Restrictive enlargement of the pulmonary annulus at surgical repair of tetralogy of Fallot: 10-year experience with a uniform surgical strategy

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Abstract

Objectives: Retrospective data suggest that a wide pulmonary annulus after Fallot repair aggravates pulmonary regurgitation. Therefore, since 1997, in our institution transannular patch enlargement was only intended for patients with a native pulmonary annulus z-score less than −4. If transannular patching was needed, enlargement was aimed to diameters within the range of a z-score of −2. We sought to determine whether this strategy of restrictive enlargement of the pulmonary annulus was adequate to reduce transannular patch rate and to limit pulmonary annulus width without increased right ventricular pressure load. Methods: Two-hundred-and-sixteen Fallot patients were retrospectively analysed. Ninety-eight patients underwent repair between 1997 and 2006 adhering to our uniform strategy (Group 1). One hundred and eighteen patients were operated between 1977 and 1996 without a uniform strategy (Group 2). Transannular patch rate, native and postoperative pulmonary annulus z-score, postoperative right ventricular outflow tract velocity on echocardiography and early reoperation rate for right ventricular outflow tract obstruction were analysed in both groups. Results: Compared to Group 2, patients in Group 1 were younger at repair, transannular patch rate was significantly reduced (32 vs 68%, p < 0.0001) and postoperative pulmonary annulus diameters were smaller (z-score −2.1 ± 1.5 vs 0.0 ± 3.1, p < 0.0001). However, no difference in right ventricular outflow tract velocity (2.4 ± 0.8 vs 2.2 ± 0.8 m/s; p = NS) or the incidence of early reoperation for right ventricular outflow tract obstruction was found between the groups (3/98 vs 1/118; p = NS). Conclusion: Restrictive enlargement of the pulmonary annulus at Fallot repair lowers transannular patch rate, limits the postoperative width of the pulmonary annulus but does not result in increased right ventricular pressure load or reoperation rate for residual right ventricular outflow tract obstruction. A limitation of postoperative pulmonary regurgitation can be expected when the extent of pulmonary annulus enlargement at repair is limited.

Keywords: Tetralogy of Fallot; Surgical repair; Pulmonary annulus diameter; Pulmonary regurgitation

1. Introduction

Surgical repair of tetralogy of Fallot (ToF) can nowadays be performed even in young infants and neonates with excellent early results. But as surgical policy has turned towards earlier repair the incidence of transannular patch enlargement of the right ventricular (RV) outflow tract has increased in some series [1,2]. However, transannular patching of the RV outflow tract may aggravate pulmonary regurgitation with deleterious effects on long-term outcome such as RV enlargement and dysfunction, reduced exercise capacity, malignant arrhythmia and sudden cardiac death [3—5]. Modern surgical strategies must, therefore, aim to reduce transannular patch rate, irrespective of age at operation.

Previous retrospective data from our group showed that a wide pulmonary annulus, often resulting from transannular patching at repair, aggravates pulmonary regurgitation and suggested that restrictive use of transannular patches and limited enlargement of the pulmonary annulus mimics pulmonary regurgitation [6]. Furthermore, these data showed that even for patients with a postoperative pulmonary annulus diameter close to a z-score of −4 RV pressure load was not significantly elevated. Since 1997, therefore, we followed a uniform surgical protocol that aimed to use transannular patches only in patients in whom the pulmonary annulus diameter has a z-score less than −4. In addition, if transannular patching was deemed necessary, we aimed to achieve a postoperative pulmonary annulus...
diameter in the range of a z-score of \(-2\), which is the lowest normal value.

The purpose of this study was to evaluate whether this strategy of RV outflow tract repair was sufficient to reduce the frequency of transannular patching and to minimise postoperative pulmonary annulus size. The extent of any residual RV outflow tract obstruction and incidence of early reoperation for significant RV outflow tract obstruction was also assessed.

2. Materials and methods

2.1. Patient population

Surgical, angiographic and echocardiographic data of 216 Fallot patients who underwent complete surgical repair at the University Hospital of Schleswig-Holstein, Kiel, Germany, between 1977 and 2006 were retrospectively analysed.

A group of 98 patients were operated on by a single surgeon (J.S.) between 1997 and 2006 according to a uniform strategy that aimed to limit transannular patch rate and restrict postoperative pulmonary annulus size in case of transannular patching (Group 1). In these patients surgery was performed after bicaval cannulation for cardiopulmonary bypass with moderate systemic hypothermia (32°C nasopharyngeal temperature). The ventricular septal defect was closed using a glutaraldehyde-fixed bovine pericardial patch via the right atrium working through the tricuspid valve or via a short right ventriculotomy where necessary and the infundibular muscles were resected. Hegar dilators were then used to assess the size of the pulmonary valve opening and if found to be less than a z-score of \(-2\) according to normative angiographic data from Sievers et al. [7], a longitudinal pulmonary arteriotomy was performed. If the comissures were found to be fused on inspection, pulmonary valvotomy was carried out by incision of the commissures. A transannular patch was inserted only in cases where the pulmonary valve was still smaller than a z-score of \(-4\) on assessment with a Hegar dilator repeated after pulmonary valvotomy. In these cases, a glutaraldehyde-fixed bovine pericardial patch was inserted from the right ventricular outflow tract to the pulmonary trunk. If necessary the patch was extended distally to repair any branch pulmonary artery stenosis. Whenever possible, the valve leaflets were spared by opening the pulmonary annulus through a commissure to limit postoperative pulmonary regurgitation. The transannular patch was tailored to restrict the pulmonary annulus diameter to a z-score of \(-2\) using an accordingly sized Hegar dilator in the outflow tract for guidance.

The data of Group 1 were compared to a historical cohort consisting of the 118 patients operated in the period between 1977 and 1996 by different surgeons following various surgical strategies (Group 2).

Patients with pulmonary atresia, absent pulmonary valve, double outlet right ventricle and patients in which homograft placement to reconstitute RV to pulmonary artery continuity was necessary, were excluded.

The parents of all patients gave their informed consent for all examinations and anonymised analysis of the data.

2.2. Angiocardiography

A biplane RV angiocardiogram was recorded before surgical repair at a median age of 0.5 (range 0.008—13.1) years in Group 1 and at a median age of 1.2 (range 0.002—7.9) years in Group 2. The RV angiocardiogram was repeated postoperatively at a median of 0.01 (range 0.002—8.4) years after surgery in Group 1 and after 2.0 (range 0.002—22.6) years in Group 2. Full pre- and postoperative angiographic data were available in 87 of 98 (89%) patients of Group 1 and 89 of 117 (76%) patients of Group 2. In many patients, mainly those of Group 1, postoperative angiograms were performed early after operation by a single bolus of contrast dye administered via the central venous line still in place from postoperative care. All angiograms were recorded on magnetic tape or digital media for later analysis. The diameter of the RV pulmonary trunk junction at the level of the pulmonary annulus was measured from the lateral angiogram [7]. In this study the term ‘pulmonary annulus’ was also used in the postoperative setting. Measurements of the pulmonary annulus diameter were normalised for body surface area as z-scores on the basis of published normative data [7].

2.3. Echocardiography

Transthoracic echocardiography was performed using a standardised transthoracic approach with a Hewlett Packard Sonos 1000 or 7500 ultrasound scanner or a GE Vivid 7 Dimension-System interfaced with a multifrequency MHz transducer. Pulmonary Doppler recordings were obtained from the parasternal short axis view with the cursor placed at the level of the pulmonary annulus. The maximal RV outflow tract flow velocity was measured and expressed as metres per seconds. All studies were stored on video tapes or digitally and therefore available for offline analysis.

To quantify the degree of any early or late postoperative RV outflow tract obstruction, an early postoperative echocardiogram performed on the day of the postoperative RV angiocardiogram and the latest available echocardiogram recorded before any reoperation of the RV outflow tract were analysed. The early postoperative study was recorded at a median of 0.01 (range 0.002—8.4) years after repair in Group 1 and after 2.0 (range 0.002—22.6) years in Group 2. The median time interval from repair to the late echocardiographic assessment was 4.39 (range 0.04—8.7) years in Group 1 and 12.6 (range 0.8—31.6) years in Group 2.

2.4. Surgical data

Data on the type of RV outflow tract reconstruction were collected from operation notes and the incidence of early reoperation for significant RV outflow tract obstruction (within 1 year after surgery) was collected from the institutions clinical database. The incidence of any additional surgical reintervention performed until December 2007 was also recorded from the patients’ records.

2.5. Statistical analysis

Data were expressed as mean value ± SD or median and range as appropriate. After testing for normality with the
Kolmogorov-Smirnov method, comparisons between groups were made using Student’s t-test or Mann–Whitney test, as applicable. Categorical data were compared using chi-square test. For all analyses a p-value < 0.05 was considered statistically significant. Statistical analysis was performed using MedCalc for windows, version 9.3.8.0 (MedCalc Software, Mariakerke, Belgium).

3. Results

3.1. Patient characteristics and surgical technique

Patient characteristics and surgical data are shown in Table 1. Patients of Group 1 were operated at a significantly younger age compared to patients of Group 2. Surgical technique of RV outflow tract reconstruction was clearly documented in 214 of 216 patients. In two Group 1 patients operation notes were no longer available so the exact nature of RV outflow tract reconstruction remained unclear. The incidence of transannular patch enlargement of the RV outflow tract was significantly lower in patients in Group 1 compared to Group 2 (32% vs 68%, p < 0.0001). Enlargement of the pulmonary annulus was only planned in patients with a native pulmonary annulus diameter with a z-score less than −2, which accounted for 27% of our patients undergoing surgery for tetralogy of Fallot in the time period reported here.

3.2. Enlargement of the pulmonary annulus at repair

The native width of the pulmonary annulus was similar in both groups (z-score −2.9 ± 1.6 vs −2.7 ± 1.7, p = NS). However, the postoperative diameter was significantly smaller in patients of Group 1 operated with our strategy that aimed to restrict postoperative annulus dimension to a z-score of −2 (z-score −2.1 ± 1.5 vs 0.0 ± 3.1, p < 0.0001; see Fig. 1).

3.3. Residual RV outflow tract obstruction and surgical reintervention

Maximal Doppler flow velocity in the RV outflow tract early after surgical repair was not different between the patient groups (Group 1 vs Group 2: 2.4 ± 0.8 (95% CI: 2.17–2.53) vs 2.6 ± 0.8 (95% CI: 2.51–2.73)).

There were 18/29 (62%) patients from Group 1 who underwent transannular patch enlargement of the pulmonary annulus with a z-score of the native annulus greater than −4 compared to 48/64 (75%) patients of Group 2 who received a transannular patch with an annulus of that size. However, there was not a single patient in Group 1 who received a transannular patch with an pulmonary annulus z-score greater than −2, whereas in Group 2 there were 24/64 (37.5%) (Fig. 2).
The range of pulmonary annulus diameter in patients operated with a transannular patch.

2.2 ± 0.8 (95% CI: 2.04—2.38) m/s; \( p = \text{NS} \) and remained similar until late assessment (Group 1 vs Group 2: 2.4 ± 0.9 (95% CI: 2.16—2.70) vs 2.1 ± 0.8 (95% CI: 1.95—2.32) m/s; \( p = \text{NS} \)).

Data on the type and incidence of surgical reintervention are given in Table 1. The incidence of early reoperation for significant residual outflow tract obstruction was similar in both groups (3/98 vs 1/118, \( p = \text{NS} \)).

4. Discussion

This study shows that a consistent surgical policy that aims to reduce the postoperative width of the pulmonary annulus and the incidence of transannular patch enlargement of the RV outflow tract is sufficient to reduce transannular patch rate and to limit postoperative pulmonary annulus size without leading to increased RV pressure load even when surgical repair is performed in early infancy.

4.1. Pulmonary annulus size and pulmonary regurgitation

It has previously been shown that the width of the pulmonary annulus contributes significantly to the degree of pulmonary regurgitation after Fallot repair [6]. Our strategy, to enlarge the pulmonary annulus only in patients with a native pulmonary annulus z-score less than −4 and to enlarge the annulus only to a z-score of −2 if needed, reduces the frequency of transannular patch enlargement and indeed limits postoperative annulus width to a z-score in the range −2 (Fig. 1). We would presume, therefore, that this strategy of RV outflow tract repair may limit pulmonary regurgitation and its long-term sequelae such as RV dilatation and dysfunction, malignant arrhythmia and sudden cardiac death [5].

4.2. Pulmonary annulus size and RV pressure load

In a previous report from our group no correlation existed between RV pressure load and pulmonary annulus width after Fallot repair [6]. Even for patients with a pulmonary annulus diameter close to a z-score of −4 the RV pressure was not significantly elevated on invasive measurement. This data implies that in many patients the postoperative annulus is larger than strictly necessary for adequate RV pressure unloading. Our current data on maximal flow velocity in the RV outflow tract and on the incidence for early reoperation for significant residual RV outflow tract obstruction confirms this finding. Maximal RV outflow tract flow velocity and the incidence of early reoperations were similar in both groups and, therefore, at early time points in follow-up no clinically relevant differences could be demonstrated.

Furthermore, it has been suggested that a combination of pulmonary stenosis and pulmonary insufficiency potentially preserves RV myocardial contractility [8]. Accordingly, we would suspect that those Fallot patients who had undergone a more conservative RV outflow tract reconstruction could profit from some degree of residual pulmonary stenosis when present.

4.3. Transannular patch rate and age at repair

Over the past two decades, surgical policy has turned towards repair of tetralogy of Fallot in early infancy. However, this coincides with increasing transannular patch rates of up to 80% in some series [1]. Our study shows that careful planning of RV outflow tract reconstruction on the basis of normative data of the pulmonary annulus can limit the rate and extent of transannular patching even when repair is performed at young age (Table 1). In fact, in our contemporary cohort of Fallot patients, transannular patch rate could be reduced to approximate the potential minimum of 27%, the proportion of Fallot patients with a native pulmonary annulus z-score of less than −4.

The incidence of commissurotomy as the only surgical intervention to relieve pulmonary valve stenosis was higher in our contemporary Fallot population (Group 1) as opposed to the historical cohort (Group 2). However, the extent of pulmonary regurgitation resulting from this procedure in isolation can be expected to be limited in comparison to transannular patch enlargement where not only the valve leaflets but also the annulus is disrupted. Furthermore, aneurysm formation resulting from transannular patch enlargement can further aggravate pulmonary regurgitation in the long term, a process that will be less likely after commissurotomy only [9].

4.4. Limitations

Though the vast majority of patients had complete angiocardiographic data on pulmonary annulus size it was not available in all patients as data were collected retrospectively. However, we would consider patient numbers in both groups large enough to draw our conclusions.

Due to the fact that many of the patients have been surgically repaired in recent years and are clinically well, no quantitative data on pulmonary regurgitation and right ventricular function from cardiovascular magnetic resonance...
imaging is available to compare potential differences between groups. Unfortunately, quantitative echocardiographic data on right ventricular function are also unavailable. Further follow-up studies ideally involving cardiovascular magnetic resonance imaging and contemporary quantitative echocardiographic modalities such as tissue Doppler or strain imaging are warranted to confirm that restrictive RV outflow tract repair limits pulmonary regurgitation and hence preserves RV function in the long term.

5. Conclusions

Restrictive RV outflow tract reconstruction at Fallot repair on the basis of normative data of the pulmonary annulus results in a decrease in transannular patch rate and is sufficient to limit postoperative pulmonary annulus size with adequate RV pressure unloading. A limitation of pulmonary regurgitation with beneficial impact on long-term outcome can be expected from this strategy. Further follow-up studies are warranted to confirm these findings and their relevance to longer-term clinical outcomes.

References


