Revisiting the utility of technical performance scores following tetralogy of Fallot repair

Daud Lodin, MPH,^a Orestes Mavrothalassitis, BS,^b Kim Haberer, MD,^c Sherzana Sunderji, MD,^c Ruben G. W. Quek, PhD,^d Shabnam Peyvandi, MD,^c Anita Moon-Grady, MD,^c and Tara Karamlou, MD^e

ABSTRACT

Objective: Although an important quality metric, current technical performance scores may not be generalizable and may omit operative factors that influence outcomes. We examined factors not included in current technical performance scores that may contribute to increased postoperative length of stay, major complications, and cost after primary repair of tetralogy of Fallot.

Methods: This is a retrospective single site study of patients younger than age 2 years with tetralogy of Fallot undergoing complete repair between 2007 and 2015. Medical record data and discharge echocardiograms were reviewed to ascertain component and composite technical performance scores. Primary outcomes included postoperative length of stay, major complications, and total hospital costs. Multivariable logistic and linear regression identified determinants of each outcome.

Results: Patient population ($n = 115$) had a median postoperative length of stay of 8 days (interquartile range, 6-10 days), and a median total cost of \$71,147. Major complications occurred in 33 patients (29%) with 1 death. Technical performance scores assigned were optimum in 28 patients (25%), adequate in 59 patients (52%), and inadequate in 26 patients (23%). Neither technical performance score components nor composite scores were associated with increased postoperative length of stay. Optimum or adequate repairs versus inadequate had equal risk of a complication ($P = .79$), and equivalent mean total cost (\$100,000 vs \$187,000; $P = .25$). Longer cardiopulmonary bypass time per 1-minute increase ($P < .01$) was associated with longer postoperative length of stay and reintervention ($P = .02$). The need to return to bypass also increased total cost ($P < .01$).

Conclusions: Current tetralogy of Fallot technical performance scores were not associated with selected outcomes in our postoperative population. Although returning to bypass and bypass length are not included as components in the current score, these are important factors influencing complications and resource use in our population. Revisions anticipated from a prospective trial should consider including these variables. (*J Thorac Cardiovasc Surg* 2017;154:585-95)

Percent of tetralogy of Fallot cases with reintervention during index hospitalization after repair stratified by cardiopulmonary bypass time and crossclamp time.

Central Message

Important factors that influence patient outcomes are not included in the current technical performance scores for tetralogy of Fallot repair.

Perspective

This study demonstrates that currently available technical performance scores for tetralogy of Fallot may lack generalizability. Specific operative characteristics, such as the length of cardiopulmonary bypass and crossclamp times, and the need to return to bypass, although resulting in the same reported score, influence clinical outcomes differently.

See Editorial Commentary page 596.

From the ^aSan Juan Bautista School of Medicine, Caguas, Puerto Rico; ^bUniversity of Maryland School of Medicine, Baltimore, Md; ^cDivision of Pediatric Cardiology, Department of Pediatrics, Benioff Children's Hospital, University of California, San Francisco, San Francisco, Calif; ^dGlobal Health Economics, Amgen Inc, Thousand Oaks, Calif; and ^eDivision of Pediatric Cardiac Surgery, Phoenix Children's Hospital, Phoenix, Ariz.

Read at the 96th Annual Meeting of The American Association for Thoracic Surgery, Baltimore, Maryland, May 14-18, 2016.

Received for publication May 25, 2016; revisions received Jan 18, 2017; accepted for publication Feb 8, 2017; available ahead of print April 29, 2017.

Address for reprints: Tara Karamlou, MD, Division of Pediatric Cardiac Surgery, Phoenix Children's Hospital, 1919 E Thomas Rd, Heart Center, Main Building, Phoenix, AZ 85016 (E-mail: tkaramlou@phoenixchildrens.com).

0022-5223/\$36.00

Copyright © 2017 by The American Association for Thoracic Surgery

<http://dx.doi.org/10.1016/j.jtcvs.2017.02.066>

Tetralogy of Fallot (TOF) is among the benchmark operations in congenital heart surgery, with excellent short- and long-term contemporary outcomes.¹ Surgical repair has evolved from an initial strategy of complete relief of right

Scanning this QR code will take you to supplemental tables and figure for this article. To view the AATS 2016 Webcast, see the URL next to the video thumbnail.

Abbreviations and Acronyms

CPB	= cardiopulmonary bypass
DORV	= double-outlet right ventricular
POLOS	= postoperative length of stay
RVOT	= right ventricular outflow tract
RVOTO	= right ventricular outflow tract obstruction
TOF	= tetralogy of Fallot
TPS	= technical performance score
VSD	= ventricular septal defect

ventricular outflow tract obstruction (RVOTO) with consequent free pulmonary insufficiency to a strategy of valve-preservation and permissive mild pulmonary valvular stenosis. A technical performance score (TPS) for the subdomains of TOF repair, as originally described by Larrazabal and colleagues in 2007,² has likewise evolved. The original lexicon specified no residual stenosis as optimal and any mild residual gradient of ≤ 40 mm Hg as adequate. Subsequent iterations of the TPS for the subdomains of RVOTO specified an optimal repair as a gradient < 2.2 m/s across the subpulmonary area and a gradient or < 2.0 m/s across the pulmonary valve itself.^{3,4} The original description of an optimum status of the right ventricular outflow tract (RVOT) following correction, therefore, may not actually reflect the best physiologic repair. Moreover, whereas the TPS represents an important metric to objectively assess the quality of surgical repairs and has been correlated with specific short-term outcomes, our group,⁵ and others,⁶ have commented on the limitations of the current TPS. One of these critical assumptions is the premise that the final result (ie, TPS composite score) is equivalent regardless of the amount of time necessary to achieve it or the number of tries necessary. Indeed, the recently launched Pediatric Heart Network-sponsored Residual Lesions Trial endeavors to address many of these shortcomings.

The objectives of this study, therefore, were to determine whether the currently available TPS for TOF are associated with purported clinical outcomes, including reintervention, morbidity, and cost (ie, determine generalizability with the current score) in infants undergoing complete repair of TOF and to determine whether there are additional intraoperative factors not currently captured by the TPS that are associated with these same outcomes (we specifically focused on cardiopulmonary bypass (CPB) time and number of CPB runs based on a priori assumptions).

METHODS**Data Source, Patient Population, and Data Collection**

This retrospective study from the University of California, San Francisco, used single-site patient records between January 2007 and June 2015. Institutional records and Society of Thoracic Surgeons Congenital

Heart Surgery Database were concurrently scanned for consecutive patients with a diagnosis of TOF undergoing surgical primary repair before age 2 years. An estimated 268 TOF interventions were initially found that included reintervention, additional repairs, and prerepair palliative interventions such as the modified Blalock-Tausig shunt, ductal stent, pulmonary valvotomy, or RVOT stent. Patients diagnosed with a variation of TOF, such as pentalogy of Cantrell, TOF with pulmonary atresia and multiple aortopulmonary collaterals, and complete atrioventricular canal were excluded from this study. However, those with tetralogy-type double-outlet right ventricle (DORV) were included, given that these patients are anatomically similar to those with TOF and there were no obvious differences in patient characteristics between these patients and the entire population. Patients undergoing right ventricle-pulmonary artery conduits were included given that the patients within this category were not those with severely hypoplastic branch pulmonary arteries and/or major aortopulmonary collateral arteries, and underwent otherwise similar repairs. Right ventricle-pulmonary artery conduits were implanted in the following 2 conditions: in patients with valvular stenosis that prohibited a valve-sparing approach or a nontransannular incision in the presence of important crossing coronary branches and patients with pulmonary atresia. This left 115 patients available for study, 113 of whom had full echocardiographic review. Preoperative, intraoperative, and discharge echocardiograms were reviewed by 2 pediatric cardiologists (S.S. and K.H.) with oversight by 2 experienced pediatric echocardiologists (S.P. and A.M.G.), with specific attention to the anatomic components needed to construct TPS scores. Only the discharge echocardiograms and in-hospital reinterventions were used to determine the component TPS scores and the final score as described by Larrazabal and colleagues.² Updated TPS criteria proposed by Nathan and colleagues³ were also incorporated, for comparison. Appropriate anatomic factors were converted to z scores, using the Boston Children's Hospital z score algorithm for calculating z scores by patient body surface area, height, and weight.⁷ Specific repair techniques and strategies were at the discretion of the surgeon and the referring cardiologist, with input from a multidisciplinary care team.

Outcomes of Interest and Study Variables

Our primary outcomes of interest were postoperative length of stay, reintervention during hospitalization, and hospital cost. Additional bypass runs were not considered additional reinterventions. We also examined in-hospital mortality and the prevalence of the 6 major complications, as defined by the Society of Thoracic Surgeons Congenital Heart Surgery Database.⁸ The 6 major complications include renal failure requiring temporary or permanent dialysis, neurologic deficit persisting at discharge, atrioventricular block, or arrhythmia requiring a permanent pacemaker, postoperative mechanical circulatory support, phrenic nerve injury, or any unplanned reintervention before discharge. Total cost was calculated summing the direct cost (the cost of services rendered during each patient's hospitalization) and the indirect cost (expenses that cannot be directly associated with patient care, such as hospital utilities, security, and administrative fees). Indirect costs were computed using an algorithm to calculate variable and fixed indirect costs.⁹ Values were adjusted for inflation using Bureau of Labor Statistics US Consumer Price Index for Medical-Cost inflation.¹⁰ Total costs were considered with and without statistical outliers, and total costs were also related to the length of stay to determine cost per day (total cost divided by total length of stay). Patient insurance status was also included in this study.

Data Analysis

Study power and type II error were 0.95 ($\alpha = 0.05$) and 0.80 ($\beta = 0.2$), respectively. The percentage of missing values was calculated before analysis and all variables with more than 25% incomplete data were excluded from our analysis. Descriptive and demographic data were conveyed with ratios and percentages for dichotomous and categorical variables, with means and standard deviations for continuous normalized variables, and

with medians and interquartile ranges for continuous nonnormalized variables. Mann-Whitney *P* value testing was used for nonparametric analysis of nonnormalized variables. Bivariate analysis to investigate basic relationships among variables and inform variable selection for multivariable models used χ^2 testing, odds ratio analysis, Pearson correlation, and *t* testing. Multivariable regression analysis identified variables associated with each of our outcomes and the influence of confounders. Sex, weight at repair, and age of repair were all included to produce models adjusted for patient characteristics. Certain predictor variables, such as CPB time, were dichotomized at the mean or median value, but were also considered as continuous factors in all multivariable analysis. Component TPS scores, in addition to the final composite TPS score, were considered as variables in all multivariable models. A list of candidate variables tested for the multivariable analysis is shown in Table E1.

Selection methods for multivariable models were chosen to optimize model performance using receiver-operating characteristics curve analysis. Linear regression was used for postoperative length of stay (POLOS), whereas logistic regression was used for the occurrence of each individual complication, with special emphasis on reintervention. Additionally, Poisson regression was used to examine factors associated with the number of these events, given the ordinal nature of this variable. All regression analyses were completed with $\alpha = 0.10$ and with mean imputation for any missing values. Results were aggregated using Microsoft Excel (Microsoft Corporation, Redmond, Wash) and statistical analysis was completed with SAS version 9.3 (SAS Institute, Cary, NC).

Permission to conduct the study was obtained by the University of California, San Francisco, institutional review board under expedited review for existing data and need for patient consent was waived.

RESULTS
TPS Calculation and Associations With Selected Outcomes

Descriptive characteristics are shown in Tables 1 and 2. TPS assessment of our cohort (calculated from 113 patients with complete echo data) found no patients that could be categorized as optimal based on the criteria originally described by Larrazabal and colleagues² (Table E2). There were no optimum repairs owing to the gradient > 0 across either the pulmonary valve or the subpulmonary area. The majority of cases were categorized as having adequate repairs (87 out of 113; 77%) and a minority was scored inadequate (26 out of 113; 23%). However, when constructing the TPS score based on the updated criteria, 28 repairs (25%) were scored optimum, 59 repairs (52%) were scored adequate, and 26 repairs (23%) were scored inadequate (Table E3). Repairs scored as either optimum or adequate versus inadequate had equal risk of having 1 or more major

TABLE 1. Patient characteristics, cardiac physiology, and total cost of care

Variable	n	%	Mean	Standard deviation
Male	68	59	—	—
LSVC	10	9	—	—
DORV	4	3	—	—
Down syndrome	6	5	—	—
Di George syndrome	7	6	—	—
Other noncardiac comorbidities	26	23	—	—
Tricuspid regurgitation				
None/trace	73	65	—	—
Mild	29	26	—	—
Moderate	11	10	—	—
Pulmonary valve diagnosis				
Normal	27	23	—	—
Stenotic/atretic	88	77	—	—
Obstruction type				
Subvalvular	105	91	—	—
Valvular	71	62	—	—
Supravalvular	29	25	—	—
Insurance coverage				
Commercial coverage	74	64	—	—
MediCal coverage	39	34	—	—
No coverage	2	2	—	—
Palliation before repair	15	13	—	—
MBT shunt	13	11	—	—
Age of repair (d)	—	—	129	65,162
Weight at repair (lb)	—	—	5.48	1.82
PV z score	—	—	−1.78	1.44
RPA z score	—	—	0.96	1.27
LPA z score	—	—	−0.98	1.44
Total cost (\$)	—	—	71	57-101
Cost per day (\$)	—	—	8461	3490

Values for age of repair and total cost are presented as median (interquartile range). LSVC, Left superior vena cava; DORV, double outlet right ventricle; MBT, modified Blalock-Tausig shunt; PV, pulmonary valve; RPA, right pulmonary artery; LPA, left pulmonary artery.

TABLE 2. Intraoperative characteristics and postoperative outcomes

Variable	n	%	Mean	Standard deviation
PA treatment				
None	19	17	—	—
Transanullar	67	58	—	—
Nontransanullar	21	18	—	—
Contegra conduit	8	7	—	—
VSD patch material				
Sauvage/polyethylene terephthalate	101	92	—	—
Other material	9	8	—	—
PA patch material				
Autologous pericardium	70	63	—	—
Synthetic material	23	21	—	—
No patch used	18	16	—	—
Number of chest tubes				
3 tubes	71	63	—	—
2 or fewer	41	37	—	—
Intraoperative techniques				
Intraoperative amiodarone used	11	10	—	—
Return to bypass required	13	11	—	—
Return to bypass to correct PA/RVOT	5	5	—	—
Return to bypass to correct VSD	7	6	—	—
PA valve spared	47	47	—	—
PA valvotomy	40	35	—	—
Extra cusp created	32	31	—	—
2-3 mm ASD window left open	72	65	—	—
Crossclamp time (min)	—	—	59.5	21.3
Bypass time (min)	—	—	84.5	29.0
End hematocrit (%)	—	—	41.1	6.61
Postoperative discharge time (d)*	—	—	8	6.10
STS postoperative outcomes				
ECMO	3	3	—	—
Phrenic nerve damage	4	3	—	—
Neurological injury	0	0	—	—
Need for dialysis	1	1	—	—
Heart block requiring pacing	9	8	—	—
Reintervention before discharge	22	19	—	—

PA, Pulmonary artery; VSD, ventricular septal defect; RVOT, right ventricular outflow tract; ASD, atrial septal defect; STS, Society of Thoracic Surgeons; ECMO, extracorporeal membranous oxygenation. *Values are presented as median and interquartile range.

complication (odds ratio [OR], 0.9; 95% confidence interval [CI], 0.4-3.0; $P = .79$) and of undergoing reintervention during their hospitalization (OR, 1.1; 95% CI, 0.3-3.7; $P = .87$). No statistically significant difference in total cost was found when comparing repairs scored as optimum or adequate versus those that were scored as inadequate (\$100,000 vs \$187,000; $P = .25$). With outliers removed, cost differences further decreased between repairs graded as optimum or adequate versus those graded as inadequate (\$95,000 vs \$83,000; $P = .43$).

Univariable Factors and Their Relationship to Outcomes

Several patient and intraoperative characteristics influenced the risk of in-hospital reintervention (Table 3) and POLOS. Greater than average CPB time ($P = .03$) and

crossclamp time ($P = .03$) were significantly associated with reintervention (Figure 1). Univariable analysis of surgical techniques and patient characteristics versus mean POLOS are depicted in Figure E1. Two risk factors were significantly associated with shorter POLOS: intraoperative chest closure (9.1 vs 18.6 days POLOS; $P < .01$) and age greater than or equal to the mean age of 129 days (7.9 vs 11.6 days POLOS; $P = .04$). Total costs analyses are shown in Table 4. When removing 3 outliers, in whom the costs were $> \$500,000$ (new mean, $\$91,775 \pm \$59,074$), nonvalve-sparing procedures (101,000 vs \$77,000; $P = .03$) had an increased total cost. In-hospital cost per day tended to be increased in patients with longer cross-clamp times (\$8803 vs \$8113; $P = .07$), in patients with supralvalvular obstruction in addition to either valvular or subvalvular obstruction (\$9115 vs \$8241; $P = .05$), those

TABLE 3. Patient and surgical characteristics versus incidence of reintervention

Variable of interest	Additional operation	%	None	%	Odds ratio	95% CI (low/high)	χ^2	P value
Intervention to main PA								
Yes	21	22	75	78				
No	1	5	21	95	5.0	0.7	40.0	.09
Crossclamp time (mean, 59 min)								
Above average	15	28	38	72				
Below average	7	12	51	88	2.9	1.1	7.7	.03
Reclamp necessary								
Yes	4	31	9	69				
No	18	18	82	82	2.0	0.6	7.3	.27
CPB time (mean, 85 min)								
Below average	15	29	36	71				
Above average	7	11	54	89	3.2	1.2	8.7	.02
PA valve spared								
Yes	7	15	40	85				
No	12	23	40	77	0.6	0.2	1.6	.30
Number of chest tubes								
3	17	24	54	76				
≤ 2	4	10	37	90	2.9	0.9	9.4	.06
Prepalliation								
Yes	2	13	13	87				
No	20	20	80	80	0.6	0.1	2.9	.54
ASD left open								
Yes	20	28	52	72				
No	2	5	36	95	6.9	1.5	31.5	< .01
Valvular obstruction present								
Yes	18	25	53	75				
No	4	9	40	91	3.4	1.1	10.8	.03
Sex								
Male	10	15	58	85				
Female	12	26	35	74	0.5	0.2	1.3	.15
PV diagnosis								
Stenotic/atretic	21	24	67	76				
Normal	1	4	26	96	8.1	1.0	63.7	.02
Age at operation (mean, 129 d)								
Above average	4	9	42	91				
Below average	18	26	51	74	0.3	0.1	0.9	.02
Genetic anomaly								
Yes	1	8	12	92				
No	21	21	79	79	0.3	<0.1	2.5	.25

CI, Confidence interval; PA, pulmonary artery; CPB, cardiopulmonary bypass; ASD, atrial septal defect; PV, pulmonary valve.

with trisomy 21 (\$10,073 vs \$8402; $P = .05$), and those with commercial insurance versus MediCal (\$8954 vs \$7473; $P < .01$).

Multivariable Factors Associated With Outcomes

Several patient characteristics such as nonvalvular obstruction ($P = .05$), having other noncardiac comorbidities ($P = .07$), and DORV-variant ($P = .07$) were all associated with increased POLOS. Regarding operative factors, longer CPB time ($\beta = 0.1$ [per minute]; $P < .01$), delayed sternal closure ($\beta = -8.3$; $P < .01$), and polyethylene terephthalate ventricular septal defect (VSD) patch material versus CorMatrix (Roswell, Ga) ($\beta = 11.9$; $P < .01$) were all

associated with a longer POLOS (Table 5). No TPS subcategory or score was associated with increased POLOS.

Regarding the prevalence of in-hospital complications, specific operative characteristics, including longer aortic crossclamp duration ($P = .02$) and synthetic patch material for RVOTO reconstruction ($P = .02$) were associated with an increase risk of a complication, after adjustment for patient and anatomic factors (Table E4). Risk factors for mortality were not sought owing to the fact that there was only 1 death.

Factors associated with an increased total cost are shown in Table 4. Return to CPB to address a residual or additional VSD was associated with increased total cost ($P < .01$).

FIGURE 1. Percentage of tetralogy of Fallot cases requiring reintervention after repair during index hospitalization stratified by cardiopulmonary bypass time and aortic crossclamp time.

None of the component nor composite TPS scores was associated with in-hospital cost.

DISCUSSION

We have described the utility of the originally proposed TPS insofar as its relationship to multiple in-hospital outcomes in our single-institution series. We found that neither the component scores nor the composite TPS score were associated with POLOS, total cost, complications, or reintervention in our population. However, our data demonstrate that increased CPB and aortic crossclamp duration, as well as additional bypass runs, none of which are included in either the initial or updated TPS criteria, are important factors influencing both the prevalence of complications and resource use. CPB times and aortic crossclamp times have been correlated with nearly every outcome examined in cardiac surgery.¹¹⁻¹⁴ A recent article by Chalmers and colleagues¹⁵ demonstrated that increased CPB time was associated with mortality and longer POLOS. Increased crossclamp times are commonly used to assess technical proficiency.¹⁵ Related surgical disciplines use operative time in a parallel fashion, and decreases in task time are often used to demonstrate improved learner skill and proficiency.^{16,17} Moreover, Jolley and colleagues¹⁸ have shown that increased operative times, which were found in cases performed by less-experienced surgeons, increased resource use. The authors stated in their conclusion, “Resident operations do appear to have real consequences for patients and may impact the healthcare system financially.”¹⁸ Clearly the end result of an operation (ie, the composite TPS) is important, but our results would support the contention that the time it takes to achieve a given result and the number of tries necessary should also be considered. Unfortunately, given the limited number of surgeons in this series, we were unable to look at the

influence of surgeon experience on outcome, but would expect that there would be an inverse relationship, as demonstrated in prior studies.

Our results demonstrating a lack of association between the current TPS and selected outcomes for our TOF population are in contrast to a study by Nathan and colleagues³ specifically examining reintervention in TOF patients undergoing valve-sparing repair. Several other manuscripts from the same group¹⁹⁻²¹ also found significant associations between TPS and both short-term and long-term outcomes in a heterogeneous group of postrepair congenital heart disease patients. Although the TOF article by Nathan and colleagues³ identified TPS as a predictor for reintervention and POLOS, other surgical characteristics that could have affected these outcomes were not considered. Importantly, the finding that pulmonary valve *z* score was highly correlated with optimum TPS score in the study by Nathan and colleagues³ may indicate that an optimum repair surrogates an anatomic subtype (larger pulmonary valve *z* score), and that it is this anatomic subtype rather than the TPS score that predicts reintervention. Unfortunately, multivariable analysis to ascertain those variables with the best predictive value regarding outcome was not presented in this article.

There are important differences between our patient population and those investigated in prior publications that may have influenced our findings. In the study by Nathan and colleagues,³ which looked at those receiving valve-sparing approaches, the distribution of scores was 22% optimum, 70% adequate, and 8% inadequate, whereas in our study, there were 25% optimum, 52% adequate, and 23% inadequate. Although the median age at repair was similar in both series (105 days and 109 days), we included patients throughout the spectrum of TOF (including DORV), and this may have contributed to this differential. The results of our present study are important because they illustrate that current TPS scoring algorithms (whether initial or updated) may not be generalizable to all centers. Moreover, given the widespread use of scoring systems, it would be important to define (or describe) patient populations (or centers) in which current scores may perform less reliably. Variation in pediatric surgical outcomes is well described in our field²² and it is critical to understand whether our available tools perform equally across the spectrum.

Clearly there have been improvements made to the initial TPS criteria. We used both the initial iteration of the 2007 score, as well as the updated TPS score, to capture these modifications. Using the initial criteria that specify no stenosis across either the RVOT or the pulmonary valve is considered optimal, we found that 25 repairs would be considered adequate rather than optimum due to having a gradient ≤ 20 mm Hg. The originally published criteria, therefore, seem at odds with the contemporary notion that pulmonary valve preservation with mild stenosis is

TABLE 4. Bivariate analysis of patient characteristics and surgical procedures versus costs

Variable of interest	n	Total cost (\$)*						Cost/LOS (\$)	Standard deviation P value	
		Total cost (\$)*	Standard deviation	P value	(outliers removed)	Standard deviation	P value			
PA patch material										
Autologous	70	104	89		96	81		8585	2054	
Artificial	23	81	46	.12	81	61	.30	8674	2065	.86
VSD patch material										
Polyethylene terephthalate	101	120	183		92	58		8514	2064	
Nonpolyethylene terephthalate	9	70	36	< .01	70	36	.26	7924	959	.14
CPB time (mean, 85 min)										
Above average	51	130	199		95	76		8768	2079	
Below average	61	107	154	.50	89	75	.59	8275	2111	.22
Intraoperative chest closure										
Yes	102	121	183		93	46		8437	2035	
No	13	84	46	.09	83	61	.59	8648	2572	.73
PA valve spared										
Yes	47	140	257		77	34		8321	2114	
No	68	101	71	.32	101	71	.03	8826	1977	.22
Valvotomy used										
Yes	40	108	183		80	38		8778	1656	
No	75	127	186	.63	97	68	.12	8449	2279	.39
Number of chest tubes										
3	71	136	215		95	63		8613	1956	
≤2	44	88	53	.08	88	53	.24	8182	2203	.30
Palliation before repair										
Yes	15	86	55		86	55		9069	1963	
No	100	122	184	.13	93	60	.69	8370	2103	.23
ASD left open										
Yes	72	121	159		98	67		8636	2116	
No	43	83	43	.06	83	43	.17	8254	2973	.37
Valvular obstruction present										
Yes	71	105	83		97	70		8739	2918	
No	44	137	59	.42	83	49	.19	8012	2149	.07
Supravalvular obstruction present										
Yes	29	160	236		104	75		9115	2320	
No	86	103	145	.22	88	53	.31	8241	1973	.05
Sex										
Male	68	132	218		89	55		8573	2185	
Female	47	95	64	.19	95	64	.62	8299	1957	.49
PV diagnosis										
Stenotic/atretic	88	114	157		94	63		8028	2126	
Normal	27	126	222	.79	85	45	.48	8594	1942	.22
Age at operation (mean, 129 d)										
Above average	46	153	261		90	56		8660	1820	
Below average	69	93	61	.13	93	61	.81	8328	2255	.41
DiGeorge patient										
Yes	7	83	36		84	36		8407	1428	
No	108	118	179	.13	90	57	.75	8496	2116	.92
Trisomy 21 patient										
Yes	6	324	444		146	90		10,073	1940	
No	109	104	141	.28	87	52	.22	8402	2055	.05
Insurance type										
Commercial	74	138	210		99	61		8954	1941	
Medical	39	78	54	.02	78	54	.07	7473	1933	< .01

LOS, Length of stay; PA, pulmonary artery; VSD, ventricular septal defect; CPB, cardiopulmonary bypass; PA, pulmonary artery; ASD, arterial septal defect; PV, pulmonary valve.

*Values divided by 1000.

TABLE 5. Multivariable linear regression analyses for total cost* and postoperative length of stay

Variable	β	Standard error	P value
Total cost (\$) ($R^2 = 0.26$)			
Trisomy 21	21.8	6.3	< .01
Preoperative ASD	−18.1	6.0	< .01
Any intervention to the PA	−5.0	1.9	.01
Return to bypass to address VSD	16.7	6.1	< .01
3 Chest tubes	6.4	2.2	< .01
POLOS in days ($R^2 = 0.33$)			
Other noncardiac comorbidities	4.1	2.2	.07
Valvular obstruction	−3.8	1.9	.05
DORV	9.1	4.9	.07
CPB time (min)	1.3	0.3	< .01
Intraoperative chest closure	−8.3	2.9	< .01
Polyethylene terephthalate VSD patch material	11.9	3.3	< .01

Refer to Table E1 for a list of all variables used in the analysis. ASD, Atrial septal defect; PA, pulmonary artery; VSD, ventricular septal defect; POLOS, postoperative length of stay; DORV, double outlet right ventricle; CPB, cardiopulmonary bypass time. *Values divided by 10,000.

preferable to free pulmonary insufficiency. Supportive of this concept, patients who underwent valve-sparing TOF repair in the present study had both a decrease in total cost and shorter POLOS. Patients amenable to valve-sparing approaches may represent a population with less-severe forms of tetralogy, could enjoy improved postrepair physiology from the avoidance of free pulmonary insufficiency, or may also have avoided prerepair palliation. Several studies have found that patients who receive valve-sparing procedures have better perioperative outcomes and shorter POLOS.^{23,24} Our correlation analysis indicated an inverse relationship between both CPB and crossclamp time versus pulmonary vessel z scores. Further studies investigating inflection points whereupon CPB and crossclamp times are minimized, whereas maximizing attempts to spare the pulmonary valve based on pulmonary valve z scores, may be useful in directing the best surgical repair strategy. Although an iterative approach to repair that attempts to minimize pulmonary valve or right ventricle muscle resection may necessitate additional crossclamp intervals guided by physiologic data such as right ventricle pressure measurements (and therefore would not be considered technical inadequacy), our data showed that the penalization regarding increased costs were confined to those additional intervals required to address residual VSDs.

Surprisingly, we found that polyethylene terephthalate VSD patch material was associated with increased POLOS. It is likely that other patch materials, such as Cormatrix, were surrogates for other favorable anatomic patient factors. Similarly, that nonautologous patch material for RVOT reconstruction was associated with increased costs is likely due to the fact that patients having synthetic material were those with antecedent palliation (ie, those with either pulmonary atresia requiring modified Blalock-Tausig shunt).

Patient Factors

Although not the main focus of this study, we investigated patient factors as determinants concomitant with the TPS. Such relationships are valuable in testing interactions (eg, do some patients with a given anatomy respond variably to the same operative characteristics?) and possible confounders. Genetic anomalies are well-known preoperative risk factors for less-favorable outcomes.²⁵ Our study was consistent with these results in that patients with trisomy 21 had increased total hospital cost. Interestingly, the total cost of care was not due to longer POLOS, possibly suggesting that the intensity or level of care required in patients with trisomy 21 is higher (ie, longer ventilation time, greater duration of sedatives, and feeding issues), but that the number of complications or duration of convalescence is equivalent. As expected, decreased weight at repair, the presence of multiple VSDs, and the presence of noncardiac anomalies were all associated with adverse outcomes.

TPS: An Imperfect Metric

The development of the TPS represents an important initial step in both quality assessment and facilitating individualized, surgeon-directed improvement. However, several authors, including our group, have elucidated limitations with the current iteration of the TPS.^{5,6} The grading system for each of these subprocedure outcomes was consensus-derived without empirically defined thresholds. Moreover, calibration and weighting were not considered because increases in subscores were assumed to be linear, and each subscore was assumed to have equal influence on the final outcome. In other words, the presence of an unintended atrial septal defect following TOF repair is weighted the same as significant RVOTO or a residual VSD despite these having variable consequence. Events conceivably within the final common pathway of adverse

outcome (eg, reintervention) were included as components of the TPS, potentially undermining attempts at correlation. Finally, the use of discharge echocardiograms, with likely unequal time components between the repair date and the echocardiogram date, introduces variability in measurement among patients. The present study does not address all of these limitations because the recently initiated Pediatric Heart Network-sponsored trial, the Residual Lesions Trial, endeavors to address many of these shortcomings. The data from that prospective multi-institutional trial will undoubtedly inform ongoing efforts at both individual-directed and specialty-directed quality improvement, and will extend the provision of value-based care.

Study Limitations

This was a single-center retrospective analysis, and therefore operative techniques varied by surgeon and postoperative care likewise varied. Lack of association between some complications and TPS may reflect a type II error. Moreover, we acknowledge that although some differences were not statistically significant (eg, cost), these differences are likely clinically relevant. Our analysis that excluded 3 outliers also suggests that some of our results could have been influenced by these particular patients. Future multi-institutional trials may provide more clarity on this issue. However, that we were able to discern significant associations between operative factors and our primary end points (both of which were continuous) is reassuring. Although echocardiographic images were all independently reviewed using a protocol designed to capture TPS criteria, the inherent subjectivity of echocardiographic interpretation may have influenced our results. We initially aimed to establish a TPS based on intraoperative echocardiograms and correlate these with discharge echocardiograms. Unfortunately, the intraoperative images available for review inconsistently ascertained all of the TPS components needed to assign a composite score. A prospective study would be needed to develop a score that is available to surgeons in the operating room and could therefore facilitate decisions regarding the utility of intraoperative revision. Our outcomes were confined to in-hospital events, and we therefore do not have longitudinal data, which would be important in evaluating the durability of a surgical repair. However, this initial study was meant to investigate generalizability of the original TPS score, and therefore we studied outcomes that mirror those used in the initial studies.

CONCLUSIONS

The current TPS was not associated with selected postoperative TOF outcomes in our patient population, indicating that prior results may not be generalizable to all centers or surgeons. Although number of bypass runs, the duration of CPB, or the aortic crossclamp intervals are not included as components in the current TPS for TOF, they are

important factors influencing both the prevalence of complications and resource use. Iterative revision to the TPS should consider the inclusion of these variables.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: http://webcast.aats.org/2016/Video/Wednesday/05-18-16_Ballroom_III_0844_Lodin-800.mp4.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

References

- Karamlou T, McCrindle BW, Williams WG. Surgery insight: late complications following repair of tetralogy of Fallot and related surgical strategies for management. *Nat Clin Pract Cardiovasc Med*. 2006;3:611-22.
- Larrazabal LA, Pedro J, Jenkins KJ, Gauvreau K, Lacro R, Colan SD, et al. Measurement of technical performance in congenital heart surgery: a pilot study. *Ann Cardiothorac Surg*. 2007;83:179-84.
- Nathan M, Marshall AC, Kerstein J, Liu H, Fynn-Thompson F, Baird CW, et al. Technical performance score as predictor for post-discharge reintervention in valve-sparing tetralogy of Fallot repair. *Semin Thorac Cardiovasc Surg*. 2014;26:297-303.
- Parthiban A, Levine JC, Nathan M, Marshall JA, Shirali GS, Simon SD, et al. Impact of variability in echocardiographic interpretation on assessment of adequacy of repair following congenital heart surgery: a pilot study. *Pediatr Cardiol*. 2016;37:144-50.
- Karamlou T. Utility of the technical performance score for the Norwood operation... every score should know its limitations. *J Thorac Cardiovasc Surg*. 2014;148:2214-5.
- Chen JM. Editorial commentary: Technical performance anxiety: utility of the technical performance scale in predicting later intervention after repair of tetralogy of Fallot. *Semin Thorac Cardiovasc Surg*. 2014;26:304-5.
- Sluysmans T, Colan SD. *Structural measurements and adjustment for growth. Echocardiography in pediatric and congenital heart disease*. New York: Wiley-Blackwell; 2009:51-62.
- Jacobs ML, O'Brien SM, Jacobs JP, Mavroudis C, Lacour-Gayet F, Pasquali SK, et al. An empirically based tool for analyzing morbidity associated with operations for congenital heart disease. *J Thorac Cardiovasc Surg*. 2013;145:1046-57.e1.
- Nguyen OK, Tang N, Hillman JM, Gonzales R. What's cost got to do with it? Association between hospital costs and frequency of admissions among "high users" of hospital care. *J Hosp Med*. 2013;8:665-71.
- US Department of Labor. Consumer Price Index. Available at: <https://www.bls.gov/cpi/>. Accessed April 24, 2017.
- Wesselink R, De Boer A, Morshuis W, Leusink J. Cardio-pulmonary-bypass time has important independent influence on mortality and morbidity. *Eur J Cardiothorac Surg*. 1997;11:1141-5.
- Chalmers J, Pullan M, Mediratta N, Poullis M. A need for speed? Bypass time and outcomes after isolated aortic valve replacement surgery. *Interact Cardiovasc Thorac Surg*. 2014;19:21-6.
- Brown WR, Moody DM, Challa VR, Stump DA, Hammon JW. Longer duration of cardiopulmonary bypass is associated with greater numbers of cerebral microemboli. *Stroke*. 2000;31:707-13.

14. Salis S, Mazzanti VV, Merli G, Salvi L, Tedesco CC, Veglia F, et al. Cardiopulmonary bypass duration is an independent predictor of morbidity and mortality after cardiac surgery. *J Cardiothorac Vasc Anesth*. 2008;22:814-22.
15. Lodge D, Grantcharov T. Training and assessment of technical skills and competency in cardiac surgery. *Eur J Cardiothorac Surg*. 2011;39:287-93.
16. Wade TJ, Lorbeer K, Awad MM, Woodhouse J, DeClue A, Brunt LM. Outcomes of a proficiency-based skills curriculum at the beginning of the fourth year for senior medical students entering surgery. *Surgery*. 2015;158:962-9; discussion 9-71.
17. Aminian A, Chaudhry RM, Khorgami Z, Andali A, Augustin T, Rodriguez J, et al. A challenge between trainee education and patient safety: does fellow participation impact postoperative outcomes following bariatric surgery? *Obes Surg*. 2016;26:1999-2005.
18. Jolley J, Lomelin D, Simorov A, Tadaki C, Oleynikov D. Resident involvement in laparoscopic procedures does not worsen clinical outcomes but may increase operative times and length of hospital stay. *Surg Endosc*. 2016;30:3783-91.
19. Nathan M, Karamichalis J, Liu H, Gauvreau K, Colan S, Saia M, et al. Technical Performance Scores are strongly associated with early mortality, postoperative adverse events, and intensive care unit length of stay—analysis of consecutive discharges for 2 years. *J Thorac Cardiovasc Surg*. 2014;147:389-96.e3.
20. Nathan M, Karamichalis JM, Liu H, del Nido P, Pigula F, Thiagarajan R, et al. Intraoperative adverse events can be compensated by technical performance in neonates and infants after cardiac surgery: a prospective study. *J Thorac Cardiovasc Surg*. 2011;142:1098-107.e5.
21. Nathan M, Karamichalis JM, Liu H, Emani S, Baird C, Pigula F, et al. Surgical technical performance scores are predictors of late mortality and unplanned reinterventions in infants after cardiac surgery. *J Thorac Cardiovasc Surg*. 2012;144:1095-101.e7.
22. Pasquali SK, He X, Jacobs ML, Hall M, Gaynor JW, Shah SS, et al. Hospital variation in postoperative infection and outcome after congenital heart surgery. *Ann Cardiothorac Surg*. 2013;96:657-63.
23. Stewart RD, Backer CL, Young L, Mavroudis C. Tetralogy of Fallot: results of a pulmonary valve-sparing strategy. *Ann Cardiothorac Surg*. 2005;80:1431-9.
24. Boni L, Garcia E, Galletti L, Pérez A, Herrera D, Ramos V, et al. Current strategies in tetralogy of Fallot repair: pulmonary valve sparing and evolution of right ventricle/left ventricle pressures ratio. *Eur J Cardiothorac Surg*. 2009;35:885-90.
25. Fudge JC, Li S, Jaggars J, O'Brien SM, Peterson ED, Jacobs JP, et al. Congenital heart surgery outcomes in Down syndrome: analysis of a national clinical database. *Pediatrics*. 2010;126:315-22.

Key Words: congenital, quality, outcomes

Discussion

Dr Christian Pizarro (Wilmington, Del). I would like to congratulate Mr Lodin, soon to be a physician, and his colleagues for a very nice presentation and a very comprehensive and sophisticated analysis of a cohort of patients undergoing repair of tetralogy of Fallot in infancy.

In this era of increased accountability and transparency, attempts to understand the influence of our surgery and its associated costs continue to gain importance.

The authors attempt to identify factors not included in the technical performance scores originally described by the Boston group that might contribute to increased postoperative length of stay, major complications, and costs.

In this cohort of 115 patients as you described, complications occurred in one-third of the patients, and in fact, 23% of the patients received an inadequate score.

The original study by the Boston group had an inadequate score of 3%. How do you think that these differences influenced your observations?

Mr Lodin. I did not quite hear your question actually. Could you please repeat that one more time?

Dr Pizarro. Sure. The original article and the original description by the Boston group had 3% inadequate score. In your experience, you had 23 patients even with the updated revised version. How do you think that influenced your observations?

Mr Lodin. Thank you for your question. For sample size reasons, we had to combine the optimum and adequate scores together. Potentially combining these categories together may have reduced our ability to find a difference. Using the initially described criteria, any gradient across the right ventricular outflow tract was considered adequate rather than optimum. As we are all well aware, the tide in tetralogy repair has shifted somewhat and now many surgeons would err on the side of leaving some gradient. As such, this criterion has now been revised.

Calibration of the score is an issue, and this is among the reasons why we endeavored to revise the score based on our center's data.

Dr Pizarro. Probably you are in a better position given the fact that you have a larger number of patients with an inadequate score to really discern or find out some differences that might occur. Surprisingly you did not, but we will get to that.

Importantly, you have identified that longer cardiopulmonary bypass time was associated with a longer length of stay and reintervention in addition to the fact that the need to return to bypass was associated with an increased cost, which is not surprising. This suggests that there is a price to pay when operations are longer, reaffirming the idea that we need to achieve a balance between good and optimal.

As you pointed out, an important component of both morbidity and costs is determined by residual lesions. Given the opportunity to study these patients, could you tell us how you think that the presence of residual atrial septal communication could have affected your observations in terms of length of stay?

Dr Chen. The question is whether a residual atrial septal defect (ASD) would have affected your data analysis.

Mr Lodin. We did analyze whether a residual ASD influenced outcomes. Were you looking at total cost in particular?

Dr Pizarro. Or length of stay. Those are the end points that you studied, correct?

Mr Lodin. Correct. I think 1 of the results that came out in our univariable analysis was that a residual ASD was responsible for increased costs and increased complications.

If you actually look at the technical performance score categorization, insufficient or inadequate cases were categorized as 1 if there was a residual ASD.

Dr Tara B. Karamlou (*Phoenix, Ariz.*). With regard to your first question, Christian, I think we had a larger number of repairs scored as adequate, which, for sample size reasons, had to be combined with the inadequate repairs. This could have actually diluted our ability to find certain differences between the groups.

In other words, it is really a calibration issue. The differences between inadequate patients and a group of patients that includes a very large number of adequate repairs may impair the ability to find meaningful differences.

Regarding ASD, that was a univariable factor that was associated with postoperative length of stay. When we looked at it in a multivariable analysis, residual ASD did not fall out as a multivariable factor.

However, one could conceptually believe that the presence of a residual popoff may potentially decrease postoperative length of stay if it simplifies the convalescence (ie, reduction in pleural effusions). Unfortunately, when reading operative notes sometimes it is difficult to figure out when other surgeons purposely left them versus when they made them. This is among the ambiguities of any retrospective study.

Dr Pizarro. The last question I have for you relates to the fact that in this particular study, you had about I believe 10% or 15% of patients who received treatment for arrhythmias, particularly junctional ectopic tachycardia. I do not think that was obviously included in the original score.

Were you deliberately trying to just get to all the variables that might influence cost? Because in the end, it seems like it is not necessarily that you are comparing apples to apples, you know. You are adding some patient-related intraoperative variables to that.

I wonder, how do you think that influenced your findings, because although it is a small percentage of patients, that could certainly have a significant influence on length of stay and cost.

Mr Lodin. I believe something that we worked on was including whatever variables previous literature had used in their analyses, and that definitely came up. Unfortunately, we did not see any sort of statistical significance in that association.

Personally, when doing the data collection process, we worked with whatever variables were available, whatever created some sort of variability. We had only 1 death so we couldn't do an analysis on mortality based on that, but we collected data as best as we could.

Dr Pizarro. I enjoyed your presentation. I congratulate you on this excellent work. Good job.

Readers who found these articles interesting may also like to read the following papers found in recent and future issues of our sister publications, *Seminars in Thoracic and Cardiovascular Surgery* and *Operative Techniques in Thoracic and Cardiovascular Surgery*!

Congenital: Tetralogy of Fallot

ORIGINAL SUBMISSION: Right Ventricular Outflow Tract Reconstruction With a Polytetrafluoroethylene Monocusp Valve: A 20-Year Experience. Mohineesh Kumar. *Semin Thoracic Surg* 2016: 463-470.

Editorial Commentary: The Right Ventricular Outflow Tract Reconstruction: A Challenge in Tetralogy of Fallot Repair. Is There a Right Way of Doing It? An Art or a Science? John M. Karamichalis. *Semin Thoracic Surg* 2016: 471-472.

FIGURE E1. Intraoperative techniques and patient characteristics versus postoperative length of stay (in days) in patients with primary repair of tetralogy of Fallot. PA, Pulmonary artery; RVOT, right ventricular outflow tract; VSD, ventricular septal defect.

TABLE E1. List of Study Variables for Tetralogy of Fallot cohort

Variable type	Variable
Preoperative patient characteristics	Weight at operation, age at operation, PV diagnosis, PV/LPA/RPA z score, RVOTO level, preoperative PDA and ASD, additional VSD, aortic anomalies, DORV, RAA, LSV, trisomy 21, 22q11 deletion, other noncardiac comorbidities
Intraoperative techniques and methods	Prepalliation (MBT shunt or catheter) crossclamp time, CPB time, end operation hematocrit, amiodarone usage, first sternotomy, PV sparing, PV valvotomy, return to bypass, PA and VSD patch material, cardiac cusp created, number of chest tubes, heart block after repair, residual ASD, end-operation rhythm
Postoperative results and outcomes	Mortality, mediastinitis, return to the CICU, renal failure requiring dialysis, phrenic nerve damage, neurologic complications, ECMO, reintervention during hospitalization, heart block requiring pacing, delayed sternal closure, POLOS, indirect, direct, and total cost
TPS and discharge echocardiogram variables	ASD state, ASD shunt flow, VSD state (conoventricular and muscular), RVOTO state, PV gradient, MPA gradient, LPA gradient, RPA gradient, PDA closure, pacemaker

PV, Pulmonary valve; LPA, left pulmonary artery; RPA, right pulmonary artery; RVOTO, right ventricular outflow tract obstruction; PDA, patent ductus arteriosus; ASD, atrial septal defect; VSD, ventricular septal defect; DORV, double outlet right ventricle; RAA, right aortic arch; LSV, left superior vena cava; MBT, modified Blalock-Taussig shunt; CPB, cardiopulmonary bypass; PA, pulmonary artery; CICU, cardiac intensive care unit; ECMO, extracorporeal membranous oxygenation; POLOS, postoperative length of stay; MPA, main pulmonary artery.

TABLE E2. Original and new technical performance rubric for tetralogy of Fallot repairs

TPS scale	ASD repair	VSD repair	VSD repair (muscular)	RVOT obstruction relief	PV repair	RPA repair	LPA repair	PDA closure	Conduction
Original criteria									
3 (Optimal)	No residual shunt, unless popoff < 3 mm	No residual shunt	No residual shunt	No residual shunt	No stenosis or regurgitation	No residual gradient or narrowing	No residual gradient or narrowing	No residual PDA	Normal conduction, or no change from preoperative
2 (Adequate)	Small residual shunt ≤ 3 mm	Small residual shunt ≤ 3 mm	Small residual shunt ≤ 3 mm	Mild residual gradient ≤ 40 mm Hg	Free regurgitation without gradient or gradient ≤ 40 mm Hg	Mild residual gradient ≤ 40 mm Hg	Mild residual gradient ≤ 40 mm Hg	Residual PDA ≤ 1 mm	Mildly abnormal sinus/AV node function
1 (Inadequate)	Reintervention or shunt > 3 mm	Reintervention or shunt > 3 mm	Reintervention or shunt > 3 mm	Reintervention or gradient > 40 mm Hg	Reintervention or gradient > 40 mm Hg	Reintervention or gradient > 40 mm Hg	Reintervention or gradient > 40 mm Hg	Reintervention or residual PDA > 1 mm	Need for permanent pacemaker
New criteria									
3 (Optimal)	No or trivial residual shunt, unless popoff	No or trivial residual defect, < 2 mm if > 10 kg < 1 mm if < 10 kg	No or trivial residual defect, < 2 mm if > 10 kg < 1 mm if < 10 kg	No residual gradient or < 20 mm Hg	RVOT peak gradient < 20 mm Hg, no/mild regurgitation	No residual gradient or < 20 mm Hg	No residual gradient or < 20 mm Hg	No residual PDA	Normal conduction, or no change from preoperative
2 (Adequate)	Small residual defect, 2-3 mm if > 10 kg, 1-2 mm if < 10 kg	Residual defect, 2-3 mm if > 10 kg, 1-2 mm if < 10 kg	Residual defect, 2-3 mm if > 10 kg, 1-2 mm if < 10 kg	Residual peak gradient 20-40 mm Hg	RVOT peak gradient 20-40 mm Hg, mild regurgitation	Residual peak gradient 20-40 mm Hg	Residual peak gradient 20-40 mm Hg	Residual PDA ≤ 1 mm	Mildly abnormal sinus/AV node function
1 (Inadequate)	Reintervention before discharge or residual defect > 3 mm if > 10 kg, > 2 mm if < 10 kg	Reintervention before discharge or residual defect > 3 mm if > 10 kg, > 2 mm if < 10 kg	Reintervention before discharge or residual defect > 3 mm if > 10 kg, > 2 mm if < 10 kg	Reintervention before discharge or peak gradient > 40 mm Hg	Reintervention before discharge or peak gradient > 40 mm Hg, moderate to severe regurgitation	Reintervention before discharge or peak gradient > 40 mm Hg	Reintervention before discharge or peak gradient > 40 mm Hg	Reintervention or residual PDA > 1 mm	Need for permanent pacemaker

Areas shaded in grey show no change in criteria. *TPS*, Technical performance score; *ASD*, atrial septal defect; *VSD*, ventricular septal defect; *RVOT*, right ventricle outflow tract; *PV*, pulmonary valve; *RPA*, right pulmonary artery; *LPA*, left pulmonary artery; *PDA*, patent ductus arteriosus; *AV*, atrioventricular.

TABLE E3. Technical performance score (TPS) breakdown and results of tetralogy of Fallot cohort*

TPS scale	ASD	VSD	VSD (muscular)	RVOT	PV	RPA	LPA	PDA	Conduction	Final TPS
Original criteria										
3 (Optimal)	92	63	0	30	5	13	15	38	93	0
%	83	56	0	28	4	13	15	100	77	0
2 (Adequate)	9	41	5	76	104	85	83	7	13	87
%	8	37	100	70	92	86	85	0	11	77
1 (Inadequate)	10	8	0	3	4	1	0	0	9	26
%	9	7	0	3	4	1	0	0	7	23
Total	111	112	5	109	113	99	98	45	115	113
New criteria										
3 (Optimal)	92	63	0	101	82	90	85	38	93	28
%	82	56	0	91	73	91	86	84	81	25
2 (Adequate)	9	41	5	7	27	8	13	7	13	59
%	8	37	100	6	24	8	13	16	11	52
1 (Inadequate)	11	8	0	3	4	1	1	0	9	26
%	10	7	0	3	4	1	1	0	8	23
Total	112	112	5	111	113	99	99	45	115	113

TPS, Technical performance score; ASD, atrial septal defect; VSD, ventricular septal defect; RVOT, right ventricular outflow tract; PV, pulmonary valve; RPA, right pulmonary artery; LPA, left pulmonary artery; PDA, patent ductus arteriosus. *Discharge echocardiography data were only available for 113 out of 115 cases.

TABLE E4. Multivariable logistic regression analysis for having one or more complications

Variable	Odds ratio	β	Standard error	P value
Crossclamp time (min)	1.0*	0.03	0.02	.02
Stenotic/atretic PV	5.5	1.7	0.9	.07
Multiple VSD	7.4	2	0.9	.03
Weight at repair (kg)	0.7†	−0.4	0.2	.02
Synthetic PA patch material	1.6	0.5	0.2	.02
PV valve sparing	2.5	0.9	0.6	.10

Refer to Table E1 for a list of all variables used in the analysis. PV, Pulmonary valve; VSD, ventricular septal defect; PA, pulmonary artery. *Odds ratio value increase as cross-clamp time increases. †Odds ratio value decreases as weight increases.