SURGERY FOR ACQUIRED HEART DISEASE

HOMOGRAFT REPLACEMENT OF THE MITRAL VALVE

Graft selection, technique of implantation, and results in forty-three patients

Because of experience gained in reconstructive mitral valve surgery, we have reevaluated the implantation of cryopreserved homografts in the mitral position. Forty-three patients, aged 11 to 69 years (mean 34 years), underwent mitral valve replacement with cryopreserved mitral homografts. The indications for the procedure were acute endocarditis ($n = 14$), rheumatic stenosis ($n = 26$), systemic lupus endocarditis ($n = 2$), and marasmic endocarditis ($n = 1$). All homografts were obtained from hearts explanted in the course of transplantation and were cryopreserved at -160°C in 10% dimethyl sulfoxide solution without antibiotics. Appropriate sizing was based on morphologic study of the homografts and preoperative echocardiographic assessment of the recipient valve. In 82 homografts analyzed, the height of the anterior leaflet was 25 ± 3 mm and the distance from the annulus to the apex of the anterior papillary muscle was 21 ± 3 mm. The morphologic features of the papillary muscles were classified according to four types of increasing complexity. Nine valves with complex (type IV) papillary muscle abnormalities were discarded. Echocardiographic measurements of the valve were matched with those of the homograft identification cards and a slightly larger homograft was selected (measurements $+ 3$ mm). Partial homograft replacement was done in case of a localized lesion (abscess or calcification) ($n = 21$). Total homograft replacement was undertaken in the presence of diffuse lesions ($n = 22$). Two hospital deaths occurred as a result of poor cardiac output. One patient required reoperation on the tenth postoperative day after a dehiscence on the valvular suture line. After a mean follow-up of 14 months, there has been one late death caused by a bronchial neoplasm and one reoperation for residual stenosis (partial replacement). The remaining patients were in either New York Heart Association class I ($n = 25$) or II ($n = 13$). Thirty-three patients were in sinus rhythm. Follow-up echocardiography has revealed no mitral regurgitation ($n = 20$), minimal mitral regurgitation ($n = 13$), and mild mitral regurgitation ($n = 5$). Surface valve area has been calculated at 2.5 ± 0.4 cm² in partial homograft reconstruction and 2.7 ± 0.3 cm² in total homograft replacement, with a transvalvular gradient of 3 ± 4 mm Hg. **Conclusion:** In a selected group of patients, the use of mitral homografts significantly extended the present limitations of reparative surgery of the mitral valve. (J THORAC CARDIOVASC SURG 1996;111:367-80)

Christophe Acar, MD^a (by invitation), Michael Tolan, MD^a (by invitation), Alain Berrebi, MD^a (by invitation), Jullien Gaer, MD^a (by invitation), Roger Gouezo, BS^b (by invitation), Thierry Marchix, BS^b (by invitation), Jean Gerota, MD^b (by invitation), Sylvain Chauvaud, MD^a (by invitation), Jean-Noel Fabiani, MD^a (by invitation), Alain Deloche, MD^a (by invitation), and Alain Carpentier, MD, PhD, Paris, France

From the Department of Cardiovascular Surgery, Hôpital Broussais,^a and the Cryopreserved Tissue Bank, Hôpital Saint-Louis,^b Paris, France.

Read at the Seventy-fifth Annual Meeting of The American Association for Thoracic Surgery, Boston, Mass., April 23-26, 1995.

Address for reprints: Christophe Acar, MD, Department of Cardiovascular Surgery, Hôpital Bichat, 46 rue Henri-Huchard, 75018 Paris, France.

Copyright © 1996 by Mosby-Year Book, Inc.

0022-5223/96 \$5.00 + 0 12/6/67995

The replacement of the mitral valve with a homograft was one of the first operations conceived in the development of valvular surgery. Experimental studies in the early 1960s in animal models¹⁻³ bore encouraging results showing rapid integration of the homograft, whose leaflets and chordae remained intact 1 year after implantation (Fig. 1). Nonetheless, the first attempts to replace the mitral valve with a mitral homograft in a clinical situation met with early failure owing to misunderstanding of valvular function and difficulty in fixation of the homograft papillary muscle.⁴⁻⁷ Progress achieved over the past 20 years in the assessment of the mitral valve by means of echocardiography greatly improved knowledge of valvular physiopathology.^{8,9} Simultaneously, experience gained in reconstructive surgery of the mitral valve has enabled surgeons to become more familiar with operative techniques involving the subvalvular apparatus.¹⁰ On the basis of general principles established by Carpentier¹⁰ for mitral valve reconstruction, we reconsidered the use of a homograft for mitral valve replacement. Preliminary animal studies have allowed us to develop a reliable technique of implantation of the homograft papillary muscle (Fig. 1). Accordingly, we have evaluated the use of a homograft for partial or total replacement of the mitral valve in a series of 43 patients.

Patients and methods

Homograft assessment and storage. Of a total of 82 mitral homografts obtained from hearts explanted at the time of cardiac transplantation, 67 valves were saved for implantation and 15 were discarded because of either structural abnormalities or positive viral serologic status.

The entire mitral apparatus was dissected free including both the attachment of the papillary muscles onto the ventricular wall and the myocardium surrounding the mitral annulus. Care was taken in dissection of the aorto-mitral triangular area to ensure that an aortic homograft could also be harvested. This dissection was performed in a sterile theater. Cryopreservation was performed within 18 hours of retrieval of the homograft in the tissue bank of Hôpital St. Louis. A preservative solution containing 5% dimethyl sulfoxide without antibiotics was used and the temperature was gradually decreased by means of vaporized nitrogen to -150°C .

The morphologic characteristics of the papillary muscles and the distribution of the chordae were noted for each homograft and recorded on a specifically designed identification card (Fig. 2). Valve characteristics noted included the height of the anterior leaflet, the area of the anterior leaflet as measured with an annuloplasty ring obturator (Carpentier; Baxter Healthcare Corp., Edwards Div., Santa Ana, Calif.), and the distance between the apex of the papillary muscle and the mitral annulus (Fig. 2).

Fig. 1. Mitral homograft 10 months after implantation in a goat. Note normal leaflet tissue and chordae with moderate fibrosis of papillary muscles.

Each papillary muscle was classified according to morphologic features into four types of increasing complexity (Fig. 3). The shape of the papillary muscle was not considered, but the classification was based on the existence or nonexistence of a division in the muscle and its location with respect to the commissure: type I, simple single muscle; type II, divided muscle in a sagittal plane forming an individual head supporting chordae of the posterior leaflet; type III, divided muscle in a coronal plane forming an individual head supporting the commissural area of the leaflet (Fig. 3); and type IV, divided muscle with multiple heads originating at different levels on the ventricular wall from the apex to the base. The commissural chordae of type IV are short, originating from an isolated muscular band close to the mitral annulus. The remaining portions of papillary muscle had their insertion from a lower level on the ventricular wall.

Morphologic type and a schematic representation of the cross section of each papillary muscle were included in the homograft identification card (Fig. 2).

Indications. Forty-three patients aged 11 to 69 years (mean age 34 ± 5 years) underwent partial ($n = 21$) or total ($n = 22$) mitral valve replacement with a cryopreserved homograft. The indications for operation were as follows: rheumatic mitral stenosis ($n = 26$), acute infective endocarditis ($n = 14$), systemic lupus endocarditis ($n = 2$), and marasmic endocarditis ($n = 1$). In all patients with calcific mitral stenosis the indication was symptomatic effort intolerance (New York Heart Association class II or III), with antecedent pulmonary edema in 15 patients.

In the patients with acute bacterial endocarditis, the indication for operation was hemodynamic instability with severe mitral insufficiency ($n = 8$), systemic embolism ($n = 5$), large mobile vegetations viewed at echocardiography ($n = 2$), and persistent septicemia despite maximal antibiotic therapy ($n = 2$). Operations were performed 5 ± 3 days after the start of antibiotic therapy.

Preoperative electrocardiograms demonstrated sinus rhythm in 32 patients and atrial fibrillation in eight

Fig. 2. Identification card with mean dimensions of 82 mitral homografts: height of the anterior leaflet, 25 mm distance between anulus and papillary muscle (anterior 21 mm and posterior 26 mm), schematic representation of cross section of papillary muscles, morphologic type of papillary muscles, and dimensions according to Carpentier ring obturator.

Fig. 3. Classification of papillary muscles (cross-sectional views are shown below the main diagram). *TYPE I*, Simple, single muscle; *TYPE II*, division in the sagittal plane forming an individual head supporting the posterior leaflet; *TYPE III*, division in the coronal plane forming an individual head supporting a commissure; *TYPE IV*, divisions with multiple levels of origin from the ventricular wall. Short commissural chordae inserted on an isolated muscular band.

patients. Nine of the procedures were reoperations: commissurotomy ($n = 2$), mitral valve repair ($n = 4$), and prosthetic valve replacement ($n = 3$). All these patients had a total homograft insertion.

All patients had given informed consent to the proposed operation.

Preoperative echocardiographic assessment. All patients had a preoperative transthoracic and transesopha-

Fig. 4. Echocardiographic measurements of the valve via a sagittal view (aortic valve and papillary muscle were visible). Height of the anterior leaflet (H) was measured in diastole (a). In systole, anteroposterior diameter of the anulus ($\varnothing$) was measured (b), as well as distance (D) between anulus and papillary muscle (c).

geal echocardiogram. This confirmed the need for a homograft, the native valve being shown to be irreparable by means of existing methods of repair. The preoperative echocardiogram guided surgical strategy; partial or total homograft replacement was performed on the basis of the extent of the lesion.

The size of the homograft was chosen according to measurements taken with the aid of the preoperative echocardiogram (Fig. 4). These parameters were measured on a sagittal view of the mitral valve passing through the papillary muscles and aortic orifice. In diastole the height of the anterior leaflet was measured. In systole the plane of the anulus was defined by joining the insertions of both leaflets, allowing measurement of the anteroposterior diameter of the orifice. The distance separating the plane of the anulus and the apex of the papillary muscle was measured (the anterior papillary muscle being closest to the anulus was taken as a reference) (Fig. 4).

These parameters were matched with those on the homograft identification card and a homograft slightly larger than the valve (measurements + 3 mm) was selected. For three patients who had undergone previous prosthetic mitral valve replacement, the sole criterion used for selection of an appropriate homograft was the diameter of the prosthesis, which was matched with the anterior leaflet height.

Surgical technique

Preparation of the homograft. The homograft was prepared before cardiopulmonary bypass was instituted. The homograft was thawed in the operating room at 40° C and then rinsed in successive baths of saline solution containing decreasing concentrations of dimethyl sulfoxide. First, the ventricular muscle inserted to the anulus of the valve was dissected off without traumatizing the valve tissue, particular care being taken in the commissural areas. Then the wall of the left atrium attached to the anulus was excised. The connective tissue of the right and left trigones, which were frequently the site of a fibrocalcereous nodule, was trimmed. Finally, the fatty tissue in the atrioventricular junction was removed.

Before the papillary muscles were prepared, their morphologic features were examined and noted to ensure that the orientation would be maintained at the time of

implantation. In cases of divided papillary muscles, sutures were placed to preserve the respective positions of the different heads. Each papillary muscle was detached from its insertion into the ventricular wall, with approximately 15 mm of muscular tissue left beyond the origin of the chordae. The valve was then placed in a container of saline solution until its use.

Technique of insertion of the mitral homograft. Myocardial protection was achieved with cold cardioplegic solution injected into the aortic root. The left atrium was approached via the classic parallel incision in the interatrial sulcus. The mitral valve was inspected to assess the pathologic process and to decide which operative technique would be necessary. In the presence of an isolated lesion affecting less than half of the valve (calcification or valvular abscess), only part of the homograft was inserted provided that the remainder of the valve was normal ($n = 21$). On the other hand, in the presence of extensive lesions involving the entire valve, total homograft replacement was performed ($n = 22$).

First, the pathologic valve tissue was excised (Fig. 5) and the relevant chordae divided at their insertion. The integrity of the papillary muscles was carefully preserved. These were mobilized by dividing the muscular bands attaching them to the ventricular wall (Fig. 5). The homograft implantation was then commenced by fixation of the papillary muscles starting with the posterior one. The exposure of the recipient papillary muscle was optimized by applying gentle traction on a stay suture placed at this level. Each homograft papillary muscle was inserted into the slit between the native papillary muscle and the wall of the left ventricle (Fig. 5). Great care was taken to maintain the respective positions of the different heads. The head supporting the commissure was used as a reference point and was positioned at the corresponding site on the native papillary muscle. This site was easily identified because the commissural chordae invariably originate from the apex of the papillary muscle.

As a general rule, the papillary muscle of the homograft was sutured side to side at a slightly lower level on the recipient. A double row of sutures was used to implant the papillary muscle (Fig. 5). First, several mattress sutures were placed at the base of the graft papillary muscle;

second, multiple interrupted sutures around the margins of the graft and then the apex were used to attach it firmly to the native papillary muscle. The sutures were placed so as not to interfere with the origin of the chordae, inasmuch as this could eventually lead to chordal erosion (Fig. 5). At the level of emergence of the chordae the problem was avoided by using sutures in a vertical mattress pattern. For all the sutures the knots abutted on the native papillary muscle and pledgets were not used.

The homograft leaflet tissue was then sutured circumferentially to the mitral annulus with continuous 5-0 Prolene polypropylene suture (Ethicon, Inc., Somerville, N.J.). The various portions of the valve were attached in the following order: (1) posteromedial commissure, (2) anterior leaflet, (3) anterolateral commissure, and (4) posterior leaflet. Particular attention was taken in positioning the commissures (see Fig. 5), and the suture was effected without tension in the areas of the anterior leaflet and commissures. In cases of excess or deficient homograft leaflet tissue with respect to the mitral annulus, the suturing style was modified to achieve equilibration while the posterior leaflet was being attached (Fig. 5).

In all cases, a remodeling annuloplasty was performed with a prosthetic ring (Carpentier ring, Classic $n = 40$, Physio $n = 3$; Baxter). The sutures for the annuloplasty ring were placed before the valve leaflet tissue was attached. The size of the annuloplasty ring was chosen according to the size of the anterior leaflet of the homograft measured with an obturator. After placement of the homograft, the final result was evaluated by infusion of saline solution under pressure into the ventricle (Fig. 5).

Partial homograft replacement. All affected areas of the mitral valve leaflets and the subvalvular apparatus were excised and a portion equivalent to 25% to 50% of the valve was replaced. The sites of partial homograft replacement were the anterolateral commissure/hemivalve area ($n = 10$), the posteromedial commissure/hemivalve area ($n = 7$), and the anterior leaflet necessitating the implantation of both papillary muscles ($n = 4$) (Fig. 6).

A corresponding portion of homograft, slightly larger to obtain a mild excess of tissue, was used for reconstruction (Figs. 7 and 8). The technique of implantation was as already described for the total homograft: implantation first of the papillary muscle, followed by attachment of the homograft leaflet tissue to the mitral annulus and the remaining portions of the native valve (Figs. 7 and 8). An annuloplasty ring was placed in all cases, the size depending on that of the reconstituted anterior leaflet.

Operative details. Duration of cardiopulmonary bypass times for partial homograft reconstruction was 105 ± 20 minutes and for total homograft replacement, 118 ± 15 minutes. An associated procedure was performed in eight cases and included aortic valve repair ($n = 3$), tricuspid valve repair ($n = 1$), aortic valve replacement with a homograft ($n = 2$), and tricuspid valve replacement with a mitral homograft ($n = 2$).

Clinical follow-up. All patients underwent intraoperative transesophageal echocardiography with a multiplanar probe and transthoracic echocardiography 2 months after the operation. After a follow-up of between 3 and 34 months (mean 14 ± 3 months), all the patients were

examined and a transthoracic echocardiogram was performed.

Results

Anatomic characteristics of homografts ($n = 82$).

The height of the anterior leaflet was 25 ± 3 mm (20 to 31 mm). The mean distance separating the mitral annulus from the apex of the anterior papillary muscle was 21 ± 3 mm and from the apex of the posterior papillary muscle, 26 ± 4 mm (see Fig. 2). The anterior papillary muscles were classified morphologically as follows: type I, $n = 47$; type II, $n = 12$; type III, $n = 14$; and type IV, $n = 9$. The posterior papillary muscles were classified as follows: type I, $n = 43$; type II, $n = 22$; type III, $n = 7$; and type IV, $n = 10$. Type IV papillary muscles were considered unsuitable for implantation and were discarded.

Preoperative echocardiographic measurement ($n = 43$). The mean height of the anterior leaflets was 22 ± 5 mm. The anteroposterior diameter of the mitral annulus was 26 ± 4 mm. The distance separating the plane of the mitral annulus and the apex of the papillary muscle was 22 ± 5 mm.

Early results

Preoperative mortality and morbidity. Two early deaths resulted from severe biventricular failure despite normally functioning homografts. These patients had severe preoperative contractile dysfunction. In one, endocarditis was affecting a mitral valve prosthesis in a patient with systemic lupus erythematosus with poor ventricular function. The second patient had triple valve disease with systemic pulmonary hypertension and had previously undergone a mitral and tricuspid valve repair.

One patient required an early reoperation at 10 days. The patient, aged 76 years, had a staphylococcal bacterial endocarditis on a Starr-Edwards mitral prosthesis (Baxter Healthcare Corp., Edwards Div., Santa Ana, Calif.). The initial echocardiogram showed satisfactory results, but a rapid deterioration occurred at 10 days and necessitated reoperation. A dehiscence of the homograft was observed at the suture line attaching the leaflet tissue to the annulus in the region of the anterior commissure, probably caused by excess traction on the chordae. A St. Jude Medical mitral prosthesis (St. Jude Medical, Inc., St. Paul, Minn.) was inserted and the patient made a subsequent uneventful recovery.

One patient had complete heart block that was completely resolved 3 weeks after the operation.

One patient who had insertion of mitral and aortic homografts for acute bacterial endocarditis

Fig. 5. Surgical technique of mitral homograft implantation: **A**, Resection of the diseased mitral valve. **B**, Division of the lateral attachments of the papillary muscles using traction on the valve leaflets by division of muscular band. **C**, Positioning of the homograft papillary muscle into the slit between the native papillary muscle and the ventricular wall.

was slow to regain consciousness after the operation because of a bacterial meningoencephalitis. This resolved with a minimal residual neurologic deficit.

All other patients had uneventful postoperative courses. The average stay in the intensive care unit was 2.1 days.

Early echocardiographic results. Echocardiographic results (transesophageal during the operation or

transthoracic 2 months after the operation) revealed mitral insufficiency to be nonexistent ($n = 21$), minimal ($n = 15$), or mild ($n = 6$). The mean transvalvular gradient was 3 ± 2 mm Hg. The mean surface area of the valve measured by planimetry was 2.5 ± 0.3 cm² for patients having total homograft replacement and 2.2 ± 0.1 cm² for those having partial homograft reconstruction.

Midterm results

Functional status. All patients were examined after a follow-up of 3 to 34 months (mean 14 ± 3 months). One patient died 5 months after the operation of carcinoma. He had undergone partial homograft replacement for an aseptic endocarditis with an inflammatory syndrome that appeared to be related to advanced lung carcinoma. A postmortem examination was not available.

One patient required reoperation at 22 months. She had continued to have symptoms after the operation (New York Heart Association class III) and echocardiography demonstrated mitral stenosis (surface valve area 1.4 cm²). This patient had undergone a partial homograft insertion and at reoperation the native valve leaflet and chordae were found to be fibrotic and unpliant, causing stenosis. The valve was replaced with a St. Jude Medical mitral prosthesis.

All 38 remaining patients had normal functional status, New York Heart Association class I ($n = 25$) and class II ($n = 13$). Thirty-three patients were in sinus rhythm and five patients were in atrial fibrillation.

Echography results. Transthoracic echocardiography revealed stable results when compared with results of earlier studies. Residual mitral insufficiency was nonexistent ($n = 20$), minimal ($n = 13$), or mild ($n = 5$). No patient had moderate or severe insufficiency. The transvalvular gradient was 3 ± 4 mm Hg and the valve surface area measured by planimetry was 2.7 ± 0.3 cm² after total homograft replacement and 2.5 ± 0.4 cm² after partial homograft reconstruction.

Discussion

In the early days of valvular surgery, replacement of the mitral valve with a homograft by various approaches was considered a promising surgical procedure.^{5,6} Nevertheless, attempts at heterotopic transplantation of a semilunar valve in the mitral position have provided disappointing results.⁷ In the early 1960s, orthotopic transplantation of the mitral valve has been the focus of a number of animal

Fig. 5, Cont'd. **D**, Fixation of the papillary muscle: Mattress sutures at the base secured by multiple interrupted sutures. **E**, Annuloplasty stitches placed before attachment of the homograft leaflets. **F**, Circumferential fixation of the homograft leaflets to the annulus. Continuous suture anchoring successively the posteromedial commissure, the anterior leaflet, the anterolateral commissure, and the posterior leaflet. **G**, Completed homograft replacement of the mitral valve with an annuloplasty ring in place.

experiments showing encouraging histologic results.¹⁻³ However, clinical cases reported in the literature remained anecdotal and invariably resulted in early failure.^{11,12} More recently, tricuspid valve replacement with a mitral homograft has been performed by Pomar and Mestres.¹³ On the other hand, continued developments in reparative surgery of the mitral valve using the principles described by Carpentier have allowed investigators to reexamine

the feasibility of homograft replacement of the mitral valve.¹⁴⁻¹⁶

The selection of the size of the homograft is an important preliminary step in homograft replacement of a valve. Whereas the cylindric form of the aortic valve allows its size to be measured solely by the transverse diameter of the orifice,⁶ the evaluation of the dimensions of the mitral valve is more difficult. Both the extent of valvular leaflet tissue and

Fig. 6. Sites of partial homograft.

that of the subvalvular apparatus must be taken into consideration.

In our series the measurement chosen to size the leaflet tissue of the valve was the height of the anterior leaflet tissue in its middle portion (see Fig. 2). This was measured by preoperative transesophageal echocardiographic study of a sagittal section of the mitral orifice (see Fig. 4). The height of the leaflet was measured in the open position (diastole) so as to clearly identify the free edge of the valve. In addition, the anteroposterior diameter of the mitral anulus in systole was measured (Fig. 4). The majority of patients in the series did not have deformation of the anulus (mitral stenosis, acute endocarditis); therefore the anteroposterior diameter of the anulus in systole was usually equivalent to the height of the anterior leaflet. In the absence of annular dilatation, this measurement allowed confirmation of anterior leaflet sizing in patients in whom direct measurement was difficult because of pathologic alteration of the valve.

Assessment of the dimensions of the subvalvular apparatus raised a difficult issue. At first, it was thought that easily identifiable chordae, such as commissural or main chordae, would serve as a reference. However, the length of these chordae did not necessarily reflect that of the neighboring chor-

dae. The commissural chordae were sometimes short. Likewise, the main chordae could be long, often ending on the ventricular aspect of the valve well beyond the free margin. Finally, because of the pathologic process, the chordae might have lengthened as in degenerative processes or shortened as in rheumatic disease. For these reasons, it did not seem appropriate to evaluate the subvalvular apparatus with a view to homograft implantation using length of the chordae as a standard.

At present, we believe that the best method of assessment is the measurement of the distance between the anulus and the apex of the papillary muscle. This parameter is not directly affected by any pathologic process involving the valve. It has the advantage of taking into consideration ventricular dilatation if present, which would indicate the need for a larger homograft. This parameter can be obtained by both direct measurement of the homograft and echocardiographic study of the patient's valve (see Figs. 2 and 4). Echocardiographic measurements of the valve were matched with those of the identification card of the homograft. A homograft 3 mm larger was selected to provide a slight excess of tissue and offer a large surface of coaptation.

In this study, important technical modifications to

Fig. 7. Partial mitral homograft implantation for calcific mitral stenosis: **A**, Localized calcification affecting the anterior commissure. **B**, Resection of the calcification with the underlying chordae. **C**, Partial mitral homograft showing the anterior commissure with adjacent portions of leaflets and subvalvular apparatus (arrow). **D**, Result after reconstruction with partial homograft and annuloplasty.

previously described methods were developed concerning (1) the technique of fixation of the papillary muscle, (2) the systematic use of a prosthetic ring annuloplasty, and (3) operative strategy for partial homograft reconstruction. These developments were initially achieved in animal models.

Contrary to various methods described in the literature,¹¹⁻¹³ which use an end-to-end fixation of homograft to native papillary muscles, we have adopted a different approach, using a side-to-side suture of the papillary muscles (see Fig. 5). The papillary muscle of the recipient was not amputated so that the maximum amount of viable myocardium remained to support the homograft. The native papillary muscle was mobilized by sectioning of the muscular bands attaching them to the ventricular wall (Fig. 5). The homograft papillary muscle was positioned into the slit between the native papillary muscle and the ventricular wall. It was then attached slightly deeper to the recipient. Contrary to other techniques,^{12,13,17,18} no material was used to reinforce the suture whether prosthetic (polytetrafluoroethylene) or biologic (pericardium). On the basis of experience acquired through the technique of

chordal shortening described by Carpentier,¹⁰ we believe that the use of foreign material at the point of origin of the chordae can weakened their insertion and induce an appreciable risk of chordal erosion and rupture. This opinion is further corroborated by the experience with Biocor mitral bioprostheses (Bio-Vascular, St. Paul, Minn.), in which papillary muscles were carefully prepared with prosthetic material and occasionally underwent early chordal rupture at their site of insertion on the papillary muscle.¹⁹

The papillary muscles of the homograft are unavoidably subjected to several hours of ischemia immediately after retrieval and subsequently undergo significant stress during the cryopreservation process. It would be delusive to expect any viability of the grafted papillary muscle; shortly after implantation papillary muscles are fated to necrosis. Histologic studies in transplanted valves in animals have shown progressive fibrotic reaction occurring within several weeks.¹⁻³ Sporadic areas of viable myocardium were observed that most likely corresponded to remnants of the native papillary muscle.

The reliability of the technique of implantation

Fig. 8. Partial homograft implantation for acute endocarditis: **A**, Acute infective endocarditis with vegetations and valvular abscess. **B**, Partial mitral homograft showing the posteromedial hemivalve and its subvalvular apparatus (arrow). **C**, Result after partial replacement. Note the suture line between the native valve and homograft.

used in this study depends on the healing process of the papillary muscles with progressive replacement with fibrotic tissue (see Fig. 1). This method contrasts with a purely mechanical approach involving interposition of prosthetic material or transfixing stitches¹² through the ventricular wall to counteract the physical stress.

The respective positions of the different heads of the papillary muscle must be maintained at the time

of implantation to obtain an even distribution of traction on the leaflet tissue. Papillary muscles of the mitral valve have a great diversity in appearance. However, the analysis of a series of mitral valves retrieved from cadavers or from explanted hearts at the time of transplantation has allowed us to establish a morphologic classification of papillary muscles to aid homograft implantation (see Fig. 3). This classification did not consider the shape of the muscle, be it rectangular or conical, thick or thin. It was based on the existence of one or several divisions of the papillary muscle and their sites with respect to the commissure.

Four types of increasing complexity were described (see Fig. 3). Simple, undivided type I muscles constituted the largest group and their implantation did not present any technical difficulty. Divided muscles were typed according to the location of the plane of division: type II muscles were cleaved in a sagittal plane forming an individual head supporting the posterior leaflet, whereas type III were cleaved in a coronal plane forming an individual head supporting the commissure (Fig. 3). These two types were also easily transplantable so long as the orientation of the separate heads was preserved. Type IV papillary muscles were divided with multiple heads all originating at different levels within the ventricle (Fig. 3). In this group the commissural chordae were invariably short and originated from a separate muscular band close to the mitral annulus. This arrangement raised such technical difficulty that we recommend that this type of papillary muscle be discarded and the opposite half of the mitral valve used as a partial homograft, if possible.

In the cases of subdivision of the papillary muscles (types II and III), the respective position of the various heads was carefully maintained at the time of implantation. Uneven traction on any one head would lead to a commensurate prolapse or restriction of the opposite leaflet. This was prevented by joining the different heads while the homograft was being prepared before implantation. The head supporting the commissural chordae was used as a marker and fixed initially at the corresponding site alongside the native papillary muscle. The other heads were then sutured accordingly on each side of the commissure.

Our experience has shown this method of implantation to be reliable at the short term and midterm. There have been no cases of rupture either of papillary muscle or chordae among the 43 patients,

either early or late. One patient was reoperated on on the tenth postoperative day with mitral regurgitation caused by dehiscence of the valvular suture in a commissural area. This complication was probably due to excessive traction on the subvalvular apparatus. Previous mitral valve replacement with a prosthesis had been performed and the ventricle was significantly dilated. Measurement of the distance from the apex of the papillary muscle to the mitral anulus was not available and the size of the homograft had been roughly estimated from the diameter of the prosthesis. In general, the insertion of a mitral homograft for replacement of a prosthetic valve has not been satisfactory in this series (one death and one early reoperation).

The proposed systematic use of a prosthetic annuloplasty ring in patients receiving a mitral homograft represents a particularity of this study. The size of the ring selected was based on measurement of the anterior leaflet of the homograft with an obturator. We believe that annuloplasty provides several advantages: (1) It permits precise adaptation of the size of the anulus to that of the homograft; (2) the semirigid structure of the ring absorbs some of the mechanical stress exerted by ventricular contraction and alleviates traction that would otherwise be directly applied on the valvular suture line; (3) ring annuloplasty allows a greater surface of leaflet coaptation, thereby lowering the tension on the subvalvular apparatus. The slight overcorrection achieved by annuloplasty may compensate for imperfections in the regulation of tension of the chordae.

The idea to partially replace the mitral valve with a portion of homograft is not new. In 1964, while working at Broussais Hospital, Cachera and associates³ introduced the concept of partial homograft replacement. They studied varied techniques of mitral valvuloplasty: (1) grafting of a patch of homologous leaflet tissue, (2) replacement of the entire anterior leaflet with its subvalvular apparatus using the corresponding portion of a homograft, and (3) total homograft replacement. More recently, Revuelta and coworkers,³ in a study using an animal model and scanning electron microscopy, demonstrated the perfect integration of a partial homograft when placed amid native mitral tissue.

Use of a partial mitral homograft should be considered as part of the wide range of techniques of mitral valve repair. It is technically feasible to use biologic material (autologous pericardium) to reconstitute a portion of mitral valve leaflet tissue, and

it is also possible to replace several chordae either by chordal transposition or with prosthetic chordae.^{10, 21} However, the presence of a voluminous pathologic process that affects both leaflet tissue and chordae, especially when involving a commissural region, represents a serious limitation to valve reconstruction.²²⁻²⁴ This situation is met most frequently in two conditions, mitral stenosis with calcification and acute bacterial endocarditis with localized abscess formation and vegetations. In our series, 21 patients with either of those indications underwent partial homograft replacement. The remainder of the valve must be normal, because a diseased remnant may lead to a mediocre result (one patient in this series).

Technically, we believe it is preferable to divide the valve vertically with the aim of replacing a commissural region or a hemivalve, rather than dividing the valve along the horizontal axis and replacing an entire leaflet. A vertical division allows selective replacement of 25% to 50% of the valve according to the extent of the lesion. A distinct advantage is that only one papillary muscle needs to be reimplanted. Also, valve closure results from coaptation between two leaflets of the same origin belonging either to the homograft or to the native valve.

Transplantation of an entire leaflet (four cases) does not appear to be fully satisfactory and presents certain drawbacks. Both papillary muscles must be reimplanted and exposure is made more difficult by the presence of the opposing leaflet and its chordae. Afterward, the presence of a suture line in the region of the commissures can impair the opening of the valve. Furthermore, valve closure results from apposition between the homograft and the opposite native leaflet, and the mildest asymmetry in chordal tension may lead to relative prolapse. Although none of the patients having undergone this type of repair have required reoperation, we no longer recommend its use. In the presence of lesions invading a whole leaflet, the entire mitral valve is replaced.

Homograft replacement of the mitral valve may be considered an extension of valvular reconstructive surgery. The theoretic advantages are multiple: cryopreserved homologous tissue has been shown to remain viable²⁵ and its longevity is probably superior to that of glutaraldehyde-treated tissue. It is a biologic material and does not require anticoagulation. In this method of mitral valve replacement the subvalvular apparatus is preserved, so that its im-

portant role in ventricular function is retained.²⁶ The mitral homograft may represent an interesting alternative in children, as shown in two patients in this series. However, long-term results with functional assessment of the transplanted valves are awaited before more liberal use of mitral homografts can be recommended.

REFERENCES

- Rastelli GC, Berghuis J, Swan HJC. Evaluation of function of mitral valve after homotransplantation in the dog. *J THORAC CARDIOVASC SURG* 1965;49:459-74.
- Vliet PD, Titus JL, Berghuis J, et al. Morphologic features of homotransplanted canine mitral valves. *J THORAC CARDIOVASC SURG* 1965;49:504-10.
- Cachera JP, Salvatore L, Hermant J, Herbinet B. Reconstructions plastiques de l'appareil mitral chez le chien au moyen de valves mitrales homologues conservées. *Ann Chir Thorac Cardiovasc* 1964;3:459-74.
- Bodnar E. Editorial. Clinical use of homologous and heterologous mitral valves. *J Heart Valve Dis* 1994;3:468-9.
- Hubka M, Siska K, Brozman M, et al. Replacement of mitral and tricuspid valves by mitral homograft. *J THORAC CARDIOVASC SURG* 1966;51:195-204.
- Ross DN. Replacement of the aortic and mitral valves with a pulmonary autograft. *Lancet* 1967;2:956.
- Yacoub MH, Kittle C. A new technique for replacement of the mitral valve by a semilunar valve homograft. *J THORAC CARDIOVASC SURG* 1969;58:859-69.
- Come PC, Riley MF. M-Mode and cross-sectional echocardiography recognition of fibrosis and calcifications of the mitral valve chordae and left ventricular papillary muscle. *Am J Cardiol* 1982;49:461-8.
- Mihaileanu S, El Asmar B, Lamberti A, Carpentier A. Intraoperative transoesophageal echocardiography after mitral repair—specific conditions and pitfalls. *Eur Heart J* 1991;12(Suppl B):26-9.
- Carpentier A. Mitral valve repair: the "French correction." *J THORAC CARDIOVASC SURG* 1983;86:323-37.
- Sievers HH, Lange PE, Yankah AC, et al. Allogeneous transplantation of the mitral valve: an open question. *Thorac Cardiovasc Surg* 1986;33:227-9.
- Yankah AC, Sievers HH, Lange PE, Bernhard A. Clinical report on stentless mitral allografts. *J Heart Valve Dis* 1995;4:40-4.
- Pomar JL, Mestres CA. Tricuspid valve replacement using a mitral homograft: surgical technique and initial results. *J Heart Valve Dis* 1993;2:125-8.
- Acar C, Farge A, Ramsheyl A, et al. Mitral valve replacement using a cryopreserved mitral homograft. *Ann Thorac Surg* 1994;57:746-8.
- Acar C, Iung B, Cormier B, et al. Double mitral homograft for recurrent bacterial endocarditis of the tricuspid and mitral valves. *J Heart Valve Dis* 1994;3:470-2.
- Acar C, Gaer J, Chauvaud S, Carpentier A. Technique of homograft replacement of the mitral valve. *J Heart Valve Dis* 1995;4:31-4.
- Kuniar AS, Chander H, Trehan H. Surgical technique of multiple valve replacement with biological valves: a new option. *J Heart Valve Dis* 1995;4:45-6.
- Duran CMG. Editorial. Mitral valve allograft: an opportunity. *J Heart Valve Dis* 1995;4:29-30.
- Morea M, de Paulis R, Galtoni M, Gastaldi L, di Summa M. Mitral valve replacement with the Biocor stentless mitral valve: early results. *J Heart Valve Dis* 1994;3:476-82.
- Revuelta JM, Cagigas JC, Bernal JM, Val F, Rabasa JM, Lequerica MA. Partial replacement of the mitral valve by homograft: an experimental study. *J THORAC CARDIOVASC SURG* 1992;104:1274-9.
- Frater RWM, Vetter HO, Zussa C, Dahm M. Chordal replacement in mitral valve repair. *Circulation* 1990;82(Suppl):IV125-30.
- Cukingnan RA, Carey JS, Wittig JH, Cimochoowski G. Early valve replacement in active infective endocarditis. *J THORAC CARDIOVASC SURG* 1983;85:163-73.
- Fuzellier JF, Acar C, Jebara V, et al. Plasties mitrales au cours de la phase aiguë de l'endocardite. *Arch Mal Coeur* 1993;86:197-201.
- Michel PL, Iung B, Drissi F, et al. La chirurgie mitrale conservatrice dans le traitement de l'insuffisance mitrale infectieuse. *Arch Mal Coeur* 1994;87:349-55.
- O'Brien MF, Stafford EG, Gardner MAH, Pohlner PG, McGiffen DC, Kirklin JW. A comparison of aortic valve replacement with viable cryopreserved and fresh allograft valves with a note on chromosomal studies. *J THORAC CARDIOVASC SURG* 1987;94:812-23.
- Gams E, Schad H, Heimisch W, Hagl S, Mendleler N, Sebening F. Importance of the left ventricular apparatus for cardiac performance. *J Heart Valve Dis* 1993;2:642-5.

Discussion

Mr. Magdi Yacoub (*London, England*). There is no doubt that the ideal valve substitute in the mitral position is another mitral valve, because the mitral valve apparatus is a sophisticated structure that changes its shape and dimensions instantaneously to achieve excellent function during both systole and diastole.

I have a few questions. First, is it necessary to use an anulus or a ring, because that will interfere with the function of the mitral valve? Second, what do you think is the fate of the muscular part left in the papillary muscle? In the early 1970s we used a similar technique. We were worried about necrosis of the muscular parts of the papillary muscle and whether that will elongate, and we used to cover it with pericardium. Can you give us your ideas about that? I have two other technical points, as well. Do you use the aortic homograft from the same donor heart, and if you do, how do you avoid encroaching

on the anterior cusp of the mitral valve? Finally, how do you make sure that the orientation of the attachment of the chordae is such that the tension will be distributed equally around these chordae?

Dr. Acar. Sir Magdi, we all are aware of your great contribution in cardiac surgery, and particularly in the field of homografts. Concerning the need for annuloplasty, we believe that ring annuloplasty is a very important addition to mitral homografts. In fact, it absorbs part of the mechanical stress that otherwise would be exerted directly on the valvular suture line. Also it allows the size of the recipient annulus to be adapted precisely to that of the homograft. Finally, use of ring annuloplasty allows an increase in the surface of leaflet coaptation; thereby, it reduces the traction on the subvalvular apparatus and on the sutured papillary muscles.

Concerning the outcome of these papillary muscles, because of the ischemic process and the cryopreservation process, they will become necrotic. Moreover, the reliability of the technique of implantation is based on the healing process of the papillary muscle with progressive fibrosis.

At present, the technicians at the Assistance Public Tissue Bank in Paris are well experienced and are able to harvest both the mitral and the aortic valves. Sometimes some tissue at the insertion of the anterior mitral leaflet is kept attached to the aortic valve. This does not compromise the use of both valves as homografts.

Your last question concerned the proper orientation of the papillary muscle during implantation. We use the commissural chordae as a landmark, which is usually easily identified. The head supporting the commissural chordae is placed at the corresponding location on the recipient's papillary muscle. Then all the other heads are sutured accordingly.

Dr. José L. Pomar (*Barcelona, Spain*). I would like to congratulate Dr. Acar and associates for their courage in this reattempt to solve the problem of replacing the atrioventricular valves with mitral homografts.

We have used cryopreserved mitral homografts to replace the tricuspid valve in four patients since 1991. The four patients had right heart endocarditis induced by their heroin addiction. In all of them antibiotic therapy was unsuccessful. The preoperative CD4 count was high enough to assume a life expectancy of more than 7 to 10 years.

The technique initially described by us does not substantially differ from that showed by Dr. Acar and his group. However, in our technique no prosthetic rings were used and only an autologous pericardial strip was used to reinforce the suture to the posterior leaflet.

In this small series there have been no deaths. A complete primary cure of the endocarditis was achieved in all patients. One patient had a new episode of endocarditis more than 12 months after the transplantation, but this was successfully treated as a native valve infection. The patients have remained free of symptoms for up to 4 years. The postoperative degree of valve regurgitation has not changed since the time of the operation. The subvalvular structures seem to stay in place.

I have a couple of questions for Dr. Acar:

We also have replaced the valve in patients with acute

disease in whom the ventricular dimensions were close to normal. On the contrary, you have implanted some homografts in patients with chronic rheumatic disease, in whom the left ventricular dimensions are supposed to recover once the valve becomes competent. Regarding the length of the chordae and papillary muscles, what is your feeling about the long-term behavior of the implanted grafts as the ventricular size regresses in time?

The second question concerns the fact of using a Carpentier annuloplasty ring in the setting of an active infection. Do you believe it is absolutely necessary to support the graft with a ring or can that be avoided when the graft versus host perimeter and shape mismatch are negligible?

Dr. Acar. We performed echocardiography in our study both immediately after the operation and as long as 34 months after the operation. We have not observed any recurrence of insufficiency or progression of a residual leak, even in patients whose ventricle recovered to normal size. Use of the mitral homograft can be considered as an extension of mitral valve reconstruction because it adheres to the same principles. After reconstruction, once a valve has become competent, the echocardiographic results usually remain stable even though the ventricle resumes a normal size and a normal shape.

We already mentioned that the use of a ring is a very important addition to mitral homografts. We have used a ring for mitral valve repair in patients with acute endocarditis, and we have not observed that recurrence is more prevalent with this operation than with other types of surgical procedures in this setting.

Dr. Radu C. Deac (*Targu-Mures, Romania*). One way to improve the late results of mitral valve replacement, less optimal than those of aortic valve replacement, is to use a stentless mitral valve substitute with the known features of the normal mitral valve: large diastolic opening, continuity to the papillary muscle, and contraction of the posterior left ventricular wall around the mitral annulus. As the authors showed, use of a mitral homograft is one of the ways to improve results. In the 1960s Ross and Senning used such mitral homografts with limited success. Could you identify those factors that allowed you to obtain superior results? One of the keys to making the valve competent on the operating table is adequate sizing and the technique of suturing at the papillary muscle, as you mentioned.

I would like to support the principle of the stentless mitral valve. From our experience with the stentless mitral valve made of stabilized autologous pericardium, used in 19 patients from 1989, we had one case in which the suture at the papillary muscle broke loose and another case in which late endocarditis developed, and both necessitated re-replacement. All the other patients had competent valves from the operation up to 72 months, nearly 7 years after the operation.

The main feature of the valve used was a large orifice area of 4.36 and a valve index superior to the standard mentioned in the literature. With our technique we managed to have secure sutures of the papillary muscle and annulus.

The patients operated on in our series enjoy a normal life with a remarkable exercise capacity, probably because

of the large orifice area and continuity to the papillary muscle.

Dr. Acar. You ask why the technique seems to be effective now whereas it failed years ago. I think two modifications made this technique more reliable.

The first modification is the method of papillary muscle implantation itself, in which a side-to-side suture is used without pledgets. We think that this method contrasts with a purely mechanical approach involving polytetrafluoroethylene pledgets or transfixing stitches through the ventricular wall as described earlier. Our technique relies more on the healing process of the papillary muscle.

The second point is the appropriate matching between the homograft and the native valve. Even sophisticated measurements can provide only an estimate of the size of the valve, and it is very important to provide a certain degree of hypercorrection to compensate for imperfection. This is achieved by using both a slightly larger homograft than the valve size and ring annuloplasty.

Dr. Charles A. Yankah (*Berlin, Germany*). I would like to make some comments from our experience in Kiel, Germany, some years ago, which will highlight the problems regarding the immunologic and technical aspects of mitral allograft surgery.

Professor Bernhard had operated on three patients using viable grafts received from the Harefield Hospital homograft laboratory. One patient's graft was explanted with strong infiltrations of inflammatory cells and macrophages, as well as identified T-lymphocytes of CD4 subtypes. We believe that if a viable graft is used, which is antigenic, it will clearly obey the rules of transplantation biology. Such changes are to be expected, and these changes are going to affect the tissue, which will then cause some structural changes.

Two of our patients had chordal ruptures. The third patient was a 64-year-old woman whose mitral homograft was in place for about 44 months, and eventually she had a papillary muscle rupture rather than a chordal rupture. All three patients underwent uneventful reoperations with prosthetic valve replacement. We have therefore identified two potential weak points for early valve failure. We believe that besides using the annular ring support, which we did not use in our patients because they all had mitral stenosis, one has to support the chordae as well as the anastomotic site of the graft-recipient papillary muscles, to reinforce the very important potential sites of complications that could cause early or late postoperative valve dysfunction. Our word of caution is that these two techniques should be considered: chordal support, which Dr. Vetter in Munich has demonstrated to be very effective, and transpapillary-epicardial suture support.

Dr. Acar, do you think these supports are very relevant for long-term durability of your homografts? How do the chordae and the structures readapt themselves when you have large ventricles, which might undergo a postoperative remodeling process with dimensional changes?

Dr. Acar. The late outcome of this type of procedure obviously remains unknown. The histologic structure of the chordae is very close to that of the leaflet tissue. We hope that mitral homografts will provide results comparable with those of aortic homografts.

I would like to make one last comment concerning the use of transfixing stitches with pledgets for papillary muscle implantation. We believe that the use of prosthetic material at the level of the papillary muscle in fact can be dangerous and can lead to progressive erosion and weakening of the chordae. In this series, there was no chordal rupture or papillary muscle dehiscence.