Outcomes of right ventricular outflow tract stenting as a palliative procedure in tetralogy of Fallot patients

Victoria Pickup and Jayneel Joshi

Department of Paediatrics and Child Health, Faculty of Health Sciences, University of Pretoria, Hatfield, Pretoria, South Africa

Address for correspondence:
Dr Victoria Pickup
University of Pretoria
Department of Paediatrics and Child Health
Faculty of Health Sciences
Lynnwood Road
Hatfield
Pretoria
0002
South Africa

Email:
v.pickup@gmail.com

ABSTRACT

Background: Certain patients with tetralogy of Fallot (TOF) require a palliative procedure until their condition permits a full surgical repair. Aorto-pulmonary shunting is the standard palliative procedure but requires a cardiothoracic surgeon in a well-equipped facility. Overwhelming caseloads and limited resources in the public sectors in developing countries frequently restrict access to such treatment. Percutaneous right ventricular outflow tract (RVOT) stenting offers an alternative.

Objectives: To evaluate the safety and effectiveness of RVOT stenting in TOF patients in a resource-limited setting.

Method: A retrospective, cohort observational study at Steve Biko Academic Hospital from January 2014 - March 2021.

Results: Thirty-seven patients required RVOT stent placement. Mean oxygen saturation increased from 65% to 95% post-stent insertion. Mean pulmonary artery (PA) growth, measured by McGoon ratio, increased from 1.36 to 2.05. Average Intensive Care Unit stay was 2 days with zero 30-day mortality. Three stents fractured and required replacement.

Conclusion: Stenting the RVOT in TOF patients presenting beyond the neonatal period, with multiple comorbidities and often in extremis, yielded good results. Significant improvement in oxygen saturations and PA growth permitted the majority of patients to proceed to full TOF surgical repair. This is an especially valuable option to have in resource constrained settings when surgical assistance is not always readily available.

SA Heart® 2024;21:36-44

INTRODUCTION

Tetralogy of Fallot (TOF) is the most common cyanotic congenital heart disease (CHD) seen at Steve Biko Academic Hospital (SBAH), a tertiary hospital in the Gauteng province of South Africa. The Paediatric Cardiology Department services approximately 15% of the population including the greater part of the provinces of Mpumalanga, Limpopo and Gauteng. It is one of only 6 state cardiothoracic surgery services in South Africa. In 2016, more than 150 cardiothoracic procedures were performed in only 2 of the 6 units.[1] Thus many paediatric patients die while awaiting surgery. Global standards require 1 cardiothoracic surgeon per 800 000 population.[1] In South Africa in 2016 there was 1 cardiothoracic surgeon per 4.5 million population with the majority practising in the private sector.

TOF is defined by 4 congenital heart defects: Right ventricular hypertrophy, ventricular septal defect, aortic override and right ventricular outflow tract (RVOT) obstruction. This report focusses on RVOT obstruction which contributes the majority of the morbidity and mortality in these patients.

The majority of patients with TOF undergo primary complete surgical repair with excellent outcomes.[2] In order for surgery to be successful certain requirements must be fulfilled (Figure 1). An adequate pulmonary artery size is necessary to enable full repair. The McGoon ratio is the ratio of the sum of left and right pulmonary artery diameters to the aortic diameter at the level of the diaphragm (Figure 2). Should the patient weigh less than 2.5kg or there is unfavourable anatomy or medical emergency management of a hypercyanotic spell has failed or the McGoon ratio is less than 2, an interim palliative procedure is indicated before circumstances permit full surgical repair. Dawoud, et al., suggest a McGoon ratio of 1.5 to guide decision making.[3] Our Institution's preference is a ratio of 2.

Aorto-pulmonary shunting is the standard palliative procedure bypassing the RVOT obstruction and supplying blood directly

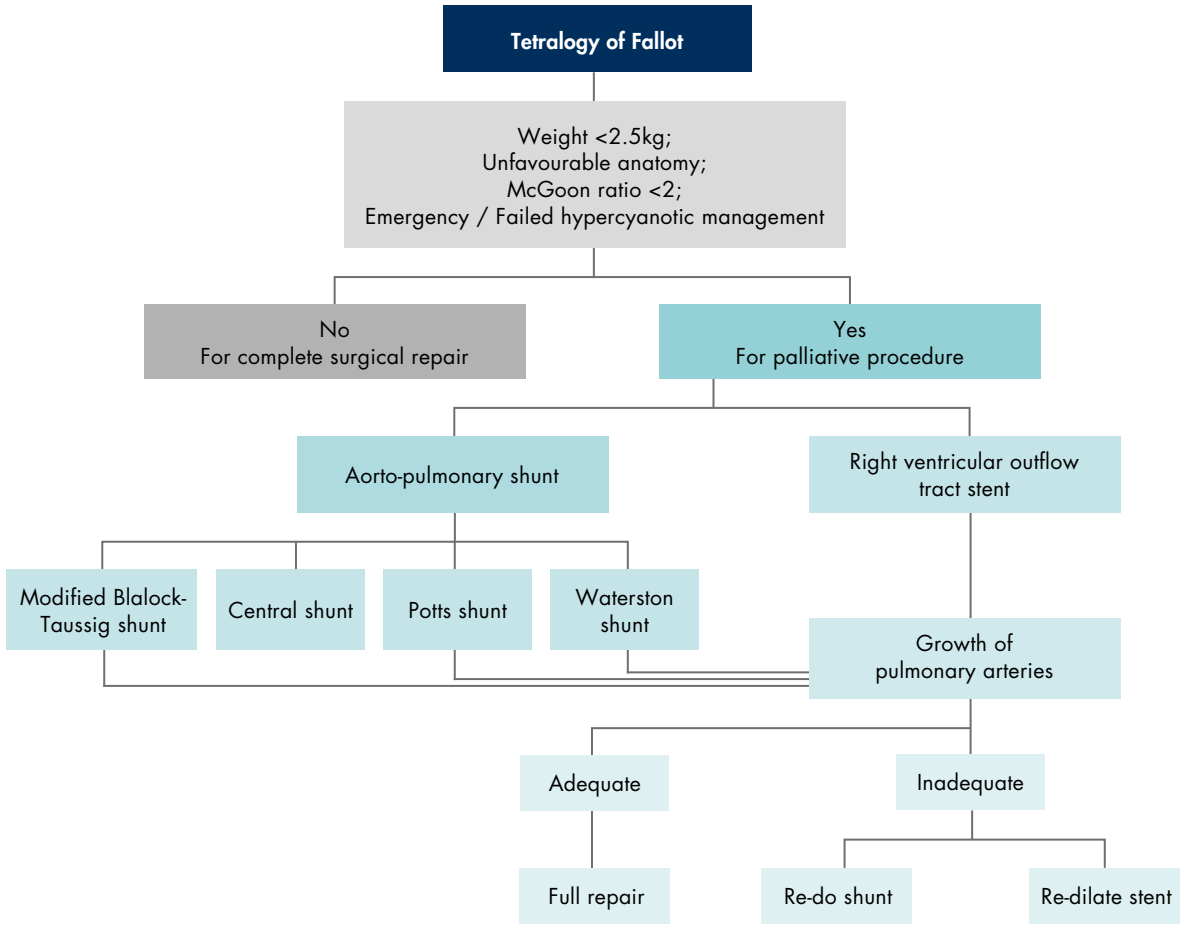

FIGURE 1: Flow diagram depicting the surgical management of tetralogy of Fallot.

to the pulmonary arteries. Amongst the various types of aorto-pulmonary shunts, none provides symmetrical blood flow to the pulmonary arteries resulting in unequal growth of the vessels.[4] Aorto-pulmonary shunting requires a well-equipped cardiothoracic surgical facility with the potential for cardio-pulmonary bypass. The Corona virus disease 2019 (COVID-19) pandemic resulted in the postponement of elective surgeries increasing the burden on a resource-limited system. In this circumstance, a palliative alternative procedure might ensure patient survival and more effectively prepare them for later definitive repair.

Percutaneous RVOT stenting offers such an alternative.[5] It avoids surgery and cardio-pulmonary bypass. Prior studies have shown promising results of the procedure in a neonatal population.[6] In South Africa, many of the TOF patients are diagnosed beyond the neonatal period.[7] Often patients present for the first time in extremis with a hypercyanotic episode. While medical management may be sufficient to treat some patients, others require emergency RVOT stenting as a lifesaving procedure.[8] Given the limited capacity of paediatric intensive care units (PICU) locally, RVOT stenting may offer a shorter post-operative PICU stay and a reduction in hospital stay.

Here we report our experience with RVOT stenting; its benefits and risks and its short- and longer-term outcomes.

METHODS

Aim and objectives

Aim

The aim of this study was to evaluate the safety and effectiveness of RVOT stenting in patients with TOF presenting beyond the neonatal period at SBAH.

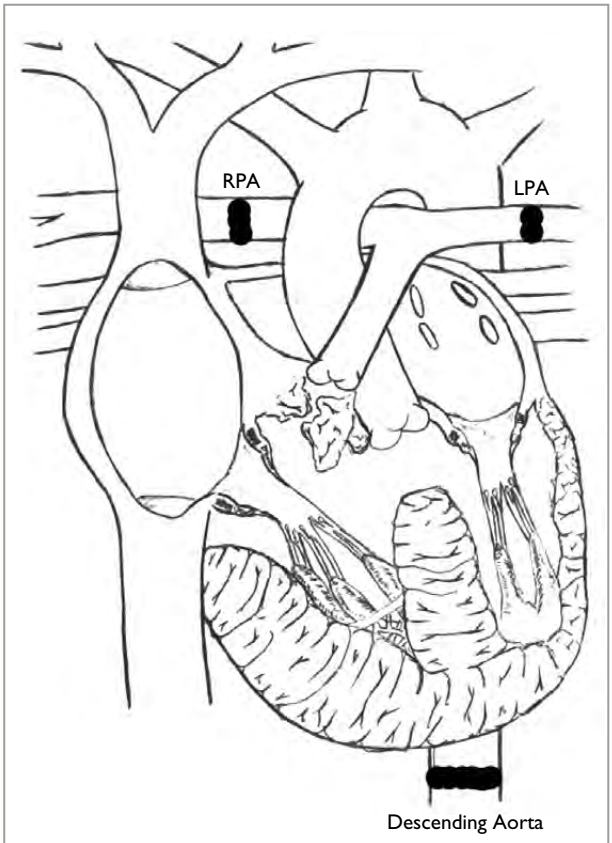

FIGURE 2: McGoon ratio: Relationship between diameters of right pulmonary artery (RPA) and left pulmonary artery (LPA) to diameter of descending aorta.

Primary objectives

- To describe positive clinical outcomes after RVOT stent placement in TOF patients.
- To identify any short- and longer-term negative clinical outcomes after RVOT stent placement in TOF patients.

Secondary objectives

- To describe the clinical and demographic profile of our TOF patients prior to RVOT stent placement.
- To describe the procedure we followed for RVOT stent placement in TOF patients.

Study design

A retrospective cohort observational study was done. All tetralogy of Fallot patients who underwent RVOT placement from 1 January 2014 - 31 March 2021 at SBAH in Pretoria, South Africa, were included. Patients with a prior palliative procedure, i.e. a central shunt, were included. Patients not fulfilling the criteria of TOF anatomy were excluded.

This study received approval from the Research Ethics Committee at the Faculty of Health Sciences at the University of Pretoria (Reference number: 566/2020).

Statistical analysis

The data analysis consisted of frequencies and proportions for short- and long-term negative clinical outcomes and categorical variables. For continuous data such as age, weight, McGoon score, oxygen saturation, the means and standard deviations were calculated to describe the data. The SAS® v.9.4 software (Statistical Analysis Systems Institute Inc., SAS Campus Drive, Cary, NC, USA) was used to perform the analysis and statistical significance was set at $p<0.05$.

Catheterisation technique

- All stent procedures were performed under fluoroscopic visualisation in the cardiac catheterisation laboratory with the patient's arms elevated for biplane views. Patients received a general anaesthetic and a topical local anaesthetic.
- A 5 French short sheath was placed in the femoral vein using the Seldinger technique. Sodium heparin was administered via the sheath at a dosage of 50IU/kg.
- A 5 French catheter was then placed in the right ventricle just below the infundibular stenosis. An angiogram was performed and the McGoon ratio was measured.
- If the pulmonary valve was too small or dysplastic then the valve was to be stented, if not, it was to be spared (Figure 3).
- The Formula stent (Cook® Medical, USA) is available in 2 systems, the 0.018 and 0.035 system.
- Patients can become unstable when crossing the RVOT. To prevent complications, a coaxial system was used, and the stent was prepared prior to deployment.
- The RVOT was crossed using a 5 French right Judkins catheter and a 0.018 Road Runner (Cook® Medical USA) wire placed in the LPA. This provides a straighter line of deployment of the stent.
- Once the wire was in position the long delivery sheath and dilator (Cook® Flexor Ansel) was then advanced over the wire and across the RVOT into the branch pulmonary artery. The sheath was then thoroughly flushed.
- The stent was then advanced to the tip of the long delivery sheath over the wire. Hand injections of contrast confirmed the desired position.

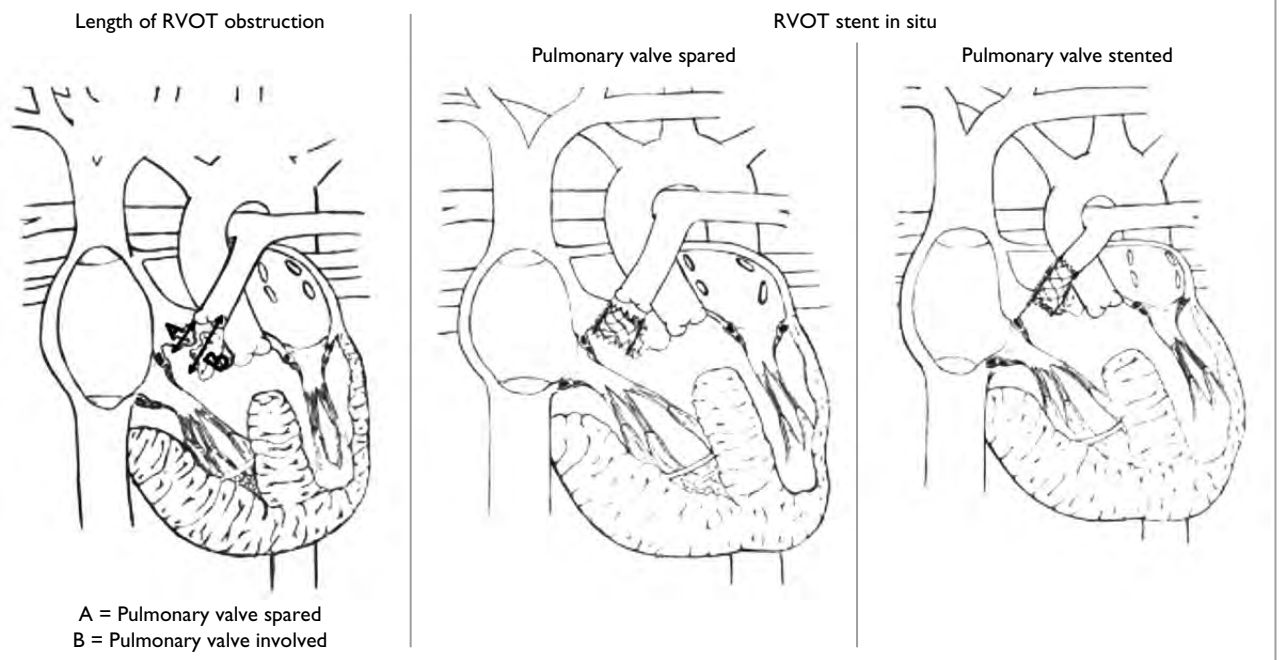

FIGURE 3: Measurement of right ventricular outflow tract obstruction with stent in situ.

- The stent covered the infundibular obstruction completely. The stent balloon was then inflated to the desired atmospheres and then deflated. A pressure injection was then performed, and the area carefully scrutinised to ensure that all of the obstruction was relieved. Any complications of the stent deployment were excluded. These included dissection, rupture and jailing of the branch pulmonary arteries. A dramatic rise in oxygen saturations was noted as the obstruction was relieved.
- If there was some residual obstruction, a second stent was deployed.
- The patient was monitored in PICU for the development of post stent pulmonary oedema which was treated with furosemide. The patient was then initiated on antiplatelet therapy using acetylsalicylic acid 5mg/kg/dose daily.

RESULTS

A total of 37 patients with the prerequisite TOF anatomy required RVOT stent placement at SBAH between 1 January 2014 and 31 March 2021. Of these patients, 4 required reintervention with either a repeat RVOT stent or balloon dilatation.

Demographics

The mean age at presentation was 27.7 months (range 1 - 89 months) with a large variation in age by the time the first stent was implanted: mean age 43.6 months (range 2.4 - 133 months) (Figure 4). Six patients had an occluded central shunt. 46% of patients were female. The average weight was 11kg (range 5 - 26kg) of whom 24% were underweight and 49% were severely underweight (WHO growth charts). The primary cardiac diagnosis was associated with a variety of congenital conditions in 40% of patients (Figure 5). The median haemoglobin level pre-stent placement was 18.2g/dL (range 10.2 - 27.5g/dL).

RVOT stent procedure characteristics

All procedures were done under ketamine-induced general anaesthetic. The Formula stents (Cook® Medical, USA) were used. The majority of the procedures required the placement of only one stent to cover the length of the infundibulum (Table I). 65% of all the procedures spared involvement of the pulmonary valve. The stent and procedural characteristics are shown in Table II.

Positive clinical outcomes post RVOT stent placement

Oxygen saturations improved remarkably (Table III & Figure 6). There was correlation between the pre-stent echocardiographic pulmonary artery (PA) size and the pre-stent angiographic size (Table IV). Echocardiograms were used to measure PA growth at an average of 35 days (1 - 71 days) after the pro-

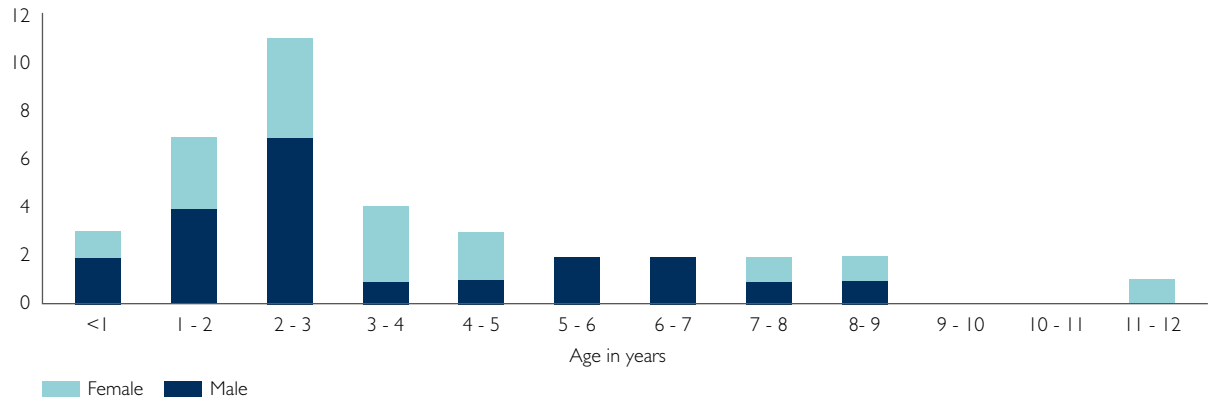

FIGURE 4: Gender and age at time of stent insertion.

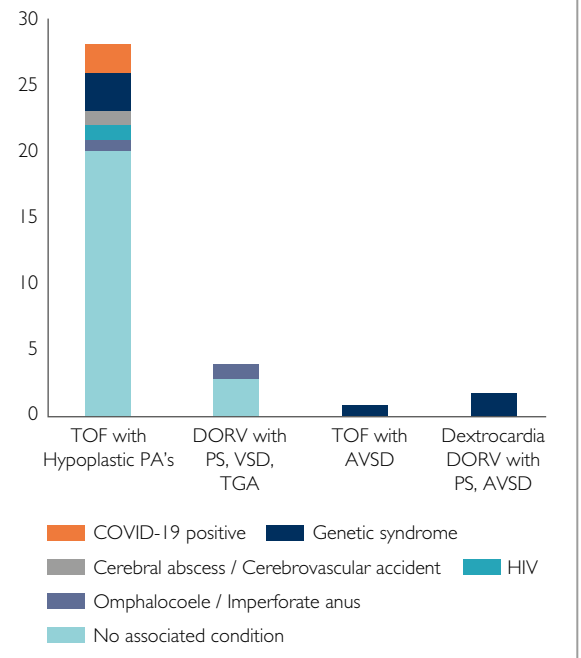

FIGURE 5: Cardiac diagnosis with associated condition.

TOF: Tetralogy of Fallot, PA's: Pulmonary arteries, DORV: Double outlet right ventricle, PS: Pulmonary stenosis, VSD: Ventricular septal defect, TGA: Transposition of the great arteries, AVSD: Atrioventricular septal defect.

TABLE I: Number of stents required per procedure.

Number of stents	Percentage of procedures (n=40)
1	88%
2	10%
3	2%

TABLE II: Stent and procedure characteristics.

	Median	Range
Stent diameter (mm)	8	6 - 10
Stent length (mm)	20	16 - 40
Balloon dilatation (atm)	10	5 - 15
Radiation exposure (min)	44	8.8 - 289
Radiation dose (mGy)	197	42 - 1 556
Contrast dose (ml)	109	30 - 480
Procedural time (min)	110	39 - 420

TABLE III: Oxygen saturations pre- and post-stent procedures.

	Oxygen saturations (mean, 95% CI)	
Procedure	**Pre-stent**	**Post-stent**
Procedure 1 (n=37)	65% (62 - 68)	95% (93 - 96)
Procedure 2 (n=4)	80% (79 - 81)	92% (85 - 99)
Procedure 3 (n=1)	71%	93%
Procedure 4 (n=1)	70%	90%

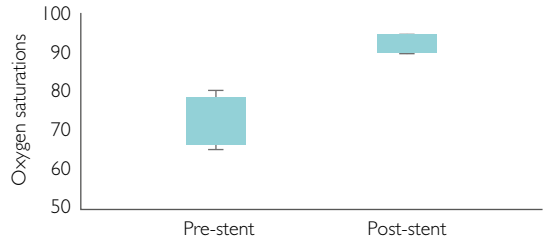

FIGURE 6: Boxplot illustrating oxygen saturations pre- and post-stent procedures.

TABLE IV: Pulmonary artery growth post procedure one.

	Pre-stent		Post-stent	
	Angiographic measurement	Echocardiographic measurement	First echocardiographic measurement	Second echocardiographic measurement
LPA diameter mm (median, range)	5 (3 - 9.6)	7 (5 - 10)	9 (7 - 13)	11 (7 - 15)
LPA diameter z-score (median, range)	-0.06 (-1.76 - 3.83)	-0.22 (-1.72 - 2.03)	0.07 (-1.33 - 2.87)	0.08 (-2.23 - 2.38)
RPA diameter mm (median, range)	6 (3 - 8)	5 (3 - 7)	7 (5 - 8)	8 (6 - 10)
RPA diameter z-score (median, range)	0.31 (-2.06 - 1.89)	-0.06 (-2.27 - 2.13)	0.37 (-1.64 - 1.37)	-0.23 (-2.34 - 1.88)
McGoon ratio (median, range)	1.35 (0.55 - 1.86)	1.36 (0.55 - 1.86)	1.71 (1 - 2.29)	2.05 (1.4 - 2.67)

TABLE V: Pulmonary artery growth post final procedure.

	Echo - Pre-stent			Echo - Post final procedure			Percentage increase %		
Patient	LPA (mm)	RPA (mm)	McGoon ratio	LPA (mm)	RPA (mm)	McGoon ratio	LPA	RPA	McGoon ratio
5	3	3	0.55	9	8	1.55	67	63	65
13	6	7	1.86	10	10	2.00	40	30	7
16	6	6	1.50	9	10	1.90	33	40	21
19	4	5	1.29	5	6	1.57	20	17	18

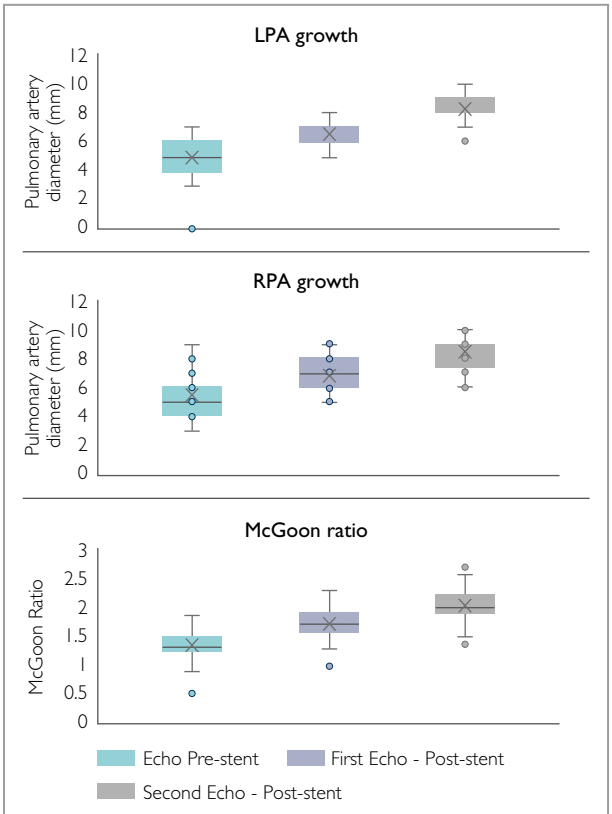

FIGURE 7: Boxplot diagrams illustrating the echocardiographic measurement of the LPA and RPA in millimetres and McGoon ratio pre-stent, 1 month post-stent, and approximately 7 months post-stent placement.

cedure and again after approximately 7 months (5 - 9 months) (Table V & Figure 7). Twenty six of 37 patients (70%) achieved a McGoon ratio of 2 or greater at the 7-month post-stent echo (Figure 8).

Short-term negative clinical outcomes post RVOT stent placement

The 30-day mortality rate was zero after stent placement. Two patients had severe hypercyanotic episodes and demised on the operating table prior to induction of anaesthesia or stent placement. The stent embolised into the aortic arch in 1 patient and a small pericardial effusion arising from guidewire perforation developed in another. There was no report of tricuspid valve damage, RVOT obstruction, stent dislodgement or branch pulmonary artery jailing. Patients spent an average of 2 days in PICU (range 0 - 10 days). The median length of hospital stay was 6.5 days (range 2 - 80 days).

Long-term negative clinical outcomes post RVOT stent placement

Stent fracture occurred in 3 patients (Figure 9) resulting in replacement in all. There has been no report of infective endocarditis nor arrythmia 6 months after the enrolment period.

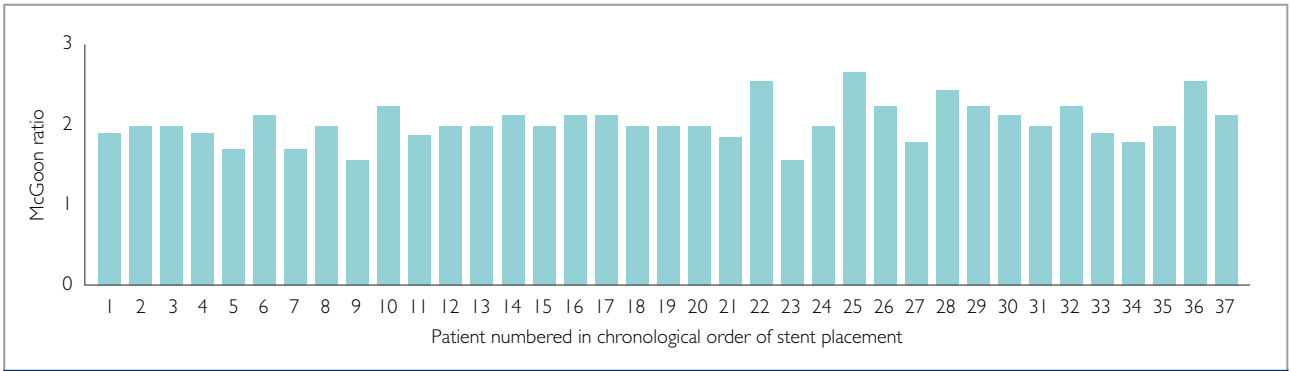

FIGURE 8: McGoon ratio post final procedure.

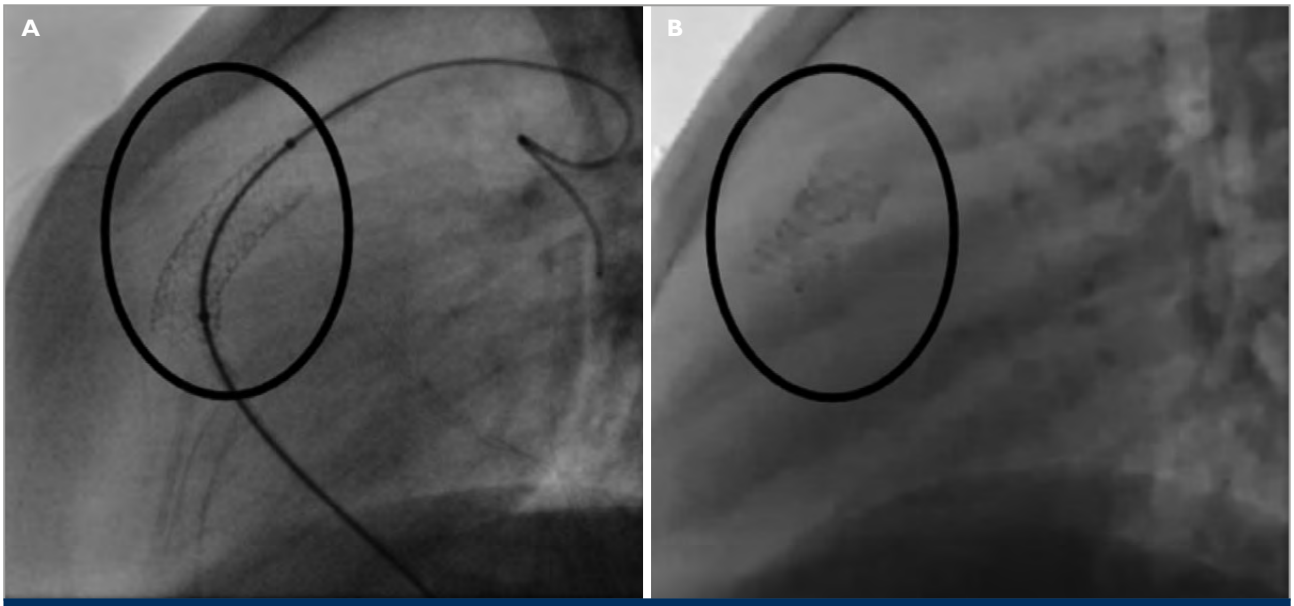

FIGURE 9: Lateral chest radiographs with right ventricular outflow tract stents in situ.
A - RVOT stent intact. B - RVOT stent fracture

DISCUSSION

We found that stenting of the RVOT is an effective and safe initial palliative procedure in patients with TOF. The pulsatile forward flow of systemic venous blood into the pulmonary arteries allows symmetrical growth and potentially permits patients to progress to complete surgical repair.

This finding is in keeping with reports in neonatal populations.[6,9-11] Despite advances in medicine, the diagnosis of many congenital conditions is delayed beyond the neonatal period in developing countries such as South Africa. In our study, the average age of diagnosis of TOF was 2 years and 4 months. Factors contributing to the delay range from poor primary healthcare, social factors and the inconsistent use of Western medicine. Furthermore there was an average delay of 15 months between the time of diagnosis and the first placement of a stent. Inadequate resources played a significant role in this delay magnified by the postponement of elective procedures after onset of the COVID-19 pandemic. Delay in referral to a tertiary centre after diagnosis, missed follow-up visits and 6 patients with occluded central shunts contributed to the longer time interval between initial diagnosis and stent placement.

Delayed diagnosis and treatment in a patient with cyanotic CHD increases the risk of complications. Two patients had a cerebrovascular accident, 1 had a cerebral abscess, 27 were malnourished, and 8 presented with refractory hypercyanotic spells requiring emergent stent placement. Two of these 8

patients tested positive for COVID-19. Neither responded to medical management of the hypercyanotic episode, and one had a brief cardiac arrest requiring cardio-pulmonary resuscitation.

During the study, there was a significant increment in operator experience and evolution in the materials employed.[12] The placement of the first stent involved the longest procedural time (420min), used the greatest amount of contrast (480ml) and required a repeat procedure following stent fracture that resulted in the largest radiation dose (1556.17mGy). Four patients required further intervention for stent replacement or balloon dilatation. These 4 patients were the first 4 participants in the study, 3 of whom had stent fractures. Though the same type of stent was used throughout the study, there were progressive improvements in design.[12] The Formula stent (Cook® Medical, USA) allows significant over-dilatation with virtually no shortening. Despite 5 patients requiring more than 1 stent to cover the infundibular stenosis, this did not contribute to stent dislodgement or jailing of the branch arteries. The use of the long sheaths or guide catheters prevented stent dislodgement or tricuspid valve damage.[5] Only 1 patient developed a small pericardial effusion due to guidewire perforation and was discharged in 5 days after conservative management. Despite the steep learning curve, no mortalities were recorded within 30 days of stenting.

A general anaesthetic was used for each of these procedures. Our study specifically made use of ketamine-induced anaesthesia, given that systemic vasoconstriction is beneficial in patients with a right-to-left shunt. The majority of patients were extubated in theatre. Seventy one percent of patients required post-operative PICU care of whom 45% were admitted for more than 3 days. Reasons for prolonged PICU admission included pulmonary oedema, convulsions secondary to electrolyte derangements, nosocomial sepsis and a patient who deteriorated and required emergency surgical repair. The total length of hospital stay exceeded that of international experience averaging 12.8 days.[13] This was influenced by the 4 patients that were admitted for more than 48 days. One developed a cerebral abscess that required drainage, while another developed a chylothorax and multiple episodes of nosocomial sepsis. Two patients developed multiple cerebral infarcts which required stabilisation prior to stenting.

A known consequence of cyanotic CHD is polycythaemia. Our patients had an average haemoglobin level of 18.4g/dL, increasing the threshold for visible cyanosis to an oxygen saturation of approximately 85%.[14] Our study participants were deeply cyanosed with an average saturation level of 65% prior to stent insertion which improved to 95% after stent insertion. We do not report on the potential improvement in polycythaemia due to the retrospective nature of the study.

In order to quantify growth, multiple assessments of the branch PA sizes were required. As in other studies, this could only be done by serial echo's as serial catheter pulmonary angiograms were not feasible nor acceptable due to the significant radiation exposure.[15] Despite the first echo being only about a month after stent placement, growth could be appreciated with the McGoon ratio increasing from 1.36 to 1.71. At this stage, 18% of the patients had a McGoon ratio greater than 2 therefore potentially qualifying them for a complete surgical repair. After the final echo, approximately 7 months post stent placement, the average McGoon ratio was 2.05 thereby potentially already qualifying 70% of the patients to a full surgical repair. As of December 2023, 9 of the patients have undergone a full surgical repair.

The pulmonary valve was spared in two thirds of patients. Not covering the pulmonary valve with a stent potentially avoids the need for a transannular patch at the time of corrective surgery.[5]

Stenting of the RVOT as the initial palliative procedure in TOF patients that present beyond the neonatal period enables effective growth of the pulmonary arteries with marked improvement in oxygen saturations and minimal post-operative complications. Further prospective studies analysing the longer-term effects of stent placement in TOF, a comparison with other palliative procedures, and outcomes in patients subsequently undergoing complete surgical repair are needed.

STUDY LIMITATIONS

This was a single centre, retrospective, non-randomised study in patients with TOF. Our 37 patients excluded the 2 who demised on the operating table prior to placement of the stent. PA growth was measured by various paediatric cardiologists allowing inter-observer variability, likely pertaining to the minimal change of the Z score measurement. The timing of the various measurements varied due to erratic patient follow-up. Observation for long-term complications was limited to 6 months post-stent placement.

CONCLUSION

Our experience of stenting the RVOT in TOF patients who present at an older age, with multiple comorbidities and often a poor prognosis, has yielded good results. In the absence of freely available access to cardiothoracic surgery and surgical ICU beds when these patients present in extremis with hypercyanotic spells, RVOT stenting can be a lifesaving procedure. The procedure has the potential to save children's lives in resource-limited hospitals throughout developing countries. Significant improvement in oxygen saturations and PA growth permitted majority of our patients to undergo a full TOF surgical repair.

ACKNOWLEDGEMENTS

Dr Pickup thanks Dr Joshi for his leadership and advice, Mr Masenge for data analysis and Mr Mahlangu for artwork.

Conflict of interest: none declared.

REFERENCES

1. Sliwa K, Lecour S, Zühlke L, et al. Cardiology-cardiothoracic subspeciality training in South Africa: A position paper of the South Africa Heart Association. Cardiovasc J Afr. 2016;27(3):188-193. DOI:10.5830/CVJA-2016-063.
2. Barron DJF, Jegatheeswaran AMDP. How and when should tetralogy of Fallot be palliated prior to complete repair? Seminars in thoracic and cardiovascular surgery: Pediatr Card Surg Annu. 2021;24:77-84. DOI:10.1053/j.pcsu.2021.02.002.
3. Dawoud MA, Abd Al Jawad MN, Hikal T, et al. Single-stage complete repair versus multistage repair of tetralogy of Fallot with borderline pulmonary arteries. JSM Heart Surg. 2018;21(6):466-471. DOI:10.1532/hsf.2075.
4. Luxford JC, Adams PE, Roberts PA, et al. Right ventricular outflow tract stenting is a safe and effective bridge to definitive repair in symptomatic infants with tetralogy of Fallot. Heart Lung Circ. 2023;32(5):638-644. DOI:10.1016/j.hlc.2023.02.010.
5. Quandt D, Penford G, Ramchandani B, et al. Stenting of the right ventricular outflow tract as primary palliation for Fallot-type lesions. J Congenit Cardiol. 2017;10(17):1774-1784. DOI:10.1016/j.jcin.2017.06.023.
6. Castleberry CD, Gudausky TM, Berger S, et al. Stenting of the right ventricular outflow tract in the high-risk infant with cyanotic teratology of Fallot. Pediatr Cardiol. 2014;35(3):423-430. DOI:10.1007/s00246-013-0796-z.
7. Ngwezi DP, Vanderdonck K, Levin SE, et al. An audit of surgical repair of tetralogy of Fallot in an African tertiary care centre. SA Heart®. 2013;10(3):520-525. DOI:https://doi.org/10.24170/10-3-1792.
8. Sasikumar N, Mohanty S, Balaji S, et al. Rescue right ventricular outflow tract stenting for refractory hypoxic spells. Catheter Cardiovasc Interv. 2023;101(2). DOI:https://doi.org/10.1002/ccd.30522.
9. Barron DJ. Tetralogy of Fallot: Controversies in early management. World J Pediatr and Congenit Heart Surg. 2013;4(2):186-191. DOI: 10.1177/2150135112471352.
10. Dryżek P, Moszura T, Góreczny S, et al. Stenting of the right ventricular outflow tract in a symptomatic newborn with tetralogy of Fallot. Postępy Kardiol Interwencyjnej. 2015;11(1):44-47. DOI: 10.5114/pwki.2015.49184.
11. Korbmacher B, Heusch A, Sunderdiek U, et al. Evidence for palliative enlargement of the right ventricular outflow tract in severe tetralogy of Fallot. Eur J Cardiothorac Surg. 2005;27(6):945-948. DOI: 10.1016/j.ejcts.2005.02.010.
12. Beshchasna N, Saqib M, Kraskiewicz H, et al. Recent advances in manufacturing innovative stents. Pharmaceutics. 2020;12(4):349. DOI: 10.3390/pharmaceutics12040349.
13. Quandt D, Ramchandani B, Penford G, et al. Right ventricular outflow tract stent vs. bt shunt palliation in tetralogy of Fallot. Heart. 2017;103(24):1985-1991. DOI: 10.1136/heartjnl-2016-310620.
14. Park MK, Salamat M. Park's paediatric cardiology for practitioners e-book: Elsevier Health Sciences. 2020;7:378-390.
15. Quandt D, Ramchandani B, Stickley J, et al. Stenting of the right ventricular outflow tract promotes better pulmonary arterial growth compared with modified Blalock-Taussig shunt palliation in tetralogy of Fallot–type lesions. JACC Cardiovasc Interv. 2017;11(10):1774-1784. DOI: 10.1016/j.jcin.2017.06.023.