Valve-Sparing Tetralogy of Fallot Repair With Intraoperative Dilation of the Pulmonary Valve. Mid-Term Results

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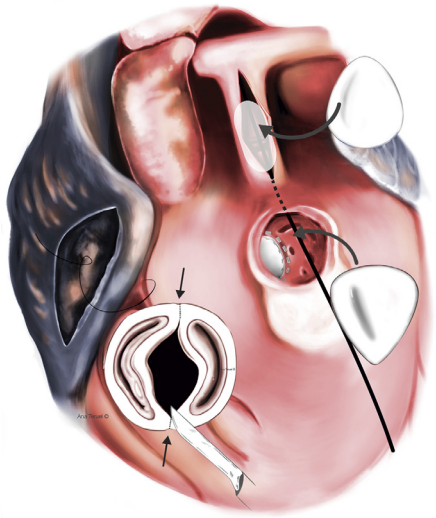
Deleterious long-term effects of chronic pulmonary regurgitation after repair of tetralogy of Fallot have become evident during the last decades. Subsequently, some groups have developed strategies to spare the pulmonary valve function at the time of repair with good early results. However, mid-term outcomes are scarce in the literature and in some cases controversial. The aim of our study is to report our results mid-term with valve-sparing repair of tetralogy of Fallot. We retrospectively reviewed patients undergoing tetralogy of Fallot repair and having preservation of the pulmonary valve with intraoperative dilation at our institution. From June 2009 through June 2017, 42 patients underwent valve-sparing tetralogy of Fallot repair. Median age and weight at surgery were 5.2 months and 7.2 kg. Median preoperative pulmonary valve diameters and Z scores by echocardiography were 6.4 mm (range 4.5−11 mm) and −2.3 (range −1.3 to −4.5). No patient died in our series. For a median follow-up of 45 months, the pulmonary valve has grown by Z score ($P < 0.0001$) as well as the pulmonary trunk ($P = 0.00216$). Significant pulmonary regurgitation has developed in 9 patients (21.4%). No patient has required reintervention/reoperation for recurrent right ventricular outflow tract obstruction. Patients with tetralogy of Fallot who had valve-sparing repair with intraoperative dilation of the pulmonary valve show good early and mid-term results with respect to right ventricular outflow tract obstruction. The pulmonary valve annulus and the pulmonary trunk grow through follow-up. Progressive development of significant pulmonary regurgitation is seen in more than 20% of patients. Long-term data with this approach and comparison with a population of patients undergoing a transannular patch repair are required to establish the real utility of this approach.

Semin Thoracic Surg 31:828–834

Keywords: Tetralogy of Fallot, Valve-sparing, Cardiac surgery



Surgical steps for valve-sparing tetralogy of Fallot repair.

Central Message

Valve-sparing repair of tetralogy of Fallot provides good mid-term results in selected patients with low incidence of recurrent obstruction.

Perspective Statement

Well-known long-term complications derived from chronic pulmonary regurgitation after repair of tetralogy of Fallot have led to adoption of valve-sparing techniques. Mid-term results of this approach are scarce and in some cases controversial with respect to the incidence of reinterventions for recurrent obstruction and the development of significant pulmonary regurgitation through follow-up.

Abbreviations: LPA, left pulmonary artery; LV, left ventricle; PR, pulmonary regurgitation; PS, pulmonary stenosis; PT, pulmonary trunk; PV, pulmonary valve; RPA, right pulmonary artery; RV, right ventricle; RVOT, right ventricular outflow tract; RVOTO, RVOT obstruction; TAP, transannular patch; TOF, tetralogy of Fallot; VSD, ventricular septal defect

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Funding: None.

Conflicts of Interest: None.

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1043-0679/$–see front matter
https://doi.org/10.1053/j.semtcvs.2019.04.007

INTRODUCTION

Initial series of patients with tetralogy of Fallot (TOF) having surgical repair in the 1960s and 1970s were mostly performed with large transannular right ventricular outflow tract (RVOT) patch.[1] The hemodynamic result of this approach is acute development of significant pulmonary regurgitation (PR).[1] Although neglected through decades, PR is now recognized as injurious to the right ventricle (RV) over the long term.[2,3] RV dilation, diastolic dysfunction and fibrosis as well as tricuspid regurgitation, left ventricle (LV) dysfunction, and ventricular arrhythmias are all recognized late sequelae of chronic PR following TOF repair.[4]

Recent studies demonstrate that patients with repaired TOF by a transannular patch (TAP) and with similar PR fractions showed less RV dilation and dysfunction in the presence of some residual pulmonary stenosis (PS).[5] Therefore, it has been suggested that a proper relief of RVOT obstruction (RVOTO) with acceptable residual stenosis is more advantageous than aggressive RVOT enlargement in the long term of repaired TOF. With this in mind, we as well as other groups have attempted to develop strategies aimed at improving RVOTO with preservation of the pulmonary valve (PV) competence.[6–8] However, the optimal balance between residual PR and PS remains unclear. Moreover, little information is available on mid-term outcomes of this approach.

The aim of this study is to report our mid-term results with pulmonary valve-sparing repair of TOF. We specifically evaluated PV and RV function as well as growth of the right sided heart structures by echocardiography through follow-up.

MATERIALS AND METHODS

We retrospectively analyzed the records of all patients undergoing TOF with PV preservation repair at our institution from June 2009 through June 2017. Our institutional approach for primary TOF repair is to perform surgery between 3 and 6 months. However, we receive patients with TOF from Africa on a regular basis who had surgery at later age. The data presurgical, predischarge, and most recent follow-up were obtained from digital medical records of each patient. Echocardiographic measurements of PV, PT, left pulmonary artery (LPA), right pulmonary artery (RPA), RV end-diastolic diameters and RVOT gradients in 2-dimensional, and color Doppler were performed on each patient before surgery (T1), before discharge (T2), and at most recent follow-up (T3). RV end-diastolic diameter was measured in the 4-apical view at the basal level (from the RV lateral wall to the ventricular septum) at the end of the diastole. PV was measured at the level of the annulus, PT diameter at the sinotubular junction and LPA and RPA at the origin of the branches. The measurements, analysis, and quantification of these values were performed by an experienced observer in our workstation (Philips Xcelera). Finally, mean echocardiographic values were indexed to body surface area to calculate Z scores. The study was in accordance with our institutional review board and informed consent was waived.

Valve-Sparing Approach

The decision on whether or not a patient should undergo valve-sparing repair was made with a combination of preoperative echocardiogram and intraoperative surgical inspection. Patients with dysplastic features and very small Z scores (−3.5 or less) of the PV were not initially considered for this approach. Any patient with any degree of valvular PS was evaluated for valve-sparing surgery. Nevertheless, the final decision was frequently made in the operating room after surgical inspection of the PV. Nonpliable, thickened, domed-shaped, and dysplastic valves were less likely to have a successful repair. When in doubt, extensive valve commissurotomies down to the annulus were carried out and resulting annular size measured with Hegar dilators. In cases where the valve annulus was 1−2 mm away from the target orifice (Z score of 0), balloon dilation was performed.

We describe briefly our surgical valve-sparing approach to TOF (Figs. 1−5). Our institutional approach to this population

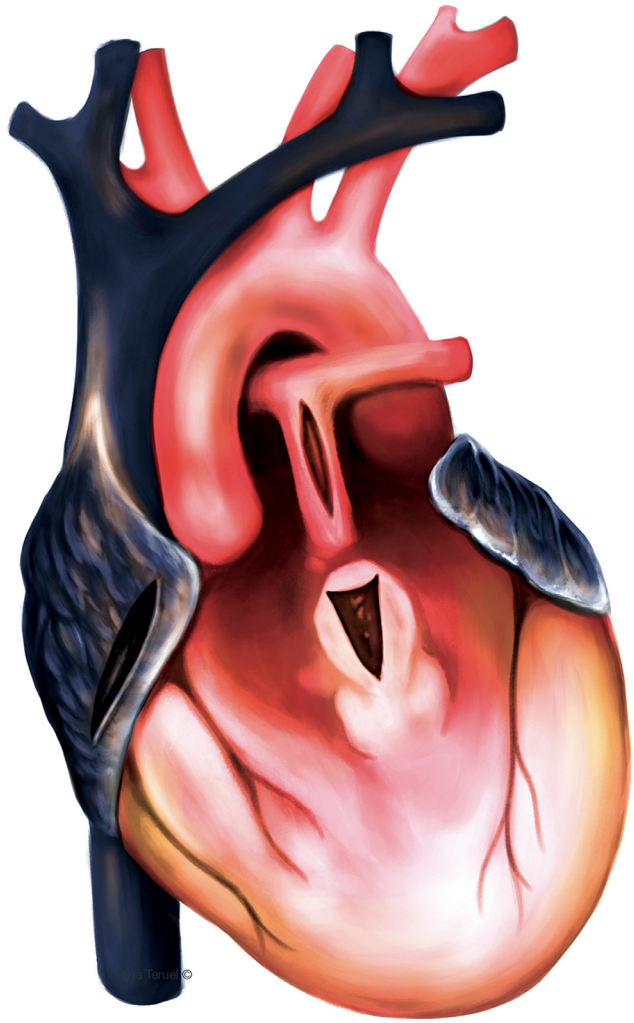


Figure 1. Valve-sparing repair of TOF. Step 1. Infundibular and PT incisions. Note that the infundibular incision is triangular-shape with the base close to the pulmonary valve annulus. The PT incision is vertical from the bifurcation to the valve sinus.

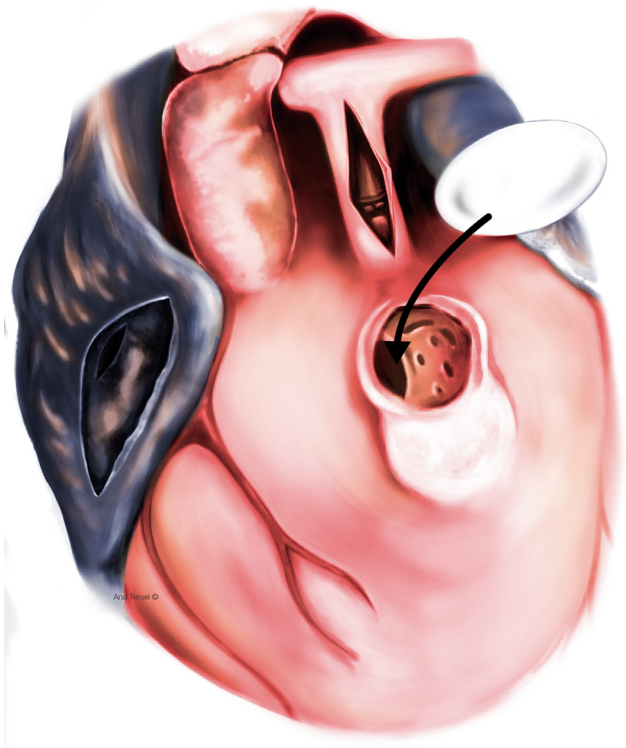


Figure 2. Valve-sparing repair of TOF. Step 2.
The ventricular septal defect is exposed and closed with a circular-shaped bovine pericardial patch after extensive resection of muscle bundles.

of TOF patients entails resection of muscle bundles and closure of the VSD through a 1 cm approximately right infundibulotomy which is performed in an inverted "T" shape. The main pulmonary trunk (PT) is opened from the bifurcation down to the level of the annulus at the hinge point of the anterior leaflet so the PT incision is separated from the infundibulotomy by a small distance which corresponds with the PV annulus.

Commissurotomies were carried out down to the level of the PV annulus, considering the annulus as the attachment of the leaflet to the arterial wall. The resultant annular orifice was tested with Hegar dilators. A guide was passed through the ventriculotomy into the LPA and then, a balloon was inserted. Dilations were made under direct inspection up to the expected PV Z scores. The same balloon was inflated 2 or 3 times at progressive pressure levels starting at 6 atmospheres and going up to 8 atmospheres. A few patients had dilation of the PV annulus only with Hegar dilators. The valve was carefully inspected looking for tears or annular disruption, and additional valve repair procedures were carried out as needed. Finally, the right infundibulotomy and the pulmonary incisions were enlarged with redundant bovine pericardial patches (Synovis Peri-Guard) (see surgical video).

If coming off by-pass a mean transpulmonary gradient of more than 30 mm Hg by transesophageal echocardiography or direct pressure measurements, a TAP approach was undertaken by splitting the PV annulus and connecting the

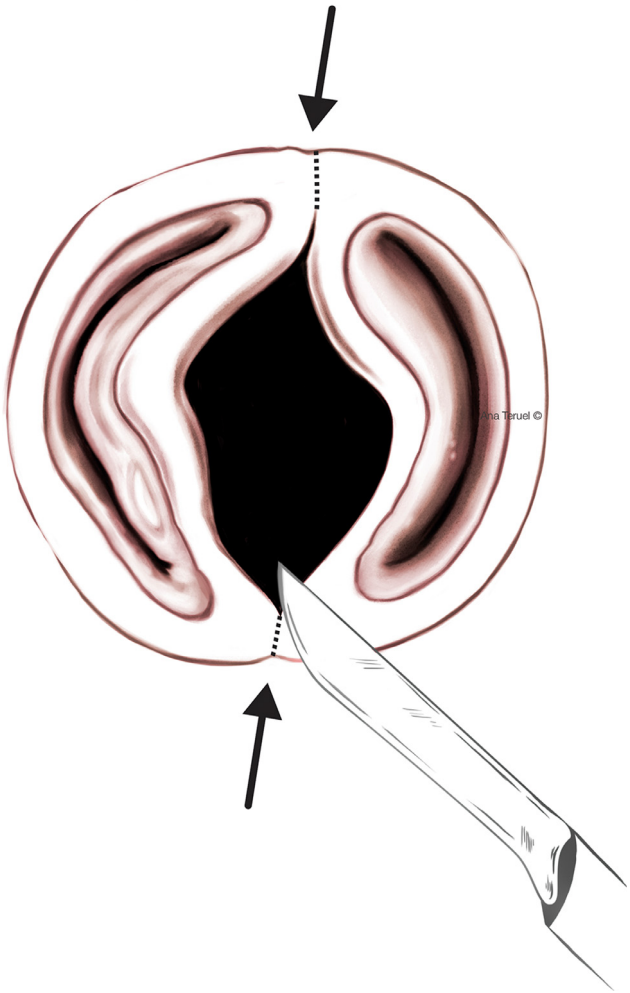


Figure 3. Valve-sparing repair of TOF. Step 3.
Typical pulmonary valve anatomy in a patient with TOF with thickened leaflets and a bicuspid valve. The commissurotomies are carried out in the fussed areas down to the level of the annulus. No further surgical procedures are performed on the leaflets.

pulmonary and infundibular patches with an extraoval-shaped patch on the beating heart.

During follow-up, reintervention criterion for stenosis was an echocardiographic mean gradient across the pulmonary valve of above 50 mm Hg, and for pulmonary insufficiency was based on dilatation of the right ventricle (mainly, RVEDV >150 mL/m^2), regardless of the degree of regurgitation.

Statistical Analysis

Continuous variables are presented as median (range). Comparison of the preoperative echocardiographic variables (T1) with those of the postdischarge initial study (T2) and most recent follow-up evaluation (T3) was done using a paired *t* test or a Wilcoxon signed-rank test with continuity correction when appropriate. Multiple comparisons of means were done with Tukey contrasts.

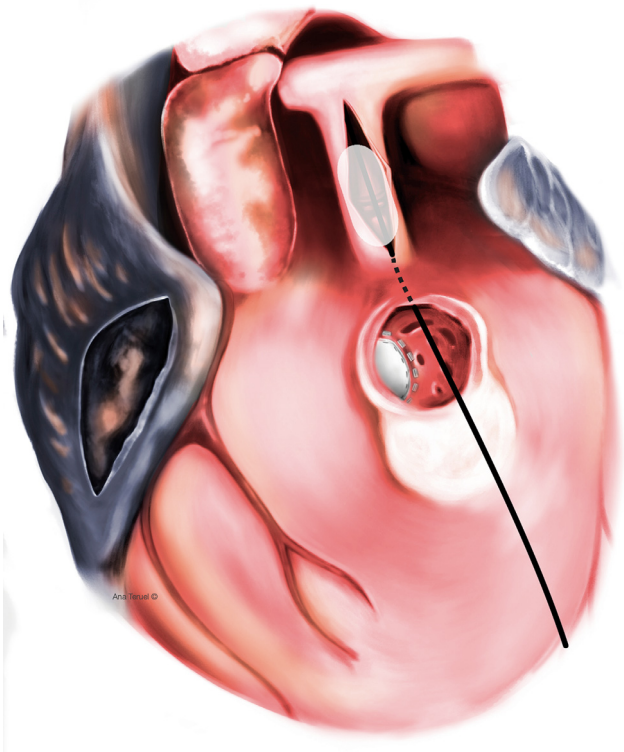


Figure 4. Valve-sparing repair of TOF. Step 4.
The angioplasty balloon is inserted through right ventricular infundibulotomy and advanced across the pulmonary valve. Sequential dilations are undertaken up to a Z score of 0. Note that a right atriotomy has been performed for septal defect inspection and reduction if necessary.

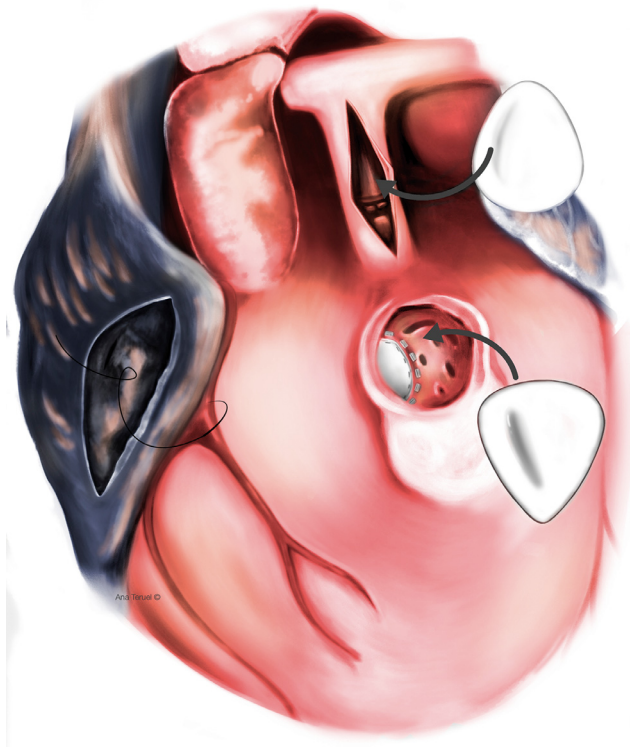


Figure 5. Valve-sparing repair of TOF. Step 5.
An oval-shaped redundant patch is used to enlarge the PT from the bifurcation to the base of the sinus. Finally, a shield-shaped patch is placed in the infundibulotomy. The atrial septal defect is reduced to a 2−4 mm defect.

A *P* value lower than 0.05 was considered significant. All data analysis and graphs were performed using R version 2.14.1 software (Vienna, Austria).[9]

RESULTS

From June 2009 through June 2017, 42 patients (16 female; 38%) underwent primary TOF repair at our institution with pulmonary valve-sparing surgery with intraoperative dilation of the PV. Ten patients in our series had dilation exclusively with Hegar dilators. Median age and weight at repair were 5.2 months (range 3.4−120 months) and 7.2 kg (range 4.7−47 kg), respectively. Preoperative median RVOT gradient was 50 mm Hg (range 30−78 mm Hg). Median PV diameters and Z scores were 6.4 mm (range 4.5−11 mm) and −2.3 (range −1.3 to −4.5), respectively.

In all cases, the RV infundibulum and the PT were opened. VSD closure and resection of muscle bundles were done through the ventriculotomy. In our series, 31 patients (73.8%) had a bicuspid and 11 patients a tricuspid PV (26.2%) with varying degrees of commissural fusion. Dilatation of the PV was performed with no technical difficulties. All patients had commissurotomies prior to dilation. Five patients had leaflet tears after dilation which were repaired with single stitches. Finally, the RVOT and PT were patched with bovine pericardium (Synovis Peri-Guard). Median cross-clamp and pump times were 67 minutes (range 43−119 minutes) and 101 minutes (57−179 minutes), respectively.

No patient died in our series. Mean ICU and in-hospital stay were 4 days (range 2−18) and 7 days (range 5−25), respectively. One patient developed a postoperative chylothorax and UTI by Serratia. One patient required early catheterization by proximal RPA stenosis which was dilated and stented. Predischarge echocardiography showed a slightly improvement in PV absolute diameter and Z score with a mean RVOT gradient of 24.5 mm Hg (range 7−38 mm Hg) and all patients had trivial or mild PR, except for 3 who showed moderate or higher PR.

For a median follow-up of 45 months (range from 10 to 102 months) the PV annulus measurement and Z score have improved significantly from preoperative data ($P < 0.0001$; Fig. 6). Moreover, the annular size normalized over time while the mean RVOT gradient remained in the mild level (median 24, range 12−36 mm Hg; Fig. 7). One patient required catheterization for LPA stenosis and had stent placement. At most recent echocardiography, 9 patients (21.4%) depict moderate or higher PR. No significant differences between RV end-diastolic diameter through follow-up were found. The PT diameter increased significative from the preoperative measurements to most recent follow-up ($P = 0.00216$). Comparison of

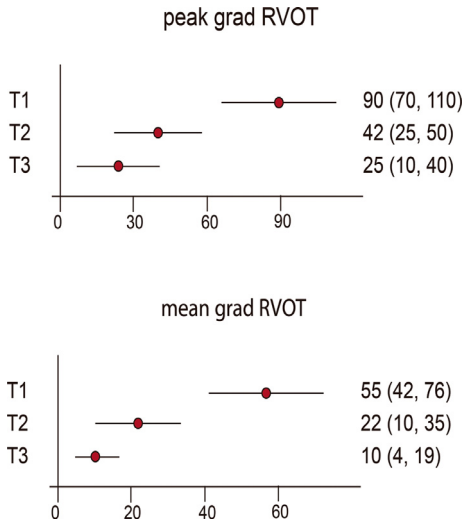


Figure 6. Growth measured by Z score of the right-sided heart structures from preoperative (T1) through early postoperative (T2) to most recent follow-up (T3) echocardiography. Note that the PV and PT grow significantly overtime. No significant differences are seen in RPA, LPA, or right ventricular end-diastolic dimension during follow-up.

different variables from preoperative to most recent follow-up echocardiography is shown in Figures 6 and 7.

COMMENTS

Preservation of the PV function in patients undergoing TOF repair is an ongoing issue in pediatric cardiac surgery.[10,11] The deleterious long-term effects of chronic PR in patients who had a TAP are now well-known. However, a survey of the Society of Thoracic Surgeons (STS) Database[12] concluded that ventriculotomy with TAP remains the most prevalent technique, both for primary repair and for repair following palliation. We report our mid-term results with 42 patients diagnosed with TOF who underwent primary repair with attempted preservation of the PV by means of balloon or Hegar dilator. No patient died in our series. For a median follow-up of 45 months (range from 10 to 102 months), patients undergoing successful preservation of the PV show significant growth of the PV annulus as well as normalization of its size with respect to preoperative dimensions, with the subsequent decrease in RVOT gradient. At most recent follow-up echocardiogram, median RVOT gradient is 24.5 mm Hg and 9 patients (21.4%) show moderate or higher PR. Two patients required reintervention for pulmonary artery branches stenosis and no patient had reoperation for either RVOTO or PR.

Although there is increasing evidence on the benefits of pulmonary valve-sparing TOF repair, reports on this issue are not common and controversial data exit. The pioneering and largest series to date evaluating the role of intraoperative dilation of the PV was initially published by Robinson et al in 2012.[7] They studied 238 patients undergoing repair of TOF at Children's Hospital Boston and divided into 4 groups: 111 had a TAP, 71 commissurotomy or rigid dilation, 32 balloon valvuloplasty, and 24 patients no valvar intervention. Only patients with mild-to-moderate PV hypoplasia (PV Z scores between −2 and −4) underwent balloon dilation. They found that this

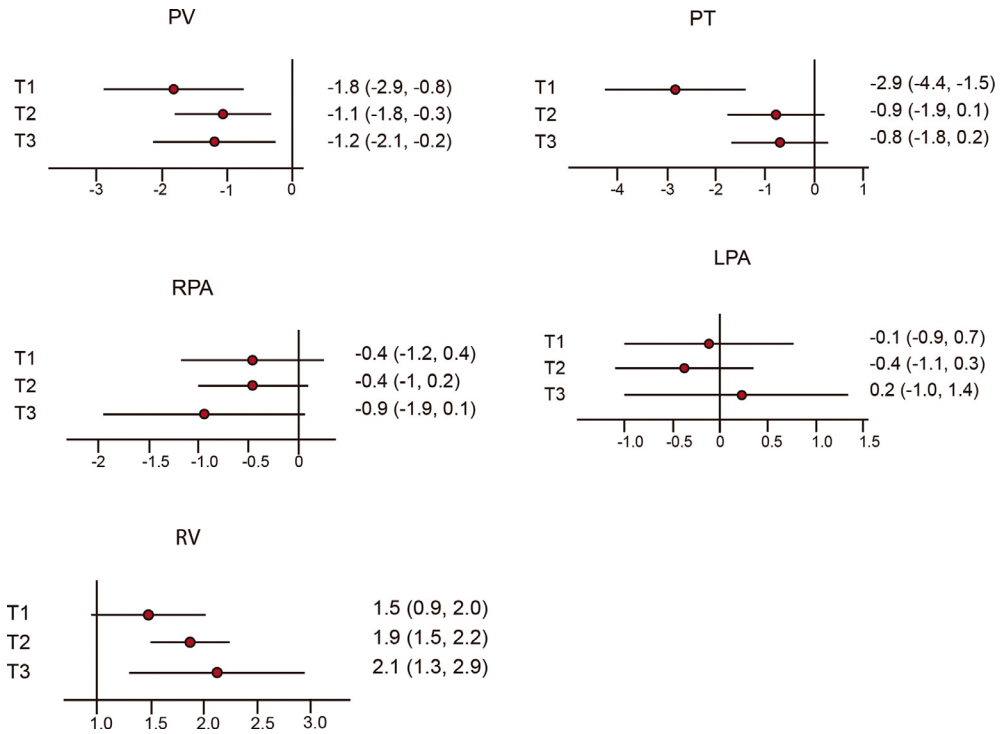


Figure 7. Progression of mean and peak RVOTO gradient from preoperative (T1) through early postoperative (T2) to most recent follow-up echocardiogram (T3). Note the progressive decrease of the gradient overtime.

technique provided significant pulmonary annular growth over time. However, significant reintervention rate was observed in the balloon valvuloplasty group with 6 patients requiring either surgical ($n = 4$) or interventional ($n = 2$) relief of residual RVOTO through a median follow-up of 1.5 years. This series has been recently updated by Nathan et al and reported on 157 considered suitable for valve-sparing repair.[10] Interestingly, 27 patients (17%) had either surgical ($n = 12$) or catheter-based ($n = 23$) reinterventions, being the most common cause residual RVOTO. Moreover, patients having a best technical performance score correlated with larger PV Z scores and less reinterventions through follow-up.[13] The last report on this series was published by Hofferberth et al on 162 consecutive patients with TOF who underwent repair under 1 year of age showed a progressive development of PR. Actually, freedom from at least moderate PR was 77%, 61%, and 43% at 1, 3, and 5 years post repair. Moreover, RV dimensions were not significantly different compared with a matched cohort of patients having a TAP and thus, the authors concluded that this technique does not preserve PV function long term. In this study, 15.4% of patients ($n = 25$) required reintervention for residual valvular stenosis.[14]

Similar to the Boston series, our surgical approach entails transinfundibular and transpulmonary incisions. In addition, we observe PV annulus growth through follow-up. However, we do not see the high rate of reintervention and have different incidences of progressive development of PR. We have reported our initial results with this technique.[6] As stated in that former manuscript, echocardiography with measurement of the PV Z score was useful for initial decision of feasibility. Any patient with a PV Z score <-3.5 was initially excluded from this approach. The final decision was made in the operating room after careful inspection of the valve. In our experience, markedly thickened and barely mobile leaflets with significant doming were considered not suitable for repair. Actually, in the timeframe of this study, we operated on 65 TOF patients but only in 42, PV-sparing repair was performed so in our experience, this approach is possible in about two-third of patients undergoing primary repair of TOF. Previous studies have stated that not only PV annulus size, but the valvular morphology is key to maintain long-term PV competency.[15] In addition, age younger than 3 months at the time of surgery came up as a risk factor for reintervention in the Boston series. In our cohort of patients, valve-sparing approach is reserved for patients older than 3 months, being the median age at surgery 5.2 months (range 3.4—120 months).

Regarding technical factors, since the beginning of our series we have placed a very redundant oval-shaped patch in the MPA and a shield-shaped patch in the inverted T-shaped incision performed on the infundibulum of the RV.[6] It is our sense that the infundibular and MPA patches have to be barely separated by a small horizontal area which corresponds to the PV annulus. In our series, the PT grows over time and thus, supravalvular stenosis has not been observed. In a paper from the Boston group on transcatheter balloon dilation for recurrent RVOTO following valve-sparing repair of TOF observed that patients with multilevel or nonvalvar obstruction had significantly shorter freedom from reintervention than patients with exclusively valvar obstruction.[16] Consistently with this finding, the PV annulus grows over time in both series. Moreover, RVOT mean gradient significantly decreases through follow-up. In our cohort, 2 patients required reintervention one early for RPA stenosis and one late for LPA stenosis which were stented. No patient has required a surgical procedure for RVOTO. Similarly, other authors have reported low incidence of reintervention or reoperation for recurrent RVOTO through follow-up with this approach.[17,18] Moreover, preservation of PV annulus has been related to a lower risk of late pulmonary valve replacement long term.[19]

Finally, valve inspection is essential to determine the feasibility of PV preservation. Z scores refer only to the pulmonary annulus but do not provide any information about the number of cusps, degree of hypoplasia, effective orifice, domed leaflets, etc. which are essential data to plan for the valve repair. In our series, all patients had commissurotomies as the only surgical procedure. Just in patients with leaflet tear after dilation patch of stitch closure of the leaflet was performed. We consider extensive manipulation requirements of the PV as a contraindication for this approach. With respect to the PV annulus, instead of dilating it to a diameter of 130—140% approximately of the preoperatively measured annulus diameter, we go up to the expected diameter of the PV annulus (Z score of 0). Similar to the Boston series, we observe progressive development of significant PR overtime but restricted to 21.4% of our population ($n = 9$) for a median follow-up of 45 months. Progression of PR during follow-up differs among series.[17,18] However, the alternative to valve-sparing repair which is a TAP is consistently related to 100% rate of severe PR at discharge.[18]

CONCLUSION

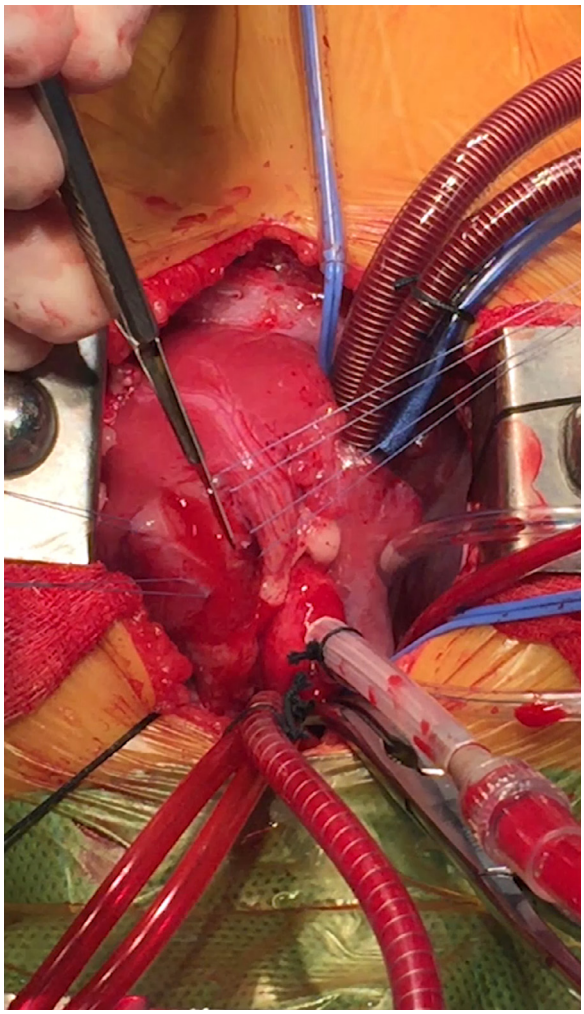
In summary, valve-sparing repair of TOF is feasible in about two-third of patients presenting for primary repair of TOF and provides good mid-term outcomes (see graphical abstract). In our series, intraoperative PV dilation provided good relief of the obstruction with one-fifth incidence of significant PR at mid-term. Moreover, surgical effects on PV and PT remained through follow-up. Patient selection and technical factors could be key to assure results. Long-term outcomes of this approach and comparison with children undergoing a TAP-type repair need to be elucidated.

Acknowledgment

We thank Ms Ana L. Teruel-Martínez for the art work included in this manuscript. anateruel.louise@gmail.com

SUPPLEMENTARY MATERIAL

The following is the supplementary data to this article:



Video 1. Video summarizing the content of the manuscript. The surgical technique for valve-sparing repair of TOF is demonstrated with intraoperative clips going over all steps and critical issues of the approach. Similar to the methodology of the paper, preoperative, early and most recent echocardiogram clips are shown.

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