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Primary repair versus surgical and transcatheter palliation in infants with tetralogy of Fallot

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Objectives: Treatment of infants with tetralogy of Fallot (ToF) has evolved in the last 2 decades with increasing use of primary surgical repair (PrR) and transcatheter right ventricular outflow tract palliation (RVOTd), and fewer systemic-to-pulmonary shunts (SPS). We aim to report contemporary results using these treatment options in a comparative study.

Methods: This a retrospective study using data from the UK National Congenital Heart Disease Audit. All infants (n=1662, median age 181 days) with ToF and no other complex defects undergoing repair or palliation between 2000 and 2013 were considered. Matching algorithms were used to minimize confounding due to lower age and weight in those palliated.

Results: Patients underwent PrR (n=1244), SPS (n=311) or RVOTd (n=107). Mortality at 12 years was higher when repair or palliation was performed before the age of 60 days rather than after, most significantly for primary repair (18.7% vs 2.2%, p<0.001), less so for RVOTd (10.8% vs 0%, p=0.06) or SPS (12.4% vs 8.3%, p=0.2). In the matched groups of patients, RVOTd was associated with more right ventricular outflow tract (RVOT) reinterventions (HR=2.3, p=0.05 vs PrR, HR=7.2, p=0.001 versus SPS) and fewer pulmonary valve replacements (PVR) (HR=0.3 vs PrR, p=0.05) at 12 years, with lower mortality after complete repair (HR=0.2 versus PrR, p=0.09).

Conclusions: We found that RVOTd was associated with more RVOT reinterventions, fewer PVR and fewer deaths when compared with PrR in comparable, young infants, especially so in those under 60 days at the time of the first procedure.

Key words: tetralogy of Fallot, primary repair, RVOT stenting, Blalock-Taussig shunt

What is already known about this subject?

Early primary repair, palliation by use of a systemic to pulmonary shunt and right outflow tract dilation and stenting are all considered to be acceptable alternatives for treating symptomatic infants with tetralogy of Fallot. It is not known how they compare to one another.

What does this study add?

Very few studies compare primary repair and palliation alternatives in tetralogy of Fallot. The current study shows that all three methods of treatment had good results, but palliation by right ventricular outflow tract dilation was associated with fewer pulmonary valve replacements and fewer deaths. Additionally, in infants undergoing primary repair, age under 60 days and the need for transannular patching and pulmonary artery interventions were associated with poorer outcomes.

How might this impact on clinical practice?

In treating symptomatic infants under 60 days of age, palliation by right ventricular outflow tract dilation might be preferable to primary repair. Systemic to pulmonary shunts still offer an alternative in patients with low surgical risk. If primary repair is performed, transannular patching and pulmonary artery interventions should be avoided if the clinical scenario permits.

INTRODUCTION

There are several options available for treating symptomatic infants with tetralogy of Fallot (ToF), including primary surgical repair (PrR), palliation with a systemic-to-pulmonary (SPS) shunt and the more recent palliation by right ventricular outflow tract or pulmonary valve dilation (RVOTd), with ductal stenting being less frequent.

Before the improvement in surgical techniques, perioperative care and the advent of transcatheter palliation procedures, the preferred treatment for symptomatic infants was an early SPS and then an elective secondary complete repair (ScR) subsequently. Data emerging on high mortality and complication rates following neonatal SPS[1] have led to alternative options to be explored, with early PrR (before 3 months) and transcatheter palliation gaining traction.[2]

Currently there is no consensus regarding the best strategy, with reports of good results with both early or neonatal repair[3,4], RVOTd[5] and even SPS[2]. We have previously shown that among all lesions with pulmonary obstruction, ToF had the lowest mortality after SPS palliation, with fewer such procedures being performed in these patients each year, likely due to better patient selection.[6] At the same time, all options have disadvantages: early PrR can increase the need for a transannular patch and late morbidity, SPS has high rates of complications while RVOTd is associated with valve lesions and reinterventions.[2]

There are only a few studies directly comparing these management strategies, but with inherent differences amongst the compared groups, since each center will have different practices.[3,5] There is a need for a direct comparative study with sufficient data to allow for adjusting for these differences. A national registry can offer both the large population and the good quality data required for such a study.

The National Congenital Heart Disease Audit (NCHDA) collects data on all cardiac procedures performed for congenital heart disease in the United Kingdom. In this study we aim to: 1) describe contemporary practice and trends; 2) compare PrR, SPS palliation and RVOTd outcomes in matched groups; and, 3) identify predictors of outcomes after these treatments.

METHODS

Patient selection and classification

National data collection has been previously described.[7] All but 4 (0.2%) of patients in the final dataset have survival data. Data on 5616 patients with ToF treated between 2000-2013 were available. We excluded the following patients: 2084 born before the registry was created, therefore without complete procedural history, 871 aged over 1 year at first procedure, 489 from overseas, Scotland or Ireland, 332 with other complex cardiac defects (transposition of great arteries, corrected transposition of great arteries, double outlet right ventricle, complete atrioventricular septal defect, double chambered right ventricle, cor triatriatum, total anomalous pulmonary connection, single ventricle morphology, ventricle imbalance, isomerism, pulmonary valve atresia, tricuspid atresia, mitral atresia), 37 with major aorto-pulmonary collateral arteries, 118 with miscellaneous data errors (empty data fields, diagnosis/procedure code errors), and 23 with other initial procedures than those of interest. This resulted in 1662 patients undergoing 2364 procedures including reinterventions - pulmonary valve replacements (PVR), SPS, pulmonary artery (PA) or right ventricular outflow tract (RVOT) reinterventions.

Statistical Analyses

Frequencies are given as absolute numbers and percentages, continuous values as median (inter-quartile range). Short term outcomes are calculated based on 30 day data. Population characteristics were compared using the Mann-Whitney, Student-t and the Fisher exact tests.

Estimates of long term outcomes are made with the Kaplan-Meier method using mortality (all cause) and reintervention (any, SPS, RVOT non PVR, PA and PVR), calculated before repair (for SPS and RVOTd), after repair and for the full follow-up (for all 3 groups, from first procedure to end). Rates of next event (Supplemental Table IV) are estimated using the data obtained after applying the modulated renewal approach.[6] When considering reintervention outcomes by type, surgical and transcatheter procedures of the same nature were considered as one event type (RVOT and PA reinterventions respectively); PVR with

and without PA repair was also grouped as one reintervention type (PVR). This was done to maintain simplicity, on the premise that reinterventions in the same group were performed under similar indications.

We conducted 3 additional analyses: pairwise three-way comparisons of procedures, and predictive models for each of the three procedure types. Matching was done using a stochastic augmentation with restriction methods (SAMUR package for R).[8,9] For both survival analysis after matching and the three predictive models, a Bayesian survival analysis using generalized Weibull approach was used (BSGW package for R).[10] To look at the effect of reinterventions in the predictive models, a modulated renewal approach was used.[6] Detailed statistical methods can be found in the Supplemental Material.

Statistical analyses were done with STATA/IC 11.2 (StataCorp LP, College Station, TX) and R version 3.1 (R Core Team, 2015).

RESULTS

A total of 1662 infants with ToF were included, with a median age of 181 (101-257) days, undergoing primary surgical repair (n=1244), SPS (n=311) or RVOTd (n=107) between 2000 and 2013, from 12 centers (mean patients/center 156, range 6-281). There was a trend for fewer SPS procedures and more PrRs and RVOTd observed during this period (Figure 1).

Demographic, clinical and procedural data, regarding the initial procedure can be seen in Table 1; data on ScR and reinterventions are shown in the Supplemental Table I. Of note are the significant differences in population characteristics, especially age and weight. A schematic of the treatment pathways is presented in Figure 2.

By plotting survival curves in 30 day increments we found that mortality at 12 years is higher when repair or palliation is performed before the age of 60 days rather than after, most significantly for PrR (18.7% vs 2.2% after, $p<0.001$), less so for RVOTd (10.8% vs 0%, $p=0.06$) or SPS (12.4% vs 8.3%, $p=0.2$). Unadjusted long-term outcomes are detailed in Supplemental Tables II and III. Short-term outcomes are

shown in Supplemental Table IV. Having a reintervention increased the risk of further reinterventions, in the whole population ($p<0.001$) but also for PrR ($p<0.001$), SPS ($p=0.03$) and RVOTd ($p<0.001$).

Due to the significant differences in patient characteristics among the three groups of interest, we proceeded to perform matched-groups analyses.

SPS versus RVOTd

Patients with SPS and RVOTd were matched in a pairwise comparison. Differences in groups before and after matching are detailed in Supplemental Table V.

RVOTd was associated with more RVOT (non-PVR) pre-repair reinterventions when compared to the SPS ($p=0.001$, Figure 3A). Post-repair outcomes did not differ significantly. This results in more overall reinterventions from initial palliation to follow-up after repair in the RVOTd group ($p=0.01$). Before and after matching comparison data are detailed in Table 3 and Supplemental Table VI. There were more complete repairs with transannular patches in the RVOTd group, with a similar proportion before and after matching (68% vs 53%, $p=0.01$ before, 68% vs 54%, $p=0.07$ after).

PrR versus SPS versus RVOTd

Patients in the PrR, SPS and RVOTd groups were matched in a three-way comparison. Differences in groups before and after matching are detailed in Supplemental Table VII.

RVOTd was associated with more RVOT (non PVR) reinterventions ($p=0.04$, Figure 3B) from initial procedure onward. We found fewer PVRs overall in the SPS and RVOTd groups compared to PrR ($p=0.05$ and 0.06 respectively, Figure 3C), with slightly fewer deaths after repair in the RVOTd group ($p=0.09$ versus PrR, Figure 3D); all three associations were borderline statistically significant and not observed in the unmatched groups. Before and after matching comparison data are detailed in Table 4 and Supplemental Table VIII.

There were fewer complete repairs using a transannular patch in the PrR group, when compared to SPS and RVOTd respectively, both before matching (42% vs 47 vs 47%, p<0.001) and after matching (43% vs 55% vs 68%, p=0.003).

Predictors of outcomes

In addition to the comparison of possible treatment options, a multivariable analysis was performed for each main group separately, taking into consideration the subsequent procedures. We found that outcomes after PrR and palliation in infants with ToF are influenced by a vast array of factors, both patient related and procedure related. Supplemental Table IX shows all identified predictors.

DISCUSSION

Both primary repair and palliation in ToF are associated with higher mortality when performed before the age of 60 days, but the differences appear to be more significant when the choice is primary repair (more than 8 times higher). After matching was performed in all three options, thus selecting the youngest, highest risk infants, those undergoing initial RVOTd have more RVOT (non-PVR) reinterventions when compared to PrR, fewer PVRs and also fewer long term deaths, the latter not reaching statistical significance. These findings, although retrospective, suggest that in those infants under the age of 60 days palliation might offer better outcomes when compared to primary repair. Even so, there were numerous factors influencing the outcomes in each group, from patient age and size, to associated conditions, need for reinterventions and even procedure era.

In the UK, as in most countries, the management of ToF varies between institutions.[11] The same patient might undergo palliation by SPS in one unit, RVOTd in another or PrR in the next, with no consensus on patient selection. No option is without its critics – early PrR might be associated with increased late morbidity due to use of transannular patching, SPSs have garnered a bad reputation due to complications, while RVOTd has yet to be adopted in all centers.[2,12] This is, to our knowledge, the first study to directly compare all three commonly used treatment options, while also adjusting for some confounding differences.

Previous studies comparing PrR to one palliation method or another[3,5] acknowledged procedural selection bias. By including all patients in a large geographical area we could compare patients which would potentially be candidates for all three options.

Comparing palliation options

Current palliation options are SPS, RVOTd and ductal stenting, the latter being rarely used for ToF in the UK. RVOT dilation or stenting is usually chosen in babies with risk factors for surgery who tend to be smaller and sicke,[5,13] which is also true in our study. We found significantly more RVOT (non-PVR) reinterventions in the RVOTd group, the differences being observed only in the pre-repair period. We assume that even after matching, those in the RVOTd group would still represent a population with surgical risk factors, and as such the true benefits of the transcathateter approach might be underestimated. As such RVOTd could be a comparable, if not superior, alternative to SPS palliation in similar patients.

Comparing all three options

There are situations when the decision to do a complete repair or a palliation in an infant depends on the centre practice. This is also true for neonates, even if there is considerable debate on whether the low early mortality is at the expense of long term morbidity.[2] There are few data on how these treatment options fare head-to-head, with no reports comparing all three simultaneously.

At a glance, looking at the whole population of unmatched infants with ToF, PrR appears to have significantly better outcomes when compared to both palliation options. Such a comparison is misleading, as many times patients differ greatly – in our cohort those referred for palliation were younger, smaller, had poorer growth for age and more genetic conditions. The differences observed in an uninformed comparison can be due to treatment selection and not the procedures themselves. Having data from consecutive patients in 12 centres allowed us to limit the three-way comparison to groups with similar characteristics in terms of age, weight, somatic development and associated abnormalities; we aimed to include only patients who could have been selected in theory for any of the three options.

In this matched analysis all three treatments achieved somewhat comparable results, but with a few notable differences. There were more RVOT (non-PVR) reinterventions in the RVOTd group as found in previous studies[3,5], but without an increase in mortality and PVR. Interestingly, we observed an overall lower risk of PVR in both palliation groups when compared to PrR, not just in one or the other, even if there were more secondary repairs using a transannular patch. In our study more than two thirds of the RVOTd procedures did not employ a stent, which would explain the much lower proportion of transannular patching (47% before matching, 68% after matching compared to 82% reported by Wilder et al and 100% by Sandoval et al, the latter using only stenting).[5,11] Quandt et al. describe a large single centre experience with RVOT stenting in a variety of lesions, transannular patch usage being comparable to SPS.[13] In our study we observed that using a balloon rather than a stent increases the risk of SPS placement afterwards due to inadequate pulmonary blood flow. Whether a palliation strategy using repeat balloon dilation rather than stenting, in an effort to preserve the valve, is preferable is still to be determined.

Previous reports described a high incidence of PA reinterventions after RVOTd.[5] After matching we found similar PA reintervention rates in all three groups. More PA reinterventions were observed in the SPS and RVOTd groups only in overall, unmatched comparisons. This suggests that the differences previously described are more likely due to infants with less developed PA branches being referred more frequently to palliation rather than PrR. During follow-up the somatic growth of the PA branches "catches up" in these groups, which further support this conclusion.[5]

Predictors of outcomes after PrR

To our knowledge this is the largest group of unselected consecutive infants with ToF undergoing PrR reported to date. This allowed for a complex analysis, including the influence of reinterventions on subsequent events.

The most discussed aspect of primary repair is age. There is no definitive age of "optimal" repair, and one might not be identified due to the large number of confounding factors. In our data when looking at age

increments of 30 days, we found a steep drop in late mortality when primary repair was performed after age 60 days (from 18.7% before 60 days to 2.2% after).

In our study worse outcomes were associated with characteristics found in those patients with underdeveloped RVOTs and PAs, like smaller age, smaller weight for age (z-score), use of transannular patching, need for PA procedures at index or afterwards and genetic syndromes. Using a palliation method to allow for more somatic growth appears to be a preferable option, as both palliation methods appear to be comparable to PrR in these patients. Our finding, that using a transannular patch is associated with both increased mortality and future need for PVR, supports other data suggesting that a key aspect of repair is preserving the pulmonary valve when possible.[5] It is reassuring that reinterventions in the first 10 years after ToF repair are not associated with increased mortality, only with further subsequent reinterventions. Also, procedures performed in recent years have had a steadily decreasing mortality and PVR rate.

Surgical PA repair at index is associated with increased mortality and a higher risk for further PA reinterventions. Additionally, PA reinterventions themselves, surgical or transcatheter, increase the chance for future such reinterventions. Wilder et al. concluded that aggressive patch augmentation for hypoplastic branch PAs might increase the reintervention rates, and suggest that after repair or palliation PA branches should develop well enough without further instrumentation.[14] Finding these associations between PA interventions and poorer outcomes in our multivariable models supports the notion that somatic growth rather than surgical patching should be preferred, when possible. PA arterioplasty performed at the time of PrR is associated with increased mortality, but not when done as a reintervention later on. This suggests that that allowing the PAs to grow before intervening might be the better option.

Predictors of outcomes after SPS

We found that smaller age and weight for age at SPS placement are associated with increased mortality, a well-documented fact.[1,6] PA repair, both at index and as a reintervention, is associated with more PA procedures, as was the case for PrR, further supporting the conclusion that patching the pulmonary arteries

instead of allowing for somatic growth might lead to poorer outcomes. This conclusion warrants further research.

Predictors of outcomes after RVOT transcatheter palliation

In multivariable analysis we did not identify any predictors of increased early mortality, but under the limitation of just 7 deaths. Taking into consideration that all deaths occurred in patients under 60 days, we can speculate that this age category remains a challenge, regardless of treatment. It is reassuring that RVOTd patients did not have a higher mortality compared to SPS and PrR, supporting the notion that RVOTd is an option in challenging cases when other methods are not feasible. [5,13] Patients with small age, genetic syndromes or where only a balloon dilation was used were at an increased risk for requiring further palliation by SPS placement. It is possible that the clinical scenario resulted in insufficient pulmonary flow, and an alternative palliation was used. The presence of a right aortic arch was strongly associated with SPS placements after RVOTd; this might be a spurious result, possibly confounded by surgical anatomy. In more recent years fewer SPS placements after RVOTd were observed, in the general context of SPS usage dropping in the UK.[6]

Limitations

The study is limited by absence of clinical data such as severity of symptoms, imaging, and the relatively short follow-up. It also has limitations inherent to a retrospective design, including the matching methods. In the three-way comparison, to balance the resulting groups' size and the matching quality, some subgroup differences remain. Finally, neonatal primary repair is uncommon in the UK so our study offers little information regarding this option.

Conclusions

The UK database offered a unique insight into how the treatment options for infants with ToF compare. We found that RVOTd was associated with more RVOT reinterventions, fewer PVR and potentially fewer deaths when compared with PrR in young infants, especially so in those under 60 days at the time of the

first procedure. The role of primary repair and SPS in this high-risk group needs to be reevaluated, as is the use of transannular patching.

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Table 1. Demographic, clinical and procedural data by initial procedure group

	All patients n=1662	PrR n=1244 (74.9)	SPS palliation n=311 (18.7)	RVOTd palliation n=107 (6.4)	p value
Patient data					
Median age; days (IQR)	181.2 (101.2;257.1)	210 (154.1;280.1)	55.1 (17.2;109.6)	38 (9.9;70.9)	<0.001
Median weight; kg (IQR)	6.5 (5;7.7)	7 (6;8)	3.8 (3;5.1)	3.4 (2.7;4.4)	<0.001
Median weight for age z score	-1.2 (-2.2;-0.3)	-1 (-1.9;-0.2)	-1.9 (-3.3;-0.8)	-2 (-3.4;-0.6)	<0.001
Neonate (n,%)	162 (9.8)	14 (1.1)	101 (32.5)	47 (43.9)	<0.001
Infant (n,%)	1500 (90.2)	1230 (98.9)	210 (67.5)	60 (56.1)	
Female (n,%)	703 (42.3)	530 (42.6)	131 (42.1)	42 (39.2)	0.8
Median follow-up, years (IQR)	4.7 (2.1;8.6)	4.4 (2.1;8.2)	7 (2.8;10)	2.4 (1.4;6.5)	<0.001
Associated defects (n,%)					
ASD	76 (4.6)	60 (4.8)	11 (3.5)	5 (4.7)	0.59
Right aortic arch	88 (5.3)	49 (3.9)	34 (10.9)	5 (4.7)	<0.001
Persistent SVC/IVC	59 (3.6)	39 (3.1)	16 (5.1)	4 (3.7)	0.25
PA stenosis/hypoplasia	61 (3.7)	40 (3.2)	14 (4.5)	7 (6.5)	0.12
PA non-confluence	5 (0.3)	2 (0.2)	3 (1)	0	0.12
Genetic syndromes	113 (6.8)	72 (5.8)	30 (9.7)	11 (10.3)	0.01

ASD = atrial septal defect; IQR = inter quartile range; IVC = inferior vena cava; PA = pulmonary artery; PVR = pulmonary valve replacement; RVOT = right ventricular outflow tract; RVOTd = right ventricular outflow tract palliation; SPS = systemic-to-pulmonary shunt; SVC = superior vena cava;

Table 2. Comparison between RVOTd and SPS in terms of mortality and reintervention in matched and unmatched groups

	Unmatched		Matched	
Outcome	Coefficient	P value	Coefficient	P value
Pre-repair reintervention				
RVOT non PVR	1.98	<0.001	1.98	0.001
SPS reintervention or placement	1.08	0.002	0.76	0.09
PA	1.09	0.04	0.8	0.3
Any	1.43	<0.001	1.16	<0.001
Overall reintervention				
RVOT non PVR	1.16	<0.001	0.98	0.01
Any	0.74	<0.001	0.58	0.02

Coefficients are for unadjusted RVOTd versus SPS comparison (positive coefficient represents an advantage for SPS).

PA = pulmonary artery; PVR = pulmonary valve replacement; RVOT = right ventricular outflow tract; RVOTd = right ventricular outflow tract palliation; SPS = systemic-to-pulmonary shunt;

Table 3. Comparison between PrR, SPS and RVOTd in terms of mortality and reintervention in matched and unmatched groups

		Unmatched		Matched	
Outcome		Hazard ratio	P value	Hazard Ratio	P value
Post-repair death	PrR	Baseline		baseline	
	SPS	1.16	0.7	0.32	0.3
	RVOTd	0.64	0.6	0.17	0.09
Overall reintervention					
RVOT non PVR	PrR	Baseline		baseline	
	SPS	1.33	0.2	0.79	0.6
	RVOTd	4.52	<0.001	2.29	0.05
PVR	PrR	Baseline		baseline	
	SPS	1.56	0.1	0.41	0.05
	RVOTd	1.43	0.5	0.32	0.06
Any	PrR	Baseline		baseline	
	SPS	2.16	<0.001	1.09	0.7
	RVOTd	4.8	<0.001	2.09	0.01

PA = pulmonary artery; PVR = pulmonary valve replacement; RVOT = right ventricular outflow tract; RVOTd = right ventricular outflow tract palliation; SPS = systemic-to-pulmonary shunt;

FIGURE LEGENDS

Figure 1. Trends in treatment of ToF in infants in the UK. There is a decrease in the number of systemic to pulmonary shunts (SPS) in favor of an increase in both PrR and right ventricular outflow tract dilations (RVOTd) between 2000 and 2012.

Figure 2. Cross-sectional summary of procedures performed in all infants with ToF treatment in the study. Initial palliation, subsequent reinterventions prior to complete repair, PrR and reinterventions in the post-complete repair period are shown, chronologically from left to right.

Figure 3. Comparison between treatment options for ToF. All panels show survival curves fitted in a univariable Weibull regression after pairwise and three-way matching, respectively. A) Freedom from RVOT (non-PVR) reintervention in SPS and RVOTd groups before complete repair - comparison after matching B) Overall freedom from RVOT (non-PVR) reintervention in PrR, SPS and RVOTd groups – comparison after matching C) Overall freedom from PVR in PrR, SPS and RVOTd groups D) Survival after complete repair in PrR, SPS and RVOTd groups.