A 17-year experience with mitral valve repair with artificial chordae in infants and children†

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Abstract

OBJECTIVES: We sought to examine our long-term results of mitral valve (MV) repair with expanded polytetrafluoroethylene (ePTFE) sutures and to determine the predictors for the outcome of this procedure.

METHODS: Between 1995 and 2011, MV repair with chordal reconstruction by artificial chordae was achieved in 78 patients (34 males and 44 females). Median age at repair was 1.5 years (range 3.6 months–13.4) and weight was 9.1 kg (2.5–31.4). The mean follow-up was 8.3 years. A Cox proportional hazards model was used to analyse the risk factors for a composite outcome of death, conversion to other MV repair techniques or MV replacement, reoperation on MV and recurrent mitral regurgitation (MR).

RESULTS: According to Carpentier classification, 65 (83.3%) patients were Type 2 and 13 (16.7%) were Type 3. Mitral annuloplasty was performed in all cases, except 2. During MV repair, 8 (10.3%) patients were ineffective with artificial chordae and converted to other techniques. Six (7.7%) patients underwent MV reoperation (three repairs and three replacements). Freedom from MV reoperation was 92.5 and 90.4% at 5 and 10 years, respectively. There was 1 in-hospital death. At the latest follow-up, moderate or more MR was observed in 3 (3.8%) patients. Risks for the composite outcome were low body weight at operation and Carpentier classification Type 3.

CONCLUSIONS: MV repair with artificial chordae in infants and children is safe and effective and associated with a low reoperation rate. Further investigation into the long-term durability and biological adaptation of ePTFE sutures after patient growth is mandatory.

Keywords: Mitral valve repair • Artificial chordae • Expanded polytetrafluoroethylene • Congenital heart disease • Long-term outcome

INTRODUCTION

After Vetter et al. [1] and Zussa et al. [2] reported their experimental works that expanded polytetrafluoroethylene (ePTFE) sutures for mitral valve (MV) repair maintained their original length, pliability and bending properties, David et al. [3] started to use ePTFE sutures for treating adult patients with mitral regurgitation (MR). Their 25-year experience of chordal replacement with ePTFE sutures for MV repair in adult patients showed excellent long-term outcome [4]. Various studies have shown the same excellent results in adult patients [5, 6]. We adopted the use of ePTFE sutures in children with congenital MR in 1995 and reported our original technique of reconstructing neochords and its favourable mid-term outcome [7, 8]. However, the limitation that the ePTFE suture does not have the potential of growth with somatic growth in children has not been solved. Thus, continuous follow-up is mandatory. The purpose of the present study was to investigate our clinical experience with MV repair using a unique reconstruction technique in children during the past 17 years.

PATIENTS AND METHODS

Patient population

All medical records of patients who underwent MV surgery between April 1995 and December 2011 at Fukuoka children’s Hospital (Japan) were reviewed retrospectively. Of 182 patients under 15 years of age who underwent primary MV surgery for MR, 78 (42.8%) underwent MV repair with chordal replacement with ePTFE sutures, 97 (53.3%) underwent MV repair without ePTFE sutures and 7 (3.9%) underwent MV replacement. Of 175 patients who underwent MV repair, 8 (4.6%) had subsequent MV replacement. Table 1 summarizes the clinical characteristics of patients who underwent MV repair with ePTFE sutures. Patients with single-ventricle physiology were excluded from this study. Our institutional review board approved this retrospective study.
the length of the ePTFE suture, moving the pledget to the appropriate point. This pledget became the mark of the tied point. Thus, the knot could be tied at the leaflet level. The free edge of the prolapsed area was then pulled upward, so that the pledget was anchored to the papillary muscle (Fig. 1). When the prolapsed area was wide, another ePTFE suture was replaced in the same fashion. One hundred and four pairs of ePTFE sutures for a total of 208 neochords were constructed. The number of neochords ranged from 2 to 6, with a mean of 2.7 ± 1.0 chords per patient.

Echocardiographic evaluation

We had previously described the definitions of the grades of MR as: none, no abnormal systolic flow was detected; trivial, the abnormal systolic flow was localized immediately posterior to the MV; mild, the abnormal systolic flow was detected at a wider area posterior to the MV, but faded away when the echo beam was directed toward the aortic root and the MV disappeared from the view; moderate, the area of the abnormal systolic flow was well presented, reaching the anterior half of the left atrial cavity; severe, the area of the abnormal systolic flow was presented diffusely all over the left atrium [7].

Follow-up

The follow-up of this study was closed on 28 March 2012. The mean follow-up period was 8.3 ± 5.6 years (range 0–17 years). During the follow-up period, all patients were evaluated for the valve and the ventricular function by transthoracic echocardiograms, and the latest was taken into the analysis. The mean echocardiographic study follow-up period was 5.5 ± 5.0 years (range 0–15 years).

Statistical analysis

Continuous variables were expressed as mean ± standard deviation or median and categorical variables as percentages. Longitudinal data were estimated by the Kaplan–Meier method. A Cox proportional hazards model was performed to identify the independent predictors of a composite outcome of death, conversion to other MV repair techniques or replacement, reoperation on MV and recurrent MR by entering all the variables that had been found to be significant on univariable analysis (P < 0.1 was considered significant in univariable analysis and P < 0.05 in multivariable analysis). Patients who did not reach the outcome were censored at the time of the last follow-up. Variables included in the Cox proportional hazards model were sex, age at operation, weight at operation, grade of preoperative MR, previous cardiac surgery, additional procedure, number of chordal replacement, Carpentier classification [9], leaflet prolapse, cardiopulmonary bypass (CPB) time and cross-clamp time.
RESULTS

Survival

There was 1 death during the follow-up. This patient was a 4-month old boy who presented with severe left ventricular dysfunction, severe aortic regurgitation (AR) and moderate MR. Severe AR occurred after balloon aortic valvotomy, and he was referred to our hospital for surgery. Emergency operation of Ross-Konno and MV repair with an ePTFE suture was performed. The haemodynamic state was stable after the operation, but he died in postoperative day 6 due to septic shock.

Conversion to other mitral valve repair techniques or mitral valve replacement during mitral valve repair with ePTFE sutures

Eight (10.3%) patients repaired with ePTFE sutures failed. Two (2.6%) patients were Carpentier classification Type 2. One (1.3%) patient with posterior leaflet prolapse was converted to quadrangular resection and annuloplasty. The other with posterior leaflet massive chordae rupture was converted to direct anastomosis of the leaflet and papillary muscle because of a fragile leaflet. This patient had a concomitant annuloplasty also. Six (7.7%) patients were Carpentier classification Type 3. The subtype was short chordae in 5 (6.4%) patients and papillary muscle commissure fusion in 1 (1.3%). All of these patients had a dysplastic valve. Two (2.6%) patients were converted to chordae shortening and annuloplasty to adapt the level of the coaptation zone because of the thickened and rigid chordae. One (1.3%) patient was converted to cleft closure and annuloplasty. The other 3 (3.8%) patients were converted to MV replacement.

Reoperations

Reoperations on the MV were performed in 6 (7.7%) patients. The aetiology of MR at initial MV repair was Carpentier classification Type 2 in 4 (5.1%) patients and Type 3 in 2 (2.6%). The indication for reoperation was recurrent MR in all cases. All ePTFE sutures were intact at reoperation. Two (2.6%) patients had leaflet prolapse at a different portion from the initial MV repair and had re-repair with replacement of ePTFE sutures. One (1.3%) patient had mitral cleft and it was closed. Three (3.8%) patients had MV replacement with a mechanical prosthesis. Their leaflets were thickened and shrunken, so that re-repair was not chosen. Median age at reoperation was 1.6 years (range 4 months–10 years). The median interval between initial MV repairs to
reoperations was 8 months (range 17 days–5 years). Freedom from reoperation was 92.5% at 5 years and 90.4% at 10 years (Fig. 2).

Risk factors of a composite outcome of death, conversion to other mitral valve repair techniques or replacement, reoperation on mitral valve and recurrent mitral regurgitation

Univariable analysis showed sex ($P = 0.004$), age at operation ($P = 0.09$), weight at operation ($P = 0.02$), Carpentier classification ($P < 0.0001$), CPB time ($P = 0.08$) and cross-clamp time (0.08) as the significant risk factors. By multivariable analysis, weight at
operation (weight per 1-kg increments; odds ratio [OR], 0.77; 95% confidence interval [CI], 0.58–0.99; P = 0.04) and Carpentier classification Type 3 (OR, 5.65; 95% CI, 1.86–17.26; P = 0.002) were found to be significant (Table 3).

### Echocardiogram

There were 62 (79.5%) patients in whom the use of ePTFE did not fail, who were not reoperated and who were alive. The latest echocardiogram of these patients showed that the left ventricular ejection fraction, left ventricular diastolic diameter, MV diameter and maximum trans-mitral flow velocity were 71.0 ± 8.5% (range 51.0–89.0%), 98.1 ± 15.1% of normal (range 66.7–158.2%), 92.0 ± 15.1% of normal (range 66.4–129.5%) and 122.2 ± 26.6 cm/s (range 57.9–195.0) respectively.

### DISCUSSION

The present study reviewed our 17-year experience with MV repair with ePTFE sutures in children. To the best of our knowledge, this study is the largest series, including long-term follow-up data.

Because of the excellent long-term durability of MV repair with ePTFE sutures in adult patients, ePTFE chordae is now a feasible material for artificial chordae [10]. Minatoya et al. [11] had found that ePTFE sutures in the human heart were covered with a new layer of collagen that would contribute to the durability of ePTFE sutures. Although the use of ePTFE sutures in growing children is controversial for its limitation of growth in length, satisfactory results were recently reported [12–14]. Our previous report [8] and Murashita et al. [12] have shown that the compensatory extensive growth of the mitral leaflet and papillary muscle was the main mechanism for biological adaptation after MV repair with ePTFE sutures in children. Although the biological adaptation demonstrated the feasibility of ePTFE sutures, there is a great concern about the restrictive motion of the subvalvular apparatus in the long-term follow-up. Our 17-year experience showed no mitral stenosis in all patients and a low incidence of recurrent MR, indicating the pliable motion of the repaired MV. This was supported by satisfactory valve function and left ventricular function measured by echocardiogram at the mean follow-up of 5.5 ± 5.0 years (range 0–15).

Our operative technique of reconstructing ePTFE sutures has not changed during the study periods, except at one point. In the earlier phase of the study, CV-4 or CV-5 was used. As our clinical experience grew, we realized that CV-6 and CV-7 have enough strength and increased flexibility. In recent years, we favoured CV-6 and CV-7. Our surgical technique is simple. The major concern to achieve MV competence is to obtain the exact length of ePTFE sutures. The suture must be tied at the exact point. We use the pledget as a marker of a tied point. We determined the length by moving the pledged, which was adjusted with the adjacent normal leaflet or the facing leaflet. The suture is then tied in the atrium, but not in the ventricle, where the space is small, particularly in paediatric patients. The pledget and the knot are finally pulled down to the papillary muscle, avoiding interference with leaflet coaptation. Even though the length is incorrect, we can remove the suture easily and repeat the procedure in the same fashion within a short time.

Freedom from reoperation was high among our patients at 90.4% at 10 years. Despite the severity of mitral disease and the complexity of repair in children, our results are comparable with those previously reported in adult patients (David et al. [4], 90.2% at 18 years; Salvador et al. [5], 92% at 15 years). Moreover, in the present study, all patients had the same ePTFE reconstruction technique, indicating that our surgical technique may be a promising procedure for MV repair in children.

There were some reports about calcified and ruptured ePTFE sutures, causing recurrent MR after 6–14 years after MV repair [15–17]. Interestingly, all of these patients were adult. To our knowledge, no cases of calcified and ruptured ePTFE sutures have been reported in the paediatric patients. We also found no ruptured ePTFE sutures during the study periods. However, we cannot abandon the possibility that calcified and ruptured ePTFE sutures will occur in the long term, thus, careful follow-up is mandatory.

Carpentier classification Type 3 was a significant predictor of negative outcomes. This type of MV disease commonly includes various malformations, such as hypoplastic leaflet, cleft, prolapse and pseudoprolapse. In our experience, 6 of the 8 patients in whom the use of ePTFE sutures failed during MV repair were Type 3 with severe dysplastic valves. MV repair of these valves are challenging. Various techniques should be combined for adequate valve reconstruction. We believe that our technique is one of the useful procedures trying to reconstruct these

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**Table 3: Predictors of composite outcome**

<table>
<thead>
<tr>
<th>Risk factors</th>
<th>Univariable analysis</th>
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<th>Multivariable analysis</th>
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<tbody>
<tr>
<td></td>
<td>OR</td>
<td>95% CI</td>
<td>P-value</td>
<td>OR</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Male/female</td>
<td>4.16</td>
<td>1.53–13.19</td>
<td>0.004</td>
<td>2.91</td>
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<tr>
<td>Age at operation</td>
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<td>0.97–1.00</td>
<td>0.09</td>
<td>1.03</td>
</tr>
<tr>
<td>Weight at operation</td>
<td>0.90</td>
<td>0.78–0.99</td>
<td>0.02</td>
<td>0.77</td>
</tr>
<tr>
<td>Carpentier classification</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Type 3/Type 2</td>
<td>9.08</td>
<td>3.38–24.82</td>
<td>&lt;0.0001</td>
<td>5.65</td>
</tr>
<tr>
<td>CPB time</td>
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<td>0.99–1.01</td>
<td>0.08</td>
<td>0.99</td>
</tr>
<tr>
<td>Cross-clamp time</td>
<td>1.00</td>
<td>0.99–1.01</td>
<td>0.08</td>
<td>1.02</td>
</tr>
</tbody>
</table>

OR: odds ratio; CI: confidence interval; MR: mitral regurgitation; CPB: cardiopulmonary bypass.
dyssplastic valves because of its simplicity and reproducibility. Furthermore, ePTFE sutures can be removed with less damage to valve tissues, which can allow adjusting different techniques.

There are some limitations in this study, particularly the retrospective nature of the analysis. Because of the small number of each negative outcome (death, \( n = 1 \); failed ePTFE sutures, \( n = 8 \); reoperation, \( n = 6 \); recurrent MR, \( n = 3 \)), risk factor analyses for each outcome were impracticable. The number of patients is relatively small, and the follow-up period is not sufficiently long to be conclusive. Regardless of these limitations, we believe that our study confirms the use of ePTFE sutures for MV repair in infants and children under continued long-term surveillance.

In conclusion, ePTFE is a useful material for the replacement of neochordae during MV repair in children. Our study showed an excellent reoperation rate and satisfactory valve function at the long-term follow-up. Our technique of ePTFE replacement for children is simple, reproducible and reliable. Further investigation into the long-term durability and biological adaptation of ePTFE sutures after patient growth is mandatory.

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Conflict of interest: none declared.

REFERENCES


APPENDIX. CONFERENCE DISCUSSION

Dr G. Ghez (London, UK): Victor Tsang was supposed to discuss the paper but he couldn’t come. The concern with Gore-Tex chordae obviously is that they do not grow and do they become restrictive with time. Now, it is fair to say that most of your experience was done in more recent years. Do you have many patients followed for more than 10 years?

Dr Ota: Yes.

Dr Ghez: And if yes, did you observe any problem with restriction of the chordae?

Dr Ota: We have no problem with restriction of the chorda. The mechanism of the biological adaptation may be the compensatory excessive growth of leaflets and papillary muscle. We have shown these data in 2005, and this year some papers from Japan have shown the same mechanism of the adaptation of these valves using ePTFE sutures.

Dr Ghez: Thank you. And the last question. You mentioned you do annuloplasty in all patients. What technique do you use exactly? Do you use prosthetic material for annuloplasty?

Dr Ota: No. Mainly Kay–Reed. If we could use a size 28 ring, we adapted to use prosthetic material.

Dr B. Asfour (Sankt Augustin, Germany): You are using a full ring?

Dr Ota: We have used two rings. One was a Cosgrove ring and one was a Physio ring.

Dr E. Belli (Le Plessis Robinson, France): I have a question concerning the mechanism, according to Carpenter classification, of your patients who are supposed to have congenital mitral regurgitation. In Europe, the dominant mechanism is restricted leaflet function and annular dilatation, in Paris we call it “mitral dysplasia” for congenital mitral regurgitation. So how do you explain a so high rate of prolapsed leaflet function in the congenital population?

Dr Ota: This technique adapts to the prolapse. We have another category of valve diseases too. In this paper we only presented the valve diseases which were reconstructed with ePTFE sutures. So I don’t now know the proportion of the prolapse leaflet in our institution.