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ORIGINAL ARTICLE

A Single-Centre Retrospective Review of Modified Blalock-Taussig Shunts: A 22-Year Experience

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Introduction This single-centre retrospective study explores demographics and outcomes of patients who underwent a modified Blalock-Taussig shunt (MBTS) over a 22-year period. The predominant surgical approach in this study is a lateral thoracotomy, in contrast to a midline sternotomy. Risks and outcomes of this approach are compared with national and international literature.

Materials and Methods Demographic, anatomical, clinical, surgical and outcome data of all patients who underwent a MBTS between 2000 and 2022 were collected and analysed, excluding Norwood procedures, which are not performed at this institution. Short- and long-term morbidity and mortality is described.

Results Over the 22-year study period, 185 MBTS were performed in 162 patients, at a median age of 16 days (interquartile range [IQR] 5–59 days) and weight of 3.47 kg (IQR 3–4.25 kg, minimum weight 2 kg). Of these, 79% of patients had a biventricular circulation. Cardiac diagnoses included both univentricular and biventricular anatomy; tetralogy of Fallot (TOF) (36%), transposition of the great arteries/ventricular septal defect/pulmonary stenosis (TGA/VSD/PS) (11%), pulmonary atresia with intact ventricular septum (PA/IVS) (23%), pulmonary atresia with ventricular septal defect (PA/VSD) (14%), other (16%). The most common size of MBTS was 4 mm (71%); 93% were performed via a lateral thoracotomy. There were 47 cases of major operative morbidity, which did not differ significantly with cardiac diagnosis. Overall all-cause mortality was 13.5%. Early operative mortality was 4.3%. Mortality varied with cardiac diagnosis, 6% with TOF and 19% with PA/IVS. There was no era effect on mortality rates, however a lower frequency of major morbidity (23% vs 7%, p=0.03) was observed in the most recent third of the study period. Risk factors for shunt reintervention or mortality included weight <2.5 kg (HR=2.79 [1.37, 5.65], p=0.005), and pre- (HR=3.31 [1.86, 5.9], p<0.001) or postoperative lactic acidosis (HR=1.37 [1.25,1.5], p<0.001). These rates are comparable to those in the literature, with the predominant approach a midline sternotomy.

Conclusion Mortality rates and risk factors for adverse outcomes are comparable to those previously reported for both univentricular and biventricular groups. These results highlight that outcomes of MBTS performed via lateral thoracotomy are comparable to those by midline sternotomy as reported in the literature. Operating via the lateral approach may be advantageous as it avoids the complications of a midline sternotomy.

Keywords Modified Blalock-Taussig shunt • Surgical outcomes • Thoracotomy versus midline sternotomy • Congenital heart surgery

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Introduction

The systemic to pulmonary shunt was first described and performed in 1944 by Alfred Blalock, Helen Taussig and Vivien Thomas [1]. Since then, the Blalock-Taussig Shunt (BTS) has historically been an ingenious avenue for palliation for children with cyanotic disease and currently a useful interim measure for patients too young or unfit for complete surgical correction or palliative procedures [2].

Despite improvements in technique, experience, perioperative care and technology leading to more efficient and effective diagnosis, intervention and management, the BTS continues to have high morbidity and mortality rates across multiple cardiothoracic units globally [3]. This may also reflect a change in patient cohort undergoing the procedure, which historically was predominantly patients with tetralogy of Fallot, with more recent increased utilisation in complex single ventricle anatomy [1]. Studies indicate that adverse outcomes may be related to patient factors, including low birth weight, genetic abnormalities [3], and univentricular cardiac lesions [1]. Factors such as increased pulmonary blood flow, shunt occlusion [3], and thrombocytosis or hypoxia in the postoperative period [4] have also been associated with poor outcomes.

The aims of this single-centre retrospective study are threefold: (1) to explore the demographic, anatomical, clinical and surgical features of patients who underwent a modified BTS (MBTS) over a 22-year period between 2000 and 2022; (2) to describe the short- and long-term outcomes and identify any risk factors for this cohort; (3) to compare outcomes with other published data. The predominant surgical approach in this study was a lateral thoracotomy, in contrast to a midline sternotomy, thus it is of interest to compare the techniques in terms of risk.

Materials and Methods

All patients under the age of 18 years who underwent a MBTS between 1 January 2000 and 31 July 2022 were entered for analysis. Norwood procedures were not included as they are not performed at this institution.

Demographic, anatomical, clinical and operative details were collected via a review of the medical record, observation charts, operative notes and imaging, cardiology, cardiothoracic and pathology electronic databases (Filemaker Pro [Claris International Inc. USA], iSoft Clinical Manager [iSoft Group plc UK], IMPAX 6 [AGFA HealthCare, Agfa-Gevaert Group], Cardiobase [Cardiobase Australia], Synapse Cardiovascular [Client v5.1.3, Fujifilm Medical Systems USA]). Data was collected until each patient's complete repair, most recent available information, or death.

Definition

Prematurity was defined as less than 37 weeks' gestation. Major cardiac morbidity was defined as cardiac arrest with or without the use of extracorporeal membrane oxygenation (ECMO), early and late shunt stenosis, shunt thrombosis and pulmonary overcirculation. Early morbidity and mortality are defined as <30 days postoperatively. Shunt stenosis is defined as a shunt narrowing leading to a decrease in shunt flow with a haemodynamic impact. Shunt thrombosis is defined as obstruction to shunt flow due to thrombosis. These have been grouped together as early and late shunt complications. Pulmonary overcirculation was diagnosed using clinical observation and investigations including higher than expected oxygen saturation for underlying anatomy, chest x-ray changes indicative of pulmonary plethora, low mixed venous saturation, rising lactate and relatively low mean blood pressure. Minor morbidity included pericardial effusion, tamponade, false aneurysm, wound infection, chylothorax, Horner's syndrome, vocal cord palsy and diaphragmatic palsy. Re-intervention on the shunt was defined as surgical revision, clipping, additional shunt placement or percutaneous intervention prior to complete cardiac repair. For patients with multiple shunts who died, the end point of mortality is counted only following the most recent shunt. Duct dependence was defined as all patients with pulmonary atresia with intact ventricular septum (PA/IVS) as well as those that required prostaglandin E1 infusion prior to surgery.

Statistical Analysis

Data analysis was completed using R (version 4.1.3) [5] within the RStudio integrated development environment and was written in RMarkdown (RStudio Team, Boston MA). A Kruskal-Wallis test was used to compare numeric demographic, clinical and surgical characteristics across diagnosis groups, and Fisher's exact test for group comparisons of categorical characteristics. Independent variables included gestation, weight, single/double ventricular circulation, patent ductus arteriosus (PDA), genetic diagnosis, shunt site and size and lactate. Cox regression modelling was used to examine impact on time to shunt failure or death, with all models stratified by cardiac diagnosis. Robust standard error estimates were used to take account of more than one surgery for some patients. Dependent variables were morbidity and mortality. Normally distributed data is represented as mean +/- standard deviation, while non-normally distributed data is reported as a median and interquartile range. A p-value of less than 0.05 was considered significant; 95% confidence intervals (CI) were utilised.

Results

Over the 22-year study period, 185 systemic to pulmonary shunts were performed in 162 patients, at a median age of 16 days (interquartile range [IQR] 5–59 days) and median weight of 3.47 kg (IQR 3–4.25 kg). Fifteen (15) (9.3%) were less than two and a half kilograms at time of surgery with a minimum weight of 2 kg. Thirty-five (35) patients (22%) were premature, 39 (24%) had a genetic diagnosis and 34 (21%) had an additional non-cardiac diagnosis. One hundred and forty-seven patients (147) (79%) had biventricular circulation

Table 1 **Demographic characteristics of patients who underwent a shunt operation.**

Characteristic	n=162
Male	91 (56%)
Female	71 (44%)
Median age at operation (days) (IQR)	16 (5.0–59)
Median preoperative weight (kg) (IQR)	3.47 (3.0–4.25)
Less than 2.5 kg	15 (9.3%)
Gestation	
Term	121 (78%)
Preterm (<37/40)	35 (22%)
Extracardiac anomaly	34 (21%)
Genetic diagnosis	28 (17%)
Trisomy 21	5
Trisomy 13	1
22q11 deletion,	7
VACTREL association	6
Noonan syndrome	1
CHARGE syndrome	2
Other	6

Abbreviations: IQR, interquartile range; VACTREL, vertebral defects, anal atresia, cardiac defects, tracheo-oesophageal fistula, renal anomalies, and limb abnormalities.; CHARGE, coloboma, heart defects, choanal atresia, growth restriction, genital abnormalities, and ear abnormalities.

Table 2 **Clinical and surgical characteristics at time of operation.**

Characteristic	n=185
Circulation	
Biventricular (%)	147 (79%)
Univentricular (%)	38 (21%)
Arch sidedness	
Left	141 (76%)
Right	44 (24%)
PDA	
Yes	107 (58%)
No	78 (42%)
Cardiac diagnosis	
TOF (%)	66 (36%)
TGA/VSD/PS (%)	21 (14%)
PA/IVS (%)	42 (22%)
PA/VSD (%)	26 (14%)
Other (%)	30 (13%)
TA/VSD/HRV	1
TAPVR	2
ccTGA /PA/VSD	2
TGA/PA/single ventricle	8
DILV	1
DORV	3
DORV/TGA/VSD	2
DILV/DORV	1
PS/HRV	1
Ebstein's anomaly	1
Unbalanced AVSD	5
Unbalanced AVSD/TAPVR/PA/VSD	2
Heterotaxy/AVSD/DORV/TOF	1

Abbreviations: PDA, Patent ductus arteriosus; TOF, tetralogy of Fallot; TGA, transposition of the great arteries; VSD, ventricular septal defect; PS, pulmonary stenosis; PA, pulmonary atresia; IVS, intact ventricular septum; PA/VSD, pulmonary atresia with VSD; TAPVR, total anomalous pulmonary venous return; ccTGA, congenitally corrected TGA; DILV, double inlet left ventricle; DORV, double outlet right ventricle; HRV, hypoplastic right ventricle; AVSD, atrioventricular septal defect; TA, tricuspid atresia.

and 141 (76%) had a left aortic arch. The cardiac diagnoses were collated in five groups: tetralogy of Fallot (TOF), transposition of the great arteries/ventricular septal defect/ pulmonary stenosis (TGA/VSD/PS), pulmonary atresia with intact ventricular septum (PA/IVS), pulmonary atresia with ventricular septal defect (PA/VSD), and "other". Ten of the patients with PA/VSD had major aortopulmonary collateral arteries (MAPCAs). The cohort was divided into three equal time intervals to examine for an era effect on outcomes. Full demographic and anatomical details are shown in Table 1 and clinical details at time of operation are shown in Table 2.

The predominant shunt inserted was a 4 mm Gore-Tex MBTS via a right thoracotomy (n=94). Of the 185 shunts placed, 172 were MBTS (subclavian to pulmonary artery), while 12 central (aorta to pulmonary artery) shunts were placed. All shunts were Gore-Tex. Complete shunt size and site details are displayed in Figures 1 and 2. The mean shunt size to patient weight ratio was 1.14 (0.94, 1.33). One hundred and fifty-seven (157) (85%) shunts were performed via lateral thoracotomy (121 right, 36 left), while 28 (15%) were via a midline sternotomy (all 12 central shunts [2 via redo sternotomy and 1 right MBTS converted to central], 14 right MBTS [1 via redo sternotomy] and 2 left MBTS). Ninety-four percent (94%) of initial and 48% of subsequent shunts were placed in the first 6 months of life. The number of shunts placed per year by diagnosis is displayed in Figure 3.

Seventeen (17) patients required two shunts and three required three shunts. The requirement for multiple shunts was due to limited shunt flow, isolated pulmonary arteries, complex anatomy/repair or allowing time for a patient to grow prior to definitive surgery, such as a Rastelli procedure. Of those with two shunt operations, 12 had an additional shunt placed while four had the first shunt replaced. Eight (8) patients received their second shunt in the early postoperative period (<30 days), while four received their second shunt within 6 months. Of those with three shunts, two had an additional shunt, then both were ligated prior to the third being placed. The remaining patient had their first shunt (right MBTS) removed as their second (central) shunt was placed. An additional left MBTS was subsequently placed.

Eighteen (18) patients (10%) had preoperative lactic acidosis. Sixty-two (62) (42%) patients required a prostaglandin infusion prior to their operation. Fifteen (15) patients

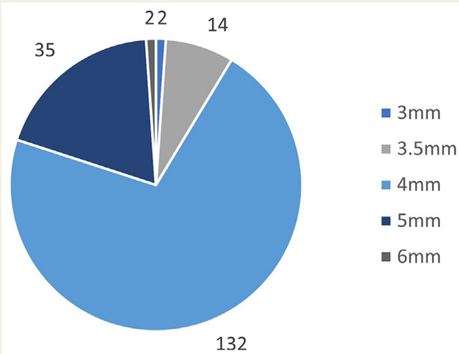

Figure 1 Size of shunt inserted.

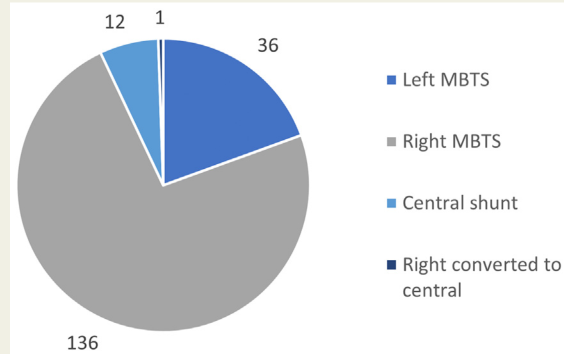

Figure 2 Location of shunt inserted.
Abbreviation: MBTS, modified Blalock-Taussig shunt.

required cardiac bypass, ten undergoing a central shunt and five undergoing a right MBTS via midline sternotomy due to anatomical abnormalities (such as large right-sided PDA and right-sided arch displacing the heart) that precluded a lateral approach. Of the 44 operations in patients with right aortic arches, 29 (66%) were right MBTS, 12 (27%) were left MBTS and three (7%) were central shunts. Four (4) patients with right aortic arches had multiple shunt revisions/replacements. A PDA was present preoperatively in 107 (58%) shunt operations. This was ligated in 17 cases, leaving 89 (48% of total patients) with a ductus postoperatively. Patients were commenced on a heparin infusion (10 units/kg/hr) postoperatively, which was converted to aspirin (3–5 mg/kg) once enteral nutrition was commenced.

Mortality

Overall all-cause mortality was 13.5% (25/185). Early operative mortality was 4.3% (8/185) with 17 late deaths. Mortality in patients with univentricular circulation was 13.2% (5/38) and 13.6% (20/147) in patients with biventricular circulation. Mortality by diagnosis is displayed in Table 3. The lowest mortality rates were seen in the TOF group (6%) while PA/IVS (19%) and the complex, yet heterogeneous "other" group recorded the highest mortality rates (26.7%). PA/IVS accounted for one third of the early deaths (3/9). No significant difference in mortality was seen across time periods as seen in Table 4. Figure 4 displays a Kaplan-Meier curve of time to shunt failure or death by cardiac diagnosis.

Patients with duct-dependent circulation had a higher mortality rate (16 deaths from 90 operations, 18%) than those who were not dependent on ductal flow (9 deaths from 95 operations, 9%). Mortality rates were higher in patients under 2.5 kg (5 deaths from 17 operations, 29%), than from 2.5 kg to 3 kg (4 deaths from 25 operations, 16%) and greater than 3 kg (14 deaths from 139 operations, 10%), respectively.

Cox regression modelling of time to shunt failure or death was undertaken to examine the impact of various demographic, clinical and surgical characteristics, with all models stratified by cardiac diagnosis, shown in Table 5. Patients who weighed <2.5 kg at time of surgery had a faster progression to shunt failure or death (Hazard rate [HR] = 2.79 [95% confidence interval 1.37, 5.65], p=0.005), particularly in the first month (HR = 3.64 [1.77, 7.49], $p<0.001$), with low weight being a stronger predictor of outcome than shunt size and shunt size to weight ratio. Patients experiencing preoperative shock experienced failure at more than three times the rate of those who did not (HR=3.31 [1.86, 5.90], $p<0.001$), with this risk factor acting independently of low weight (multivariable model: preoperative shock acidosis: HR=3.24, $p<0.001$; weight <2.5 kg: HR=2.72, p=0.003). Increased lactate levels in the postoperative period were also associated with higher event rates (HR=1.37 [1.25, 1.50], $p<0.001$). Patients who underwent a central shunt suffered shunt failure or death at more than three times the rate of patients who had peripheral shunts (HR=3.27 [1.05, 10.23], p=0.04). In our institution, an approach via midline sternotomy was reserved for patients with complex underlying anatomy or those requiring additional surgery. Of the 12 central shunts placed, eight were in patients with multiple shunts, four of whom died. There were four isolated central shunts, with three deaths. Seven of the 20 patients who had multiple shunts died. The only surgical option for some of these patients was palliation with a MBTS. There was no significant difference in the rate of progression to shunt failure or death in infants weighing 2.5 kg to 3 kg or >3 kg ($p>0.4$). No significant difference in time to shunt failure or death was observed by year of operation.

Morbidity

Major and minor early cardiac morbidity is displayed in Figure 5. There were 49 cases of major morbidity which included cardiac arrest with (n=6) or without (n=3) ECMO, ECMO without arrest (n=4), early (n=3) or late shunt stenosis/thrombosis (n=23), and pulmonary overcirculation (n=10). All but three patients who suffered a cardiac arrest or required ECMO died. Twenty-nine (29) cases required shunt re-intervention prior to complete repair, including percutaneous intervention (n=14), surgical revision (n=10), the

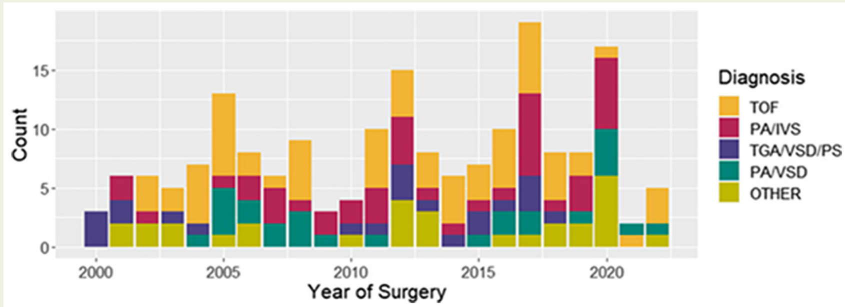

Figure 3 Shunts inserted per year by diagnosis.
Abbreviations: TOF, tetralogy of Fallot; PA, pulmonary atresia; IVS, intact ventricular septum; TGA, transposition of the great arteries; VSD, ventricular septal defect; PS, pulmonary stenosis.

placement of an additional shunt (n=2), hybrid procedure (n=1), shunt clipping (n=1) or conservative management (n=1). Major morbidity rates decreased (7.2% vs 23%, p=0.028) in the most recent time interval of the study period, as seen in Table 4. There were 41 cases of minor operative morbidity including pericardial effusion/tamponade (n=3), false aneurysm (n=2), wound infection (n=10), chylothorax (n=3), Horner's syndrome (n=10), vocal cord palsy (n=7) and diaphragmatic palsy (n=6). Morbidity prevalence did not significantly differ with cardiac diagnosis.

Of the ten patients with pulmonary overcirculation, four had a PDA preoperatively and two returned to theatre (one on the same day and one four days postoperatively) for PDA ligation. There were 12 cases of multiple complications. These included five cases requiring ECMO due to cardiac arrest, resulting in four deaths, two early and two late. Of the remaining seven cases, there were two cases of early and one case of late morality. Of all the patients who had cardiac morbidity requiring intervention, only three had left pulmonary artery (LPA) stenosis. Of the 16 cases requiring bypass, six had complications including, one case of acute bleeding in the immediate postoperative period, three complicated by late shunt thrombosis, two cardiac arrests with ECMO, two episodes of pulmonary overcirculation, one chylothorax and one wound infection. There were no cases of significant scoliosis in the cohort.

Table 3 Mortality rates by cardiac diagnosis.

Cardiac diagnosis	Mortality rate % (n)
TOF	6% (4/66)
TGA/VSD/PS	14.3% (3/21)
PA/VSD	12% (3/26)
PA/IVS	19% (8/42)
Other	26.7% (8/30)

Abbreviations: TOF, tetralogy of Fallot; TGA, transposition of the great arteries; VSD, ventricular septal defect; PS, pulmonary stenosis; PA, pulmonary atresia; IVS, intact ventricular septum.

Discussion

Despite improvements in outcomes for complete repair in smaller and younger patients, the MBTS remains a useful procedure for patients too young, too unwell or not suitable for such surgical options. We have demonstrated an overall mortality rate of 13.5% and operative mortality rate of 4.3%. These rates are similar to those noted in the literature. Hobbes et al. [4] published outcomes from the Royal Children's Hospital in Melbourne, Australia noting an overall mortality rate of 12.8% and operative mortality rate of 5.2% for MBTS cases between 2004 and 2014 with 48-month follow-up. Patients with genetic and/or additional non-cardiac diagnoses were included while those with single ventricle anatomy were excluded. Ninety-one percent (91%) of cases were via a midline sternotomy. Sasikumar et al. [6] reported an overall mortality of 16% and operative mortality of 10% for MBTS procedures at the Hospital for Sick Children in Toronto in the same time period, however including smaller weight infants. The majority (97%) of cases were via sternotomy and excluded cases with nonconfluent pulmonary arteries, shunts to unifocalise aortopulmonary collaterals, rescue procedures after another cardiac surgery, shunt after takedown, those undergoing other concomitant procedures and Norwood procedures. Williams et al. [1] from the John Hopkins Medical Institution in Maryland collected retrospective data from 1944 to 2006 and noted an overall mortality rate of 14% across the 62 years, excluding those who underwent central shunts. Given the extended duration of review, it is not surprising that variations were observed over this period. The predominant anatomy was tetralogy of Fallot (74%), however improved mortality rates have been observed with MBTS being utilised in patients with increasingly complex single ventricle anatomy later in the series. Since the 1990s a midline sternotomy has become the preferred approach. Petrucci et al [7] described outcomes from the multi-institutional Society of Thoracic Surgeons Congenital Heart Surgery database reporting an overall mortality in MBTS of 7.2% in 1,273 patients with both single and double ventricle anatomy from 2002 to 2009, excluding those with hypoplastic left heart syndrome, conduit failure and a concomitant procedure other

Table 4 Mortality and major morbidity across time periods.

	Total n=185	2000–2007 n=54	2008–2015 n=62	2016–2022 n=69	P-value[1]
Mortality	25 (14%)	6 (11%)	10 (16%)	9 (13%)	0.7
Major morbidity	31 (17%)	12 (22%)	14 (23%)	5 (7.2%)	0.028

[1]Pearson's Chi-squared test.

than PDA ligation. Patients from 1.5 kg (29 who were <2.5 kg) were included. One third of deaths occurred within 24 hours and 75% within 30 days postoperatively. They do not comment on approach. Alsoufi et al. [3] reviewed 174 cases of MBTS performed via midline sternotomy between 2002 and 2012, from Children's Healthcare of Atlanta, excluding those as part of a Norwood operation, unifocalisation of multiple aortopulmonary collaterals or for the management of severe cyanosis following pulmonary artery banding. Overall mortality was reported as 11% at one month, 27% at one year, 31% at five years and 32% at eight years.

In our data, the lowest mortality rates were seen in patient with TOF, consistent with previous studies [1]. As surgeons have become more comfortable with earlier repair in TOF, fewer MBTS are being performed in this patient group, with the majority reserved for smaller, younger and sicker patients or those with less favourable anatomy [1], which may impact mortality rates in this group in the future. In addition, utilisation of ductal or right ventricular outflow tract stenting may be utilised as a bridging procedure prior to complete repair in patients with suitable cardiac lesions which may decrease the requirement for MBTS in this cohort. These procedures were not utilised during the study period at our institution and, as such, patients are temporised with a MBTS. The highest mortality was in patients with functionally univentricular hearts and PA/IVS consistent with published literature [4,7–9]. Duct dependent circulation also conferred a higher risk. The most frequently observed major morbidities were late shunt stenosis and thrombosis consistent with previous reports [2,6,7,10], while Horner's syndrome and wound infection were the most common minor morbidity. Morbidity prevalence did not significantly differ with cardiac diagnosis but did decrease in the later study period. Shunt reintervention was required in 15% of cases prior to complete repair.

Surgical approach has been a topic of controversy with various benefits and challenges of both sternotomy and thoracotomy reported. In our cohort, both midline sternotomy and central shunts were reserved for patients with more complex anatomy and those requiring additional procedures, likely contributing to the less favourable risk profile. Due to the small number of each in this series, we are unable to draw meaningful conclusions from our cohort and further clinical trials or meta-analyses are required.

There has been a trend towards a midline sternotomy as the preferred approach for MBTS around the world. Thoracotomy has been reported to have four times higher risk of shunt failure [11] and risks lung adhesions, Horner's syndrome, late scoliosis [12] and preferential lung flow resulting in unbalanced lung growth [11]. A MBTS via thoractotomy has also been reported as technically more challenging to perform [13]. Despite this, it has been proposed that surgery performed through a thoracotomy may expose patients to fewer wound infections, reduced postoperative respiratory compromise, decreased hospital stay and cosmetic concerns [14]. In our study, the majority of MBTS were conducted via a lateral thoracotomy (86%) rather than a midline sternotomy. We did not observe any cases of scoliosis or unbalanced

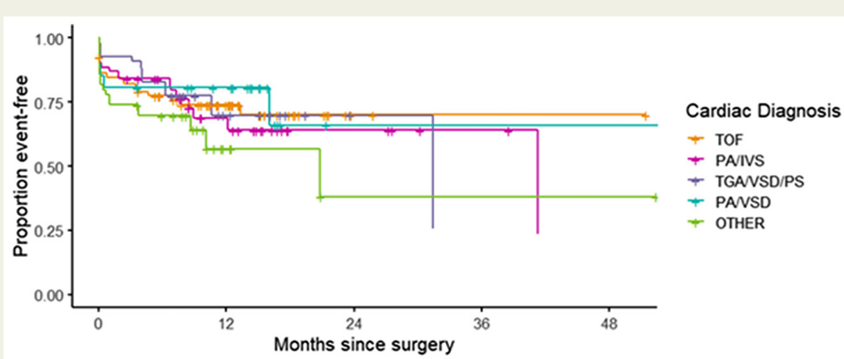

Figure 4 Survival curve of time to shunt failure or death following MBTS by cardiac diagnosis.
Abbreviations: TOF, tetralogy of Fallot; PA, pulmonary atresia; IVS, intact ventricular septum; TGA, transposition of the great arteries; VSD, ventricular septal defect; PS, pulmonary stenosis.

Table 5 Cox regression analysis for time to shunt failure or death by demographic, clinical and surgical factors (total, early and late).

	Total			Events before 30 days			Events after 30 days		
	HR	95% CI	p	HR	95% CI	p	HR	95% CI	p
Age months	0.98	(0.93,1.04)	0.5	1.00	(0.95,1.05)	0.9	0.93	(0.82,1.05)	0.2
Sex (ref: Female)									
Male	1.17	(0.67,2.06)	0.6	1.03	(0.49,2.17)	0.9	1.40	(0.65,3.04)	0.4
Weight (kg)	0.87	(0.71,1.07)	0.2	0.93	(0.71,1.22)	0.6	0.79	(0.58,1.06)	0.1
Weight (ref: ≥2.5 kg)									
<2.5 kg	2.79	(1.37,5.65)	0.005	3.64	(1.77,7.49)	<0.001	0.93	(0.15,5.69)	0.9
Weight (kg) (ref:<2.5 kg)									
(2.5–3 kg)	0.62	(0.24,1.57)	0.312	0.60	(0.23,1.56)	0.003	1.19	(0.16,8.84)	0.9
(3,1–3.5 kg)	0.32	(0.15,0.71)	0.005	0.21	(0.09,0.49)	<0.001	1.05	(0.17,6.43)	1.0
Shunt size	0.64	(0.38,1.07)	0.09	0.64	(0.29,1.42)	0.3	0.64	(0.31,1.31)	0.2
Shunt size/kg weight	2.63	(1.21,5.71)	0.01	3.04	(0.98,9.40)	0.05	2.11	(0.83,5.38)	0.1
Premature	1.27	(0.67,2.39)	0.5	1.50	(0.70,3.24)	0.3	0.91	(0.31,2.63)	0.9
Disorder type (ref: None)									
Genetic	1.42	(0.76,2.67)	0.3	1.54	(0.68,3.47)	0.3	1.28	(0.50,3.28)	0.6
Extra-cardiac	0.97	(0.49,1.93)	0.9	1.06	(0.42,2.66)	0.9	0.85	(0.30,2.43)	0.8
Site (ref: Left)									
Right	1.11	(0.56,2.19)	0.77	0.79	(0.37,1.69)	0.545	1.83	(0.472,7.10)	0.4
Central	3.27	(1.05,10.23)	0.04	4.33	(1.60,11.73)	0.004	1.24	(0.079,19.41)	0.9
Double ventricle (ref: No)									
Yes	1.63	(0.80,3.32)	0.2	1.96	(0.74,5.22)	0.2	1.26	(0.42,3.82)	0.7
Aortic arch (ref: Left)									
Right	1.46	(0.83,2.59)	0.2	2.24	(1.12,4.45)	0.02	0.67	(0.26,1.73)	0.4
Right arch, right shunt (ref: No)									
Yes	1.22	(0.66,2.27)	0.5	1.70	(0.82,3.52)	0.2	0.64	(0.22,1.88)	0.4
Preoperative shock (ref: No)									
Yes	3.31	(1.86,5.90)	<0.001	2.73	(1.22,6.08)	0.01	4.52	(1.71,11.93)	0.002
Preoperative PDA (ref: No)									
Yes	1.18	(0.68,2.03)	0.6	0.88	(0.41,1.91)	0.8	1.75	(0.78,3.93)	0.2
Postoperative PDA (ref: No)									
Yes	1.03	(0.63,1.69)	0.9	0.71	(0.36,1.40)	0.3	1.73	(0.77,3.87)	0.2
PDA ligated in theatre (ref: No)									
Yes	1.27	(0.52,3.10)	0.6	1.79	(0.70,4.60)	0.2	0.51	(0.062,4.15)	0.5
Mean lactate	1.37	(1.25,1.50)	<0.001	1.37	(1.24,1.50)	<0.001	1.37	(0.93,2.02)	0.1
day 1	1.02	(0.98,1.06)	0.4	1.02	(0.96,1.08)	0.5	1.02	(0.96,1.08)	0.6
Year	1.02	(0.98,1.06)	0.4	1.09	(1.01,1.18)	0.02	0.94	(0.89,0.99)	0.03
Cohort (ref: [2000–2007])									
[2008–2015]	1.24	(0.67,2.30)	0.5	1.40	(0.44,4.44)	0.57	1.20	(0.54,2.67)	0.66
[2016–2022]	1.18	(0.63,2.23)	0.6	2.65	(0.93,7.59)	0.07	0.25	(0.07,0.92)	0.04

Abbreviations: PDA, patent ductus arteriosus; BP, blood pressure.

lung growth. An overall wound infection rate of 5.4% was observed, compared to 13–30% reported during the same period [1,4,6].

Central shunts arise from the aorta, rather than the subclavian artery as with a MBTS. They have been reported to be associated with prolonged mechanical ventilation, increased inotrope usage and prolonged intensive care and hospital admission [15]. In our cohort, patients who received a central shunt had higher mortality rates than those with a MBTS, but given the small number (n=12, 6.5%), these results should be interpreted with care and require further exploration.

This study found that patients with preoperative weight <2.5 kg and those with acidosis in the perioperative period experienced shunt failure or death at higher rates than those who did not, irrespective of cardiac diagnosis, consistent with previous work [2,4,8]. Despite being reported elsewhere in the literature [4,8], genetic or extracardiac anomalies were not found to be independent predictors of poor outcomes. A

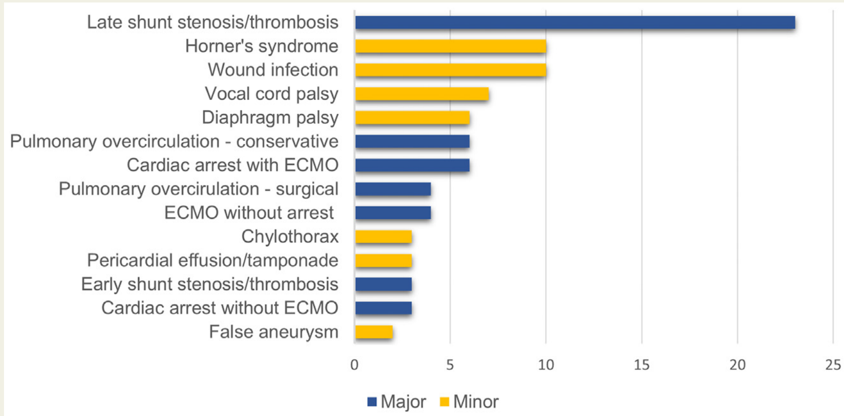

Figure 5 Major and minor early postoperative morbidity following modified Blalock-Taussig shunt procedure. Abbreviations: ECMO, extracorporeal membrane oxygenation.

pulmonary overcirculation rate of 5.4% is similar to that published by Bove [10] but lower than other reports [6]. This may be another benefit of an approach via thoracotomy. As stated in Poiseuille's law, flow is proportional to the 4th power of the radius of the tube in which it runs. Placing the MBTS more distally may in fact protect against pulmonary overcirculation as the diameter of the subclavian artery contributes towards the haemodynamics and acts as a 'flow regulator' [16] limiting excessive flow. A more distal shunt position may also allow the placement of a slightly larger shunt, decreasing thrombosis risk, without contributing to additional pulmonary blood flow. This potential benefit must be balanced against the disadvantage of limited access to ligate the PDA.

Shunt size to weight ratio is utilised in obtaining the optimal shunt size in a patient while balancing the risk of thrombosis with pulmonary overcirculation [17]. Shunt size however is not the only contributor to excessive or inadequate pulmonary blood flow, with the vessels both distal and proximal contributing to overall haemodynamics. Shunt size to pulmonary artery size has thus been proposed as a superior predictor of thrombosis [18], which requires further study in this cohort.

This paper suggests approaching a MBTS via a lateral thoracotomy is not inferior to a midline sternotomy in regard to mortality and morbidity for both univentricular and biventricular cardiac patients. Both approaches have benefits and limitations as described above.

Limitations

There are the inherent challenges with drawing conclusions from observational, retrospective studies and all comparisons to other published data are limited by differences in cohort and institutional medical practice and as such, must be made with that caveat. Due to the size of our institution, only a relatively small number of patients were included in this series. This was prohibitive to more complex and detailed statistical analysis including further study of factors predicting suboptimal outcomes. Multicentre trials and meta-analyses will be useful to combat these issues, however confounders of surgical technique and institutional practice must be accounted for.

Conclusion

The mortality rates in this study are comparable to those previously reported for both univentricular and biventricular circulations. These results highlight acceptable outcomes of MBTS performed via lateral thoracotomy which are similar to those reported for midline sternotomy. The choice of midline or lateral approach should be based upon published evidence and surgical expertise.

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Declarations of Interest

None

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