgitation</td>
<td>25</td>
</tr>
<tr>
<td>Predominant regurgitation, significant stenosis</td>
<td>17</td>
</tr>
<tr>
<td>Predominant stenosis, varying degrees of regurgitation</td>
<td>21</td>
</tr>
<tr>
<td>Destroyed fibrotic regurgitant, stenotic valve</td>
<td>4</td>
</tr>
<tr>
<td>Destroyed calcified regurgitant, stenotic valve</td>
<td>8</td>
</tr>
<tr>
<td>Traumatic regurgitation</td>
<td>2</td>
</tr>
<tr>
<td>Hole in anterior leaflet (previous subacute bacterial endocarditis)</td>
<td>1</td>
</tr>
<tr>
<td>Incompetent mitral valves (part of atrio-ventricularis communis complex)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>82</td>
</tr>
</tbody>
</table>
Improvement in valve sounds is now being observed, which was very infrequent in patients operated upon with the closed technics. Right-sided cardiac catheterization, with and without exercise, a simple and entirely safe procedure, is routinely employed to determine the status of and changes in the pulmonary vasculature, as well as to give information regarding cardiac output and reserve. Pulmonary wedge pressure studies obtained at this time not only provide an index of left atrial pressures but also provide suggestive evidence as to the presence of regurgitation or stenosis, or both. We have found the pulmonary wedge pressures to correlate closely with left atrial pressures obtained at operation. Furthermore, such preoperative objective findings are invaluable for postoperative evaluation. We are now attempting to obtain such data preoperatively, at the operating table, prior to discharge, 6 months postoperatively, and again several years postoperatively, to obtain as complete an understanding as possible of the hemodynamic changes.

It is important to determine the presence or absence of rheumatic activity by sedimentation rates, the presence of C-reactive proteins, and a period of observation in the hospital of temperature and pulse. Liver and kidney function tests are employed when indicated. In some instances a longer period of observation is necessary to determine the patient's response to definitive therapy in the presence of failure.

Criteria for Recommending Surgery

If the studies show the patient to be symptomatic, to have an enlarged heart, electrocardiographic evidence of left atrial and ventricular overloading, evidence of pulmonary hypertension aggravated by exercise and without signs of activity, operation is recommended. This is particularly so if serial examinations reveal a definite progression in such signs, especially with regard to the x-rays and electrocardiograms. An increase in the size of the cardiac silhouette as well as a progressive shift of the mean electrical axis to the right, an expression of aggravated pulmonary hypertension, constitutes important evidence. The cardiopulmonary reserve is frequently relatively good in patients with mitral regurgitation. Once these signs appear or there is evidence of progress, we believe it is unwise to postpone operation because of the detrimental effect on the myocardium, which may compromise an otherwise successful result.

Present Outlook of Surgical Correction

Approximately 85 per cent of the patients with mitral regurgitation can today be greatly benefited by surgical correction by the open technic and can be restored to a useful healthful life. In the remaining group of patients not helped or in whom there is a high surgical risk, 3 facets of the problem remain to be corrected or improved. These problems pertain to the heart, the type of pathology, and the surgical correction.

To be reasonably successful the surgeon must have a patient with sufficient myocardial reserve to withstand the operative procedure, a valvular mechanism that is not so severely destroyed that it cannot be surgically corrected, or a surgical technic by which to make this correction in the presence of a destroyed valve. In contrast, the surgeon is unlikely to be successful in a patient with severe myocardial failure, a badly destroyed valve, and without a technic for complete valvular replacement for those valves that cannot be benefited materially otherwise. It is not meant to imply that all 3 of these aspects of the problem go hand in hand, for a patient with a relatively good valve from a technical point of view may have a severely dilated and hypertrophied heart. These problems, however, are responsible for the morbidity and mortality and require further emphasis and improvement.

The first facet of the problem is the myocardial reserve of the patient. The incidence of "last resort" surgery is unquestionably too high. Until recently there was no effective means for surgical correction. Insufficient myocardial reserve to tolerate the operative procedure is one of the main causes of failure. The surgeon may improve the valve markedly,
with lowering of the left atrial pressure, only to see the heart fail because of its inability to withstand the operative procedure or to pump against the severe pulmonary vascular resistance. Now that there is an effective technic, this phase will undoubtedly improve with time. Patients will be seen earlier by the surgeon while they are in relatively good general condition. When it is evident that the disease is significant or progressive, operative intervention should be recommended before obvious myocardial failure or extensive pulmonary vascular sclerosis develops (fig. 1).

The second facet of the problem is the pathologic state of the mitral valve. A small percentage, perhaps 10 per cent of the valves, are so severely destroyed that with past technics they could not be salvaged. A destroyed valve that cannot be sufficiently corrected to improve the hemodynamics has been the most common cause of failure in the past (fig. 2). Success in this group means the solution of the final problem—that of the surgical correction by complete valvular replacement with an artificial valve. Such a valve has been developed in the laboratory made out of woven Teflon fabric and patterned after the normal anatomic valve with leaflets and chordae tendineae (fig. 3).* This valve holds much promise for future correction of severely destroyed valves.

**Surgical Technics**

**Pump-Oxygenator**

All of the patients have been operated upon with the use of the Kay-Cross rotating disk oxygenator. A flow rate usually of 50 ml. per Kg. per minute, which results in an arterial inflow of 3 to 3.5 liters per minute, has sufficed to maintain a mean arterial pressure of 70 to 80 mm. Hg. The inflow cannula is always in the common femoral artery through the superficial femoral artery. There is controlled venous return regulating the vena caval flow by maintaining the vena caval pressure at pre-perfusion levels. This, we think, gives better control over body blood balance. Constant monitoring of the mean arterial pressure, mean vena caval pressure, electrocardiogram, electroencephalogram, $pO_2$, $pCO_2$, and pH, body and oxygen temperature, provide a constant physiologic status of the patient. Hematocrit, hemoglobin, and body weight are determined immediately prior to and following surgery.

As an anterolateral incision with transection of the sternum is made, the femoral can-
nulations for arterial input, arterial manometer, and intravenous infusion are simultaneously completed.

**Exploration and Visualization of the Valve**

A routine re-evaluation of the heart is first made. The status of the tricuspid valve is determined by digital exploration. Pressure recordings of the aorta and left ventricle are then obtained to verify or eliminate coexistent aortic valvular disease. Pressure recordings of the pulmonary artery and left atrium are then made. The extracorporeal perfusion is then begun while the left atrium is incised and the mitral valve is digitally explored. If the mitral valve is obviously incompetent, the sump is introduced into the left ventricle through the mitral valve to make sure ventricular systole is ineffective in pumping blood or foam through the aortic valve. The various factors contributing to the regurgitation are visualized and assessed. If a significant degree of stenosis is also present, the valve is opened as widely as possible digitally, and then the sump is inserted between the valve leaflets into the left ventricle. The commissurotomy is then completed under direct vision, with mobilization of the valve cusps, chordae tendineae, and papillary muscles. Then the insufficiency is corrected.

**Repair of Valve**

**Pure Regurgitation**

The principle of annular plication, to reduce the size of the dilated annulus and in turn to approximate the valve leaflets, is still employed.
Initially, the annular plication was made primarily at the level of the anterior and posterior commissures (fig. 4), by approximating the annulus above and below this site with several mattress sutures. In at least 2 patients these sutures tore out of the heart wall and annulus during the postoperative period. Consequently, the next modification was to insert the sutures through sections of compressed Ivalon so that the tension was against the Ivalon rather than the cardiac wall. Here again, however, in 1 patient with a huge heart and severely dilated annulus, the sutures pulled out from the heart. Initial improvement was excellent in that the left atrial pressures fell from 60/24 to 14/11 mm. Hg. It was apparent that in greatly hypertrophied hearts several sutures even when reinforced with plastic material were insufficient to maintain the reduction in the size of the annulus in all instances. Therefore, the principle of multiple fixation was then employed. In this technic, sections of an annular piece of Teflon felt, of varying length but smaller than the dilated mitral annulus, are fashioned. The middle of this segment is sutured first at the level of the posterior commissure. The anterior and posterior ends of the felt are then sutured as far laterally on the anterior and posterior aspects of the mitral annulus as it appears necessary to correct the insufficiency. The anterior and posterior limbs of this circular felt are considerably shorter than the corresponding segments of the mitral annulus. Then a running suture, taking larger bites of the annulus than of the Teflon, fixes the dilated ring to the plastic, thereby reducing the size of the dilated annulus in a circular fashion by multiple points of fixation. If necessary, a second partial circular segment of Teflon is employed in a similar manner, beginning at the level of the anterolateral commissure. It is important to overcompensate slightly for the dilated annulus, for its size is smaller in the heart empty of blood than when it is again distended with blood. In the instance of the flail leaflet resulting from ruptured chordae tendineae, this leaflet is sewn to the remaining chordae tendineae and papillary muscle. If necessary, artificial chordae tendineae could be employed.

Combined Lesions

In patients with mixed stenosis and regurgitation it is important that a complete commissurotomy and mobilization of valve leaflets be accomplished prior to correction of the insufficiency. Our interpretation today of a complete commissurotomy differs from previous teachings in that the fused commissure is a pathologic and not an anatomic entity, and as such the separation of the 2 fused leaflets should not be taken to the mitral annulus as previously recommended since regurgitation would then occur at these sites. In reality the mitral valve is a sleeve valve divided into a large anterior leaflet, a smaller posterior leaflet, and small lateral and medial
leaflets. In some instances these small lateral and medial leaflets may not have developed completely as such but do exist as functional valvular tissue joining the anterior and posterior leaflets and preventing regurgitation at these sites.

Frequently, the rolled inverted leaflets fused with the chordopapillary structures can be separated by sharp and blunt dissection, providing both greater mobility and functional valve surface. Over fifty per cent of the patients have had significant subvalvular stenosis with complete fusion of the leaflets to the papillary muscles with absorption of the chordae tendineae. In such instances it is impossible to perform the commissurotomy or valvuloplasty in the usual manner. We have found that in this type, the dissection is best begun peripheral to the fused commissure (fig. 5). An instrument is inserted at this site through the fused leaflets to delineate the exact relationship of the fused papillary muscles to the leaflets. Care has to be exercised that each leaflet be left with sufficient papillary support. The incision in these fused leaflets is then carried centrally so as to be centered over the fused papillary muscles, which are then incised into 2 equal segments down to the ventricular endocardium. A variety of technics has been employed in the correction of the residual insufficiency, including the addition of valvular tissue in the form of partial plastic leaflets or selective annular plication. Care must be exercised not to reduce significantly the size of the frequently restricted mitral annulus. In some severe types with complete loss of valvular function with absorption and scarring of the valvular components, only partial correction can be obtained at best. Such patients do not comprise over 10 per cent of the entire group. Such lesions in the future will undoubtedly be corrected by complete valvular prosthesis.

The 2 patients with traumatic regurgitation, secondary to the laceration of the leaflets by the commissurotomy knife during surgery for mitral stenosis, were treated by completing the valve mobilization as described above, then by resuturing the lacerated leaflets, and by reinforcing the sutures with pledgets of plastic material.

**Calciﬁed Valves**

Approximately 30 per cent of the patients with combined lesions have varying degrees of calcium deposits in their valves. For the most part this is of little concern and in no way compromises an otherwise successful correction. In 8 patients in this series (10 per cent), the degree of fibrocalcific destruction not only caused complete loss of valvular function but also prevented any signiﬁcant correction by past technics. In the first 5 it was obvious that little had been accomplished. All of these patients died during the postoperative period from lack of signiﬁcant hemodynamic improvement. It was apparent that success in this group required excision of the diseased valve and replacement by a complete valvular prosthesis. During the ensuing months all patients were carefully screened with the image amplifier, and those with extensive calciﬁcation were excluded from surgery. During this period of time a complete artificial valve was developed. Preliminary laboratory observations of the valve indicated that it would be suitable for valvular replacement. This valve has now been used in 3 instances. Unfortunately there are no survivals as yet. However, the valve appeared to function well in each patient with considerable drop in left atrial pressure. Two of the patients died from renal complications; the longest survival was
7 days. This patient died immediately following overperfusion with the artificial kidney, employed because of a renal shutdown. He had had known multiple infarctions of the lungs and kidneys preoperatively. The third patient had been operated upon 5 years previously for mitral regurgitation by the closed technic. She had had severe ventricular failure preoperatively, and little myocardial reserve. Autopsy examination in all 3 patients revealed no complications related to the artificial valve.

Results of Surgery

Since this paper pertains primarily to rheumatic mitral regurgitation, the results of surgery and the postoperative evaluation will be based on those patients whose significant defect was the mitral valvular lesion due to rheumatic fever (table 2). Those patients with multivalvular surgical correction are eliminated from the group in this discussion, as well as those of the congenital variety.

Pure Mitral Regurgitation

In 18 of the 25 patients with pure mitral regurgitation the disease was limited primarily to the mitral valve. There were 2 deaths in this group; an operative mortality of 11.1 per cent. One of the deaths resulted from air embolism; this complication has now been eliminated in the last 62 patients. The second death occurred 3 months postoperatively in an 11-year-old boy with severe pulmonary hypertension, marked cardiomegaly, poor myocardial reserve, and greatly reduced pulmonary reserve from pulmonary vascular sclerosis and atelectasis.

Death from air embolism in the future should be preventable, since the conditions conducive to its occurrence have been determined and eliminated. In regard to the second death, we realized preoperatively the desperate risk involved but accepted it, knowing in advance that it was the boy's only opportunity. In the future it is hoped that few cases of this severity will be seen.

Of the 16 surviving cases in this group, 13 have been operated upon 3 months to 2 years previously, not long enough to know their eventual course but long enough to provide some indication of possible benefit. In 2 patients done early in the series, initial improvement was followed in 3 to 4 months by recurrence of evidence of their mitral insufficiency. Both had huge hearts, and in both the surgical correction by annular plication was performed in the original manner without the re-enforcing plastic sutures or the more recent technic of multiple point fixation. The murmur has returned in both, and it is thought that the sutures have torn out. A third patient, a 56-year-old man, has had very significant clinical improvement, with resumption of activity and loss of the systolic blowing murmur, but his physicians reported no reduction in the pulmonary artery pressures at 6 months. The other patients have all been greatly improved. In the other 2 patients with catheterization studies, the hemodynamic data have returned to normal. In one the pulmonary artery pressures fell from 37/18 to 25/11 mm. Hg and in the other from 47/16 to 28/14 mm. Hg.

Mixed Lesions—Predominant Regurgitation

There has been 1 death in this group of 17 patients who had predominant mitral regurgitation with varying degrees of mitral steno-
From the technical viewpoint, the satisfactory correction of the stenosis and of the insufficiency could be relatively easily obtained.

Of the 16 surviving patients, 14 have been operated upon between 3 months and 2 years. Twelve (85.7 per cent) have had marked clinical improvement, 1 moderate improvement, and 1 no improvement. Six of these patients have had catheterization studies from 3 months to 1 year postoperatively. In 5 patients there was significant hemodynamic improvement.

**Combined Lesions**

There were 21 patients in this group with predominant mitral stenosis and varying degrees of regurgitation. They did not show the same degree of cardiomegaly as the 2 previous groups, nor such severe pulmonary vascular findings. There were no operative or late deaths.

Twenty patients have been operated upon 3 months to 2 years previously. All these patients but 1 have shown marked clinical improvement. In this patient the stenotic lateral commissure was severed at the annulus fibrosus, so that the valve was incompetent. This defect was subsequently corrected surgically with what appears initially to be a successful result. Six have had catheterization studies from 9 months to 2 years after operation; 5 have essentially normal hemodynamic findings, and the sixth showed significant improvement.

**Destroyed Valves**

There were 4 patients with rigid stenotic incompetent valvular tunnels for which no significant operative correction could be obtained. In addition, 8 patients had severely calcified valves, in 5 of whom no significant operative improvement could be obtained by previous technics. All these patients, unimproved by surgery, died during the postoperative period. Three patients with destroyed calcified valves had valvular replacement by complete artificial valves. There was marked hemodynamic improvement in these 3 but they all died, 2 from renal complications and the third from myocardial failure.

**Summary**

The incompetent valves in the majority of patients with mitral regurgitation can be surgically corrected by the technics described above. The ease and effectiveness of the correction are largely dependent upon the severity of the pathologic process. The roles of chronic myocarditis, myocardial failure, pulmonary vascular sclerosis, and the presence of other valvular defects are important factors in the eventual result. Fortunately, the abnormality in the majority of valves can be corrected, and the myocardial reserve is usu-

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**Table 2**

<table>
<thead>
<tr>
<th>Type</th>
<th>No. of patients</th>
<th>Operative mortality</th>
<th>Significant improvement (3 months to 2 years) clinical hemodynamics</th>
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</thead>
<tbody>
<tr>
<td>Pure</td>
<td>18</td>
<td>(2) 11.1%</td>
<td>84.6% 2 of 3</td>
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<tr>
<td>Mixed</td>
<td></td>
<td></td>
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<tr>
<td>Predominant regurgitation</td>
<td>17</td>
<td>(1) 5.8%</td>
<td>85.7% 5 of 6</td>
</tr>
<tr>
<td>Combined (pliable valve)</td>
<td>21</td>
<td>0</td>
<td>95% 6 of 6</td>
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<tr>
<td>Destroyed</td>
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<tr>
<td>Fibrotic</td>
<td>4</td>
<td>(4) 100%</td>
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</tr>
<tr>
<td>Calcified</td>
<td>8</td>
<td>(8) 100%</td>
<td></td>
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<tr>
<td>Traumatic</td>
<td>(Previous commissurotomy)</td>
<td>2</td>
<td>0</td>
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<tr>
<td>Hole in anterior leaflet</td>
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<td></td>
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<tr>
<td>(Subacute bacterial endocarditis)</td>
<td>1</td>
<td>0</td>
<td>100%</td>
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</table>
ally sufficient to provide satisfactory function. With continued progress in this field, earlier surgical intervention, and probably less severe disease from improved treatment, better results can be anticipated in the future.

**Summario in Interlingua**

In le majoritate del patientes con regurgitation mitral, le incompetent valvulas pote esser corrige per le technicas describite in le presente articulo. Le facilitate con que le correction pote esser effec-tuate e le efficiencia del resultatos depende in grande mesura del grado de severitate del processo pathologic. Le presentia de myocarditis chronic, de disfallimento myocardial, de sclerosis pulmo-vascular, e de altere defectos valvular es importantes factores in le determination del resultatos a longe vista. Felicemente, in le majoritate del valvulas il es possibile corriger le anormalitate, e le reserva myocardial es usualmente adequate pro provider un functionamento satisfactori. Quanto al futuro, il es justificate expectar melior resultatos, non solmente in consequentia de continue progressos in iste campo e de plus precoce interven-ționes chirurgic sed etiam proque le severitate del morbo va esser reduceite per plus efficace modos de tractamento.
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