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Abstract

Objective. Despite the challenges of surgical management of congenital heart disease excellent outcomes are being achieved. Newly appointed congenital heart surgeons may have limited first operator experience for many complex conditions but are expected to achieve similar outcomes. A strategy of routine mentorship from more experienced surgeons may be the key to enabling new surgeons to become proficient while maintaining excellent outcomes for patients.

Methods. The arterial switch operation is a technically demanding but relatively commonly performed, reproducible, and easily visualised neonatal procedure, making it valuable for mentoring newly appointed congenital heart surgeons. We examined early and late mortality, and markers of both morbidity and technical proficiency following 449 arterial switch operations at a single institution over 26 years during which time three new surgeons were appointed and each mentored by a more experienced surgeon, to observe the effect of mentorship.

Results. Overall survival was 96.5% at 15 years, with an early mortality of 1.2% (5/449). There was no significant difference in mortality between surgeons, or with time. Freedom from re-intervention following the arterial switch operation was not significantly different between the four surgeons. All new surgeons underwent similar periods and levels of mentorship with zero mortality.

Conclusion. Newly appointed surgeons can become proficient in performing the arterial switch procedure without compromising patient outcomes, through a process of mentorship utilising standardised techniques and close teamwork.

Key words: Mentorship, Arterial switch operation, Learning curve

Introduction

Surgical management of congenital heart disease is intellectually and technically demanding, resource intensive and emotionally charged. A wide variety of complex surgical procedures are undertaken for a broad range of cardiac malformations in a heterogeneous population. Despite this, outcomes following treatment of congenital heart disease have improved considerably over the preceding decades such that surgery for the majority of congenital heart disease is now undertaken with a very low mortality [1]. Newly appointed congenital heart surgeons are expected to achieve the same excellent outcomes as more experienced surgeons. However the environment for training remains challenging for all of the aforementioned reasons, and newly appointed surgeons may have limited first operator experience for complex procedures.

Since being introduced successfully by Jatene in 1975 [2], the arterial switch operation (ASO) has significantly improved the outcomes of children born with transposition of the great arteries (TGA). Advances in both prenatal detection and perioperative management [3], together with technical refinements such as the Lecompte manoeuvre [4] and coronary artery transfer techniques [5] have led to low mortality following the arterial switch operation in the current era [6].

We believe that the arterial switch operation is a valuable procedure for mentorship of newly appointed surgeons for the following four reasons: Firstly, the prevalence of TGA is approximately 5% of all congenital heart defects [7], making the arterial switch operation relatively commonplace. Secondly, although technically demanding, the procedure is readily reproducible and includes important transferable techniques in congenital heart surgery that may be applicable to repair of less commonly encountered defects and thirdly, all steps of the procedure are easily visualised by both the primary and the assisting surgeon, so that the procedure should be able to be performed safely by a newly appointed surgeon assisted by an experienced mentor.

Accordingly, we examined key outcomes following the arterial switch operation at a single centre over 26 years during which time three new surgeons joined the team, each mentored by a more experienced surgeon, to test the hypothesis that complex surgical procedures can be learned and performed safely and effectively by newly appointed surgeons with appropriate mentorship and support.

Material and methods

Patients

701 patients underwent the arterial switch operation at Birmingham Children's Hospital from January 1988 to September 2014. In order to focus on mentorship, we excluded patients:

1. With complex anatomy (concomitant aortic arch pathology, Taussig-Bing anomaly etc.) as they were not regarded as suitable mentorship cases for newly appointed surgeons.
2. Who underwent ASO aged over 1 year as they represent a different pathophysiological subset compared to neonatal or young infant patients with TGA.
3. Who were operated on by a surgeon who left the programme before this mentorship study began (ie was replaced by Surgeon B), and took no part in the mentorship process

449 patients were included in this study, of which 333 patients were classified and treated as transposition of the great arteries with intact ventricular septum (TGA-IVS), and 116 patients classified and treated as transposition of the great arteries with ventricular septal defect (TGA-VSD).

Personnel and mentorship

Surgeon A was appointed in 1988 and led the mentorship programme. Surgeons B, C and D were appointed in 1999, 2005, and 2011 respectively, none having held a previous consultant appointment and each had performed no more than one ASO as a senior trainee. All performed the arterial switch operation using the same technique (detailed below), which remained consistent throughout the study period.

Surgical mentorship comprised of a more senior surgeon initially being double-scrubbed with the newly appointed surgeon for the entirety of the case. As the new surgeon gained confidence the senior surgeon would scrub for only part of the case or be unscrubbed but present in theatre. Finally, the new surgeon would perform the procedures independently, but with the knowledge that the senior surgeon was available and in the building.

Surgical technique

Following median sternotomy an autologous pericardial patch was harvested and kept moist in a cold saline swab. The great vessels were mobilised as necessary. A single right atrial cannula was used in infants weighing less than 3kg, and those with no ventricular septal defect. Bicaval cannulation was used for all cases in which closure of a ventricular septal defect was planned. When a single atrial cannula was used, the nasopharyngeal temperature was lowered to 22°C and a brief period of circulatory arrest was used for closure of the atrial communication. When bicaval cannulation was used, the nasopharyngeal temperature was normally lowered to between 22 and 25°C. Alphastat pH strategy was used during cardiopulmonary bypass (CPB). The ductus arteriosus was double ligated, divided and both ends oversewn. Further mobilisation of the pulmonary arteries to the hilar vessels was performed. The ascending aorta was clamped and cold crystalloid cardioplegia was administered via the isolated aortic root. Ventricular septal defects were routinely approached transatrially, and were closed with a bovine pericardium or double velour Dacron patch held in place with interrupted polypropylene sutures reinforced with pledgets.

The ascending aorta was then transected 3-5 mm above the aortic valve commissures and the coronary arteries were excised on generous cuffs of aortic sinus tissue and mobilized. The resultant aortic defects were repaired with untreated autologous pericardium as a single patch. The main pulmonary artery was transected at the same level as the aorta and the coronary artery buttons were relocated to medially hinged trap-door incisions to construct the proximal neo-aorta [5]. The Lecompte manoeuvre was performed in all patients [4]. In those patients with side-by-side great vessels, the pulmonary artery bifurcation was relocated as necessary by incising the branch pulmonary artery to accommodate the main pulmonary artery, oversewing the native opening. The neo-aorta was reconstructed, the heart re-perfused and reconstruction of the neo-pulmonary artery was completed while re-warming and with the heart beating.

Cardiopulmonary bypass was discontinued with inotropic support and a left atrial pressure line in situ. Sternal closure was undertaken in presence of stable haemodynamics and if the heart was not enlarged. If the sternum was left open, temporary closure was achieved by means of skin closure or a GoreTex patch sewn to the wound edges. Delayed sternal closure was then undertaken electively on the intensive care unit, usually within 48 hours of surgery, as dictated by the clinical condition of the patient.

Data collection and statistical analysis

Data from all patients undergoing the arterial switch operation at Birmingham Children's Hospital were collected retrospectively, reviewed and validated by the authors (SM, ND, JS, TJ) from patient records and the institutional cardiac electronic database. Morphological data were collected from detailed descriptions in operative records. Coronary pattern was described according to the Yacoub classification [8], as this was used consistently since the arterial switch programme began. Date of last follow-up was the date of last documented clinic review by the patient's cardiologist.

Cardiopulmonary bypass times, ischaemic times and reinterventions were used as surrogates for technical proficiency, and intensive care and hospital length of stay data were used as markers of morbidity.

Statistical analysis was performed using *R* (https://www.r-project.org/). All continuous data were expressed as median with interquartile ranges and categorical data expressed as counts and percentages where relevant. Estimated survival and freedom from reoperation were determined by the Kaplan–Meier method. The subgroups were compared using the log-rank test. Fisher's exact test was used to compare categorical variables and the Kruskal-Wallis rank sum test was used for continuous variables. Significance testing was 2-sided with the significance level set at $p < 0.05$.

Results

Patient characteristics and baseline data

Patient characteristics and perioperative data are detailed in Table 1. Patients with TGA-IVS most commonly underwent ASO aged 7 (IQR 5-12) days, at a median weight of 3.4 (3.0-3.8)kg. They were mostly male (72%), and the majority (86%) underwent balloon atrial septostomy prior to ASO. Approximately one quarter (26%) were ventilated pre-operatively. At operation, 72% were found to have the usual coronary pattern (Yacoub A) and the remainder had other variants (Figure 1a). Median cardiopulmonary bypass (CPB) time was 99 (88-118) minutes, median ischaemic time was 62 (56-74) minutes and median circulatory arrest time was 7 (6-9) minutes. Over a quarter of patients (28%) left the operating room with the sternum open. Length of stay averaged 4 (3-6) days in intensive care and 8 (7-11) days in hospital. There were three deaths within 30 days of ASO (early mortality 0.9%).

Patients with TGA-VSD underwent ASO and VSD closure at a median age of 10.5 (6-24) days and weight of 3.4 (2.9-3.8) kg. They were also mostly male (74%), with 61% undergoing pre-operative septostomy but only 13% requiring pre-operative ventilation. 69% were found to have the usual coronary pattern and others had variants (Figure 1, panel B). There was no difference in the incidence of coronary patterns between the four sugeons, data was analysed according to Type A vs non-type A coronaries (p=0.09) and in terms of intramural vs non-intramural coronaries (p=0.97).

Median CPB time was 123 (100-146) minutes, median ischaemic time was 82 (71-95) minutes and median circulatory arrest time was 4 (0-23) minutes. Over a third of patients (38%) left the operating room with the sternum open. Length of stay averaged 5 (7-11) days in intensive care and 9 (7-14) days in hospital. There were two deaths within 30 days of surgery (early mortality 1.7%).

Surgeon specific data

When first appointed to a consultant position, Surgeon B undertook 8 arterial switch operations with a more experienced surgeon assisting before undertaking an independent case. Similarly, Surgeons C and D were assisted by more experienced surgeons for 11 cases and 3 cases respectively before undertaking an independent ASO. This reflected a period of between 6 -12 months according to the surgeon. As described above, the senior surgeon would continue to supervise without being scrubbed in theatre for the next cohort of cases until both the new surgeon and senior surgeon felt confident to proceed independently. Surgeons did not act as a mentor until they had been in post for at least 4 years.

Surgeon A undertook the greatest number of ASO (265) of which 29% were TGA-VSD, Surgeon B undertook 127 cases of which 22% were TGA-VSD, Surgeon C undertook 41 cases of which 20% were TGA-VSD, and Surgeon D undertook 16 cases of which 13% were TGA-VSD. Weight at operation and coronary pattern were not significantly different between surgeons ($p=0.17$ and $p=0.55$ respectively). Over half of all patients for each surgeon had undergone pre-operative balloon atrial septostomy, and a third or less of patients for each surgeon were ventilated pre-operatively (Table 2).

Median cardiopulmonary bypass times for the arterial switch operation for TGA-IVS were significantly different between surgeons (Table 2, $p<0.01$). Surgeons A and B had the shortest median bypass times (94 and 101 minutes respectively), and Surgeon C the longest (138 minutes). Of interest, cardiopulmonary bypass times for consecutive ASO remained remarkably consistent over time for each surgeon (Figure 2).

Surgeons A and B were less likely to leave the chest open after surgery than surgeons C and D. Patients operated on by surgeon A had statistically shorter lengths of stay in the intensive care unit and in hospital than patients operated on by surgeons B, C and D (Table 2, $p<0.01$).

There were a total of five early deaths (within 30 days of ASO), three with TGA-IVS and two with TGA-VSD. Surgeons C and D had no early deaths. Surgeon B had a single death (case number 102), occurring after uneventful ASO with VSD closure from severe sepsis secondary to congenital ichthyosis. Surgeon A operated on the remainder of the patients who died early after ASO (3 TGA-IVS, 1 TGA-VSD). Of the patients with TGA-IVS, one patient was referred from another centre for salvage surgery after the discovery of intramural coronary arteries at operation, a second patient presented at 3 months of age and was found to have an involuted left ventricle and intramural coronary arteries, and a third patient had unexplained poor left ventricular function after uneventful surgery in the setting of non-complex anatomy. The patient with TGA-VSD failed to wean from cardiopulmonary bypass following an emergency arterial switch operation undertaken after balloon atrial septostomy was complicated by injury to the tricuspid sub-valvar apparatus. None of these cases were undertaken by a new surgeon in their intial mentorship period.

Long-term survival

Survival for the entire cohort was 96.5% at 15 years, 97.1% for patients with TGA-IVS and 94.8% for patients with TGA-VSD. Survival was not significantly different for patients operated on by any of the four surgeons as evidenced by the Kaplan-Meier curves for individual surgeons (Figure 3, p=0.77).

To examine the impact of appointing new surgeons to the team, the entire patient cohort (TGA-IVS and TGA-VSD) was arranged by date of ASO and then divided into quintiles (q1 to q5) where q1 represents the earliest 90 patients and q5 the most recent 90 patients in the cohort. Surgeon B was appointed during the time period encompassed by q2, Surgeon C during q4 and Surgeon D during q5. Survival was not significantly different between quintiles (Figure 4) suggesting that not only did survival remain consistent over time but it was also unaffected by the appointment of three new surgeons.

Re-intervention

There were 22 occasions (<5% of all patients) during which second or prolonged runs of cardiopulmonary bypass were required during initial surgery (prolonged bypass time was defined as over 150 minutes for TGA-IVS patients and over 175 minutes for TGA-VSD patients). Of the 15 occasions in patients with TGA-IVS, 9 were for re-fashioning coronary buttons, 2 for dehiscence of the reconstructed right ventricular outflow tract (discovered following significant bleeding after cessation of bypass), 2 for unexplained low cardiac output syndrome, and 2 for repeat neo-pulmonary artery reconstruction. Of the 7 occasions in patients with TGA-VSD, 1 was for re-fashioning a coronary button, 2 for significant residual VSDs, 1 to close an additional VSD, 2 for repeat neo-pulmonary artery reconstruction, and one for which no description was available. Surgeon A undertook 6 intra-operative revisions, Surgeon B undertook 11, and Surgeon C undertook 5. Surgeon D had no intra-operative revisions.

Of these 16 revisions performed by the mentored surgeons, a senior surgeon was routinely called in all cases, attended theatre, and scrubbed in alongside the operating surgeon on 12/16 occasions. 63% of the cases (10/16) requiring intra-operative revision were during the first half of the mentored surgeons personal experience. There were no deaths and no post-operative coronary events in these patients.

There were 28 re-interventions within one year of ASO. Three were undertaken to re-fashion coronary buttons in the immediate post-operative period for low cardiac output syndrome, all of which required temporary mechanical circulatory support. Sixteen re-interventions were undertaken on the right ventricular outflow tract and/or branch pulmonary arteries, 7 of which were surgical reconstructions, and 9 of which were catheter-based interventions. The remaining 9 re-interventions were classified as miscellaneous and included pacemaker implantation and repair of unrelated structural heart defects. Twelve re-interventions were required in patients initially operated upon by Surgeon A (5% of total cases), 9 by Surgeon B (7%), 4 by Surgeon C (10%), and 2 by Surgeon D (13%). Overall freedom from re-intervention was not significantly different between the surgeons (Figure 5, p=0.41).

Discussion

Congenital cardiac surgery is a technically demanding sub-specialty, encompassing a broad range of structural cardiac defects that are amenable to surgical treatment. There are often variations within each condition that may necessitate a change in strategy, approach and technique to achieve the best outcome. Some conditions are seen rarely and it may be difficult to accrue the appropriate individual experience to manage them effectively. In addition, there is understandable anxiety from parents and families, and transparent reporting of outcomes leading to both professional and public scrutiny. Coupled with truncated training programmes and an enforced reduction in working hours [9], it has become increasingly difficult to train surgeons interested in pursuing a career in congenital heart disease. Therefore, newly appointed surgeons may have minimal experience as primary operators for many congenital heart abnormalities, although they may have considerable first operator experience in related surgical disciplines. Developing proficient congenital heart surgeons, while maintaining excellent outcomes for patients, is a challenging issue.

The key finding from this study is that newly appointed surgeons can become proficient in performing complex congenital cardiac surgical procedures without compromising patient outcomes, using the arterial switch operation as a platform for mentorship.

The learning curve

The learning curve is a graphical representation of an increase in performance or proficiency with increasing experience. It is a concept well established in healthcare settings, particularly so in procedure-based specialties such as surgery. There are some excellent examples demonstrating the learning curve as it relates to congenital heart surgery [10,11]. Inexperience places many newly appointed surgeons at the beginning of their learning curve for complex procedures. However, more experienced surgeons have successfully negotiated the early part of the curve and now achieve excellent outcomes.

The steady improvement and increasingly transparent reporting of outcomes following surgery for congenital heart disease translates to higher expectations and less acceptance of the learning curves of newly appointed surgeons. How do new surgeons accrue the necessary experience to become proficient, but continue to match the excellent outcomes of their more experienced colleagues? We believe that the answer is mentorship.

Mentorship

With its origins in Greek mythology, mentorship is difficult to define precisely but has been described as a process for the informal transmission of knowledge, entailing informal communication, usually face-to-face and during a sustained period of time, between a person who is perceived to have greater relevant knowledge, wisdom, or experience (the mentor) and a person who is perceived to have less (the mentee) [11,12]. In surgery the term is used to describe the transfer of skills and knowledge between senior and junior consultant/attending surgeons, and is distinct from but an extension of training. In congenital cardiac surgery, mentorship encompasses all aspects of patient care that contribute to achieving the optimum outcome for the patient and family such as joint pre-operative decision making, selection of cases appropriate to the mentee's level of experience, planning surgical strategy, assisting the mentee in the operating room and a joint approach to post-operative care.

The professional relationship between mentor and mentee is vitally important, with a mutual understanding and trust that does not encroach on the mentee's autonomy and leadership. It relies heavily on the goodwill of the mentor in sharing their time and expertise with their junior colleague. The point at which an established consultant feels able to take on the role of mentor is a complex decision based on experience, confidence and the inter-relationships between colleagues. In this example the decision to act as a mentor was a team decision made within the whole department, which was helped by the fact that there was a period of at least 4 years between each new appointment, allowing even the most recent surgeon to gain experience and further insight before considering the role as mentor.

The arterial switch operation – a platform for mentorship in congenital cardiac surgery

Since first being performed successfully in 1975, the arterial switch operation is established as the standard of care for children born with transposition of the great arteries. The procedure has undergone technical refinements such as the Lecompte manoeuvre and the use of medially hinged trapdoor incisions to receive relocated coronary buttons, and in combination with advances in antenatal diagnosis and perioperative management, outcomes have improved such that mortality following an isolated arterial switch operation has become a rare event.

Apart from incorporation of the aforementioned refinements, the technique, although demanding, has remained remarkably consistent. The procedure is therefore relatively reproducible and because the majority of the procedure is spent working around the roots of the great arteries, both the primary surgeon and the assistant are able to see the anatomy and each step of the procedure without difficulty. In addition, morphological variations that may significantly increase the complexity of repair form a consistent and relatively small subset of all patients with TGA. Not all surgeons use a single cannula for simple TGA, but this arrangement does provide excellent exposure to the aortic root and coronaries and it also avoids the need for an atriotomy as the septum is repaired working through the atrial cannulation site. In terms of this study we felt that the use of a consistent and reproducible technique was important, and to tried avoid using multiple different bypass strategies. Finally, TGA is common within the sphere of congenital heart disease and therefore the procedure is performed relatively frequently in most centres, enabling all members of the surgical team to develop familiarity with, and acquire personal experience of the procedure. Techniques such as pulmonary artery mobilisation and coronary button harvest and relocation are important skills to master, as they are applicable to the repair of other, perhaps less frequent and more complex, congenital heart defects.

These features make the arterial switch operation particularly suitable for mentoring newly appointed surgeons. However, this assertion must be put in context: the vast majority of newly appointed congenital cardiac surgeons are highly motivated, highly trained, technically able individuals who are already able to perform complex surgical procedures independently. They have often been waiting for the opportunity to perform procedures such as the ASO and we may therefore expect that the learning curve for this type of procedure to be steep. This study suggests that with appropriate mentorship, the learning curve may be avoided altogether.

Outcomes

The study has shown that the mentorship process was associated with all surgeons achieving similar early and long term survival, with no adverse effect on survival over time despite the appointment of new surgeons. This could be explained in part by differences in patient cohorts operated on by individual surgeons i.e. that less experienced surgeons operated on patients with a lower risk profile. However, in our cohort all surgeons operated on patients with a similar weight, age and coronary artery pattern and the only difference was that the more recently appointed surgeons operated on a lower proportion of patients with TGA-VSD.

However, these findings could also be explained by the influence of the mentorship programme. The aim of such a programme is to allow surgeons to gain experience without compromising patient outcomes. All surgeons undertook ASO such that they were operating independently within twelve initial cases, but patient survival was unaffected. It is entirely appropriate that newly appointed surgeons undertake surgery on patients with a lower risk profile as part of the mentorship process. The selection of cases commensurate with the surgeon's level of experience is important to allow the newly appointed surgeon to gain necessary expertise before being able to tackle cases of greater complexity.

Technical proficiency

Cardiopulmonary bypass time and ischaemic time are useful surrogate markers of technical proficiency, as they are universally measured and documented for cases undertaken on CPB. Most cardiac surgeons have a personal idea of their approximate CPB time and ischaemic time for particular operative procedures and may use these figures to give an indication that a procedure was completed without undue technical difficulties. They are not necessarily useful as absolute comparators between surgeons and have not been used to compare surgeons in this study.

An interesting observation is that CPB times for individual surgeons in this study remained remarkably consistent with time. This may be explained by the effect of mentorship. We may expect that early in a surgeon's experience a particular procedure may take longer, and as proficiency develops for there to be a reduction in the CPB time. However, effective mentorship with a more experienced surgeon involved in selection of a case at an appropriate level of complexity for the newly appointed surgeon, and assisting during the procedure, may mean that the operation proceeds without difficulty and the CPB time is shorter than would be expected for a newly appointed surgeon.

A further strength of the mentorship programme was the availability of a senior surgeon to attend the operating room for discussion and to scrub with the operating surgeon if required, and by mutual agreement. Intra-operative revisions were undertaken in this series but did not lead to additional morbidity or mortality. Surrogate measures of morbidity such as intensive care and hospital length of stay were not dissimilar between surgeons, again suggesting that mentorship enabled surgery to be performed proficiently. Re-intervention rates were low overall and not significantly different between surgeons, suggesting that all surgeons in the team were able to undertake complex neonatal surgery in a technically sound fashion.

Limitations

The data in this study has been collected and analysed retrospectively. Although the overall cohort of patients is large, some sub-groups contain small numbers of patients (TGA-VSD group for some surgeons) precluding meaningful analysis. The relatively low mortality across the series meant that the analysis could be under-powered in the use of mortality as a sensitive enough variable to detect differences in performance - however, the use of bypass data and reintervention data are much more sensitive. Finally, by necessity, the data has been collected from patient episodes over a long period of time, and while the surgical technique may have remained consistent, cardiology and intensive care approaches may have changed over time and are not accounted for in this study.

Avoiding the learning curve – future directions

The concept of the learning curve is a well established in surgery. However, when outcomes are universally excellent there is little margin for poor outcomes that may occur through the surgical inexperience of a newly appointed surgeon. Sharing the knowledge, skills and experience already gained by more senior members of the team can mitigate this concern. Although beyond the remit of this study, the question is also whether this process should be achievable for senior trainees rather than after appointment at consultant level. This is a challenge for training programmes and historically has been very difficult to achieve, as it requires considerable experience, technical ability and maturity in the trainee. The North American programmes have shown more recently that training in complex neonatal procedures is possible, but not always easy despite considerable investment [13].

This study shows that the learning curve may be avoided in complex, technically demanding procedures such as the arterial switch operation through mentorship. This concept should be extended to other complex procedures such as the Ross procedure, aortic arch reconstruction, and the Norwood procedure, and also to improve training in congenital cardiac surgery

Conclusion

This study of 449 patients with transposition of the great arteries demonstrates that newly appointed surgeons were successfully mentored to become proficient in the arterial switch procedure without compromising patient outcomes. This mentorship model could be applied to all forms of complex congenital cardiac surgery.

Table 1. Patient characteristics and peri-operative data.

	TGA-IVS (n=333)	TGA-VSD (n=116)
Age at operation (days)	7 (5-12)	10.5 (6-24)
Weight at operation (kg)	3.4 (3.0-3.8)	3.4 (2.9-3.8)
Male (%)	72	74
Balloon atrial septostomy (%)	86	61
Ventilated pre-operatively (%)	26	13
Yacoub type A coronary pattern (%)	72	69
Cardiopulmonary bypass time (mins)	99 (88-118)	123 (100-146)
Ischaemic time (mins)	62 (56-74)	82 (71-95)
Circulatory arrest time (mins)	7 (6-9)	4 (0-23)
Open sternum after arterial switch (%)	28	38
ICU length of stay (days)	4 (3-6)	5 (3-7)
Hospital length of stay (days)	8 (7-11)	9 (7-14)
30 day survival (%)	99	98

Table 2. Patient characteristics and peri-operative data, by individual surgeon.

	A (n=265)		**B (n=127)**		**C (n=41)**		**D (n=16)**	
	TGA-IVS (n=187)	TGA-VSD (n=78)	TGA-IVS (n=99)	TGA-VSD (n=28)	TGA-IVS (n=33)	TGA-VSD *(n=8)	TGA-IVS (n=14)	TGA-VSD *(n=2)
Age at operation (days)	8 (5-13)	13.5 (7-30)	7 (5-10)	7.5 (5.5-12)	8 (6-13)	NA	5 (3-6)	NA
Weight at operation (kg)	3.4 (3.0-3.8)	3.4 (3.0-3.8)	3.4 (3.1-3.8)	3.2 (3.0-3.6)	3.2 (2.8-3.5)	NA	3.4 (3.0-3.6)	NA
Balloon atrial septostomy (%)	94	69	83	46	58	NA	64	NA
Ventilated pre-operatively (%)	21	10	33	21	27	NA	7	NA
Usual (Yacoub A) coronary pattern (%)	77	72	64	64	73	NA	64	NA
Cardiopulmonary bypass time (mins)	94 (83-107)	115 (91-132)	101 (95-111)	135 (117-151)	138 (127-149)	NA	120 (117-128)	NA
Ischaemic time (mins)	59 (53-69)	79 (69-91)	62 (59-69)	84 (71-95)	83 (79-89)	NA	76 (68-82)	NA
Sternum open after arterial switch (%)	18	23	23	56	72	NA	67	NA
ICU length of stay (days)	3 (2-5)	4 (3-5)	5 (3-6)	6 (4-8)	5 (4-8)	NA	5 (4-6)	NA
Hospital length of stay (days)	8 (7-11)	8 (7-13)	9 (7-11)	11 (9-17)	11 (8-15)	NA	10 (8-12)	NA
30 day survival (%)	98	98	100	96	100	NA	100	NA

* Summary statistics not useful for small numbers (n<10), values are expressed as medians and interquartile ranges.

Figure legends

Figure 1. Coronary artery patterns in patients with transposition of the great arteries with intact ventricular septum (TGA-IVS) and with ventricular septal defect (TGA-VSD).

Graphical representation of coronary artery patterns A-E according to the Yacoub classification [8] (U indicates unable to be classified) in patients with transposition of the great arteries with intact ventricular septum (panel A, n=333 patients) and with ventricular septal defect (panel B, n=116 patients).

Figure 2. Cardiopulmonary bypass times for consecutive arterial switch operations for transposition of the great arteries with intact ventricular septum, by individual surgeon.

Total cardiopulmonary bypass time for each arterial switch operation for transposition of the great arteries with intact ventricular septum plotted consecutively against date (1988-2014) for each surgeon A-D (Surgeon A – n=187 patients, Surgeon B – n=99 patients, Surgeon C – n=33 patients, Surgeon D – n=14 patients).

Figure 3. Survival following arterial switch operation for transposition of the great arteries, by individual surgeon.

Kaplan-Meier estimates of survival following the arterial switch operation for transposition of the great arteries with intact ventricular septum (n=333 patients), and ventricular septal defect (n=116 patients) for Surgeons A-D. Survival estimates for individual surgeons compared using the Log Rank test were not found to be significantly different (p=0.773). Numbers at risk each year for each surgeon are detailed in the lower part of the panel.

Figure 4. Survival following arterial switch operation over time.

Kaplan-Meier estimates of survival following the arterial switch operation for transposition of the great arteries (n=449 patients). Patients were ordered consecutively and divided into quintiles q1 – q5, q1 representing the earliest 90 patients in the series and q5 representing the most recent 90 patients. Surgeon B was appointed during the second quintile (q2), Surgeon C during the fourth quintile (q4) and Surgeon D during the fifth quintile (q5). Survival estimates for each quintile compared using the Log Rank test were not found to be significantly different (p=0.98), suggesting that the appointment of new surgeons did not affect survival. Numbers at risk each year for each quintile are detailed in the lower part of the panel.

Figure 5. Freedom from re-intervention following arterial switch operation, by individual surgeon.

Kaplan-Meier estimates of freedom from intervention following the arterial switch operation for transposition of the great arteries (n=449 patients), grouped by Surgeons A-D. An intervention was defined as the first surgical or catheter based procedure undertaken subsequent to the primary procedure. Estimates of freedom from intervention for individual surgeons compared using the Log Rank test were not found to be significantly different (p=0.409), suggesting that all surgeons were able to undertake complex neonatal surgery in a technically sound fashion.

References

1. Jensen HA, Brown KL, Pagel C, Barron DJ and Franklin RC., Mortality as a measure of quality of care in infants with congenital cardiovascular malformations following surgery. Br Med Bull, 2014. 111(1): p. 5-15.

2. Jatene AD, Fontes VF, Paulista PP, Souza LC, Neger F, Galantier M, et al., Anatomic correction of transposition of the great vessels. J Thorac Cardiovasc Surg, 1976. 72(3): p. 364-70.

3. Villafane J, Lantin-Hermoso MR, Bhatt AB, Tweddell JS, Geva T, Nathan M, et al., D-transposition of the great arteries: the current era of the arterial switch operation. J Am Coll Cardiol, 2014. 64(5): p. 498-511.

4. Lecompte Y, Zannini L, Hazan E, Jarreau MM, Bex JP, Tu TV, et al., Anatomic correction of transposition of the great arteries. J Thorac Cardiovasc Surg, 1981. 82(4): p. 629-31.

5. Brawn WJ and Mee RB, Early results for anatomic correction of transposition of the great arteries and for double-outlet right ventricle with subpulmonary ventricular septal defect. J Thorac Cardiovasc Surg, 1988. 95(2): p. 230-8.

6. Fricke TA, d'Udekem Y, Richardson M, Thuys C, Dronavalli M, Ramsay JM, et al., Outcomes of the arterial switch operation for transposition of the great arteries: 25 years of experience. Ann Thorac Surg, 2012. 94(1): p. 139-45.

7. Samanek M, Congenital heart malformations: prevalence, severity, survival, and quality of life. Cardiol Young, 2000. 10(3): p. 179-85.

8. Yacoub MH and Radley-Smith R, Anatomy of the coronary arteries in transposition of the great arteries and methods for their transfer in anatomical correction. Thorax, 1978; **33**: 418-24.

9. Sádaba JR, Loubani M, Salzberg SP, Myers PO, Siepe M, Sardari Nia P, et al., Real life cardio-thoracic surgery training in Europe: facing the facts. Interact Cardiovasc Thorac Surg, 2010; **11**(3): 243-6.

10. Bull C, Yates R, Sarkar D, Deanfield J and de Leval M, Scientific, ethical, and logistical considerations in introducing a new operation: a retrospective cohort study from paediatric cardiac surgery. Br Med J, 2000; **320**(7243): 1168-73.

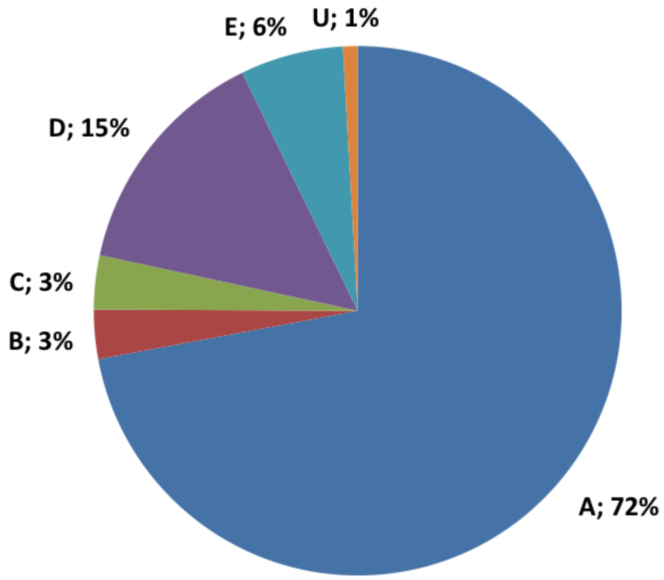
11. Cohen MS, Jacobs JP, Quintessenza JA, Chai PJ, Lindberg HL, Dickey J, Ungerleider RM. Mentorship, learning curves, and balance. Cardiol Young. 2007; **17 Suppl 2**:164-74

12. Bozeman B and Feeney MK (October 2007). Toward a useful theory of mentoring: A conceptual analysis and critique. Administration & Society, **39** (6): 719–739.

13. Kogon B, Karamlou T, Baumgartner W, Merrill W, Backer C. Congenital cardiac surgery fellowship training: A status update. J Thorac Cardiovasc Surg. 2016 Jun;151(6):1488-95

Figure 1. Coronary artery patterns in patients with transposition of the great arteries with intact ventricular septum (TGA-IVS, panel A) and with ventricular septal defect (TGA-VSD, panel B).

A. TGA-IVS



B. TGA-VSD

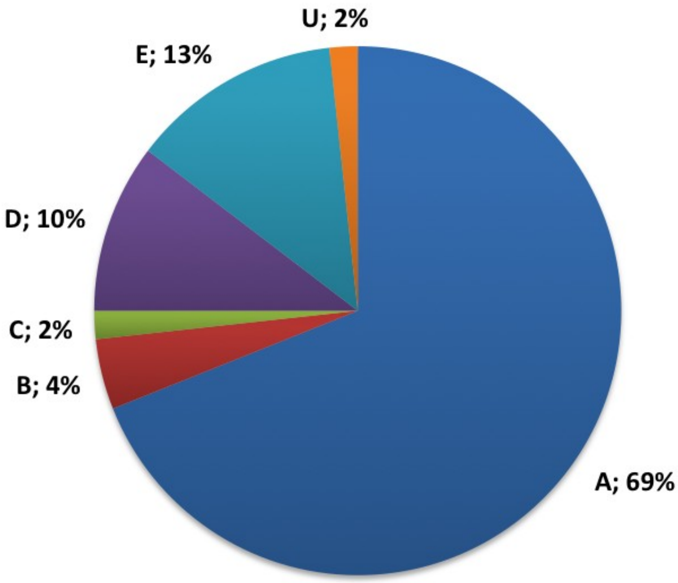


Figure 2. Cardiopulmonary bypass times for consecutive arterial switch operations for transposition of the great arteries with intact ventricular septum, by individual surgeon.

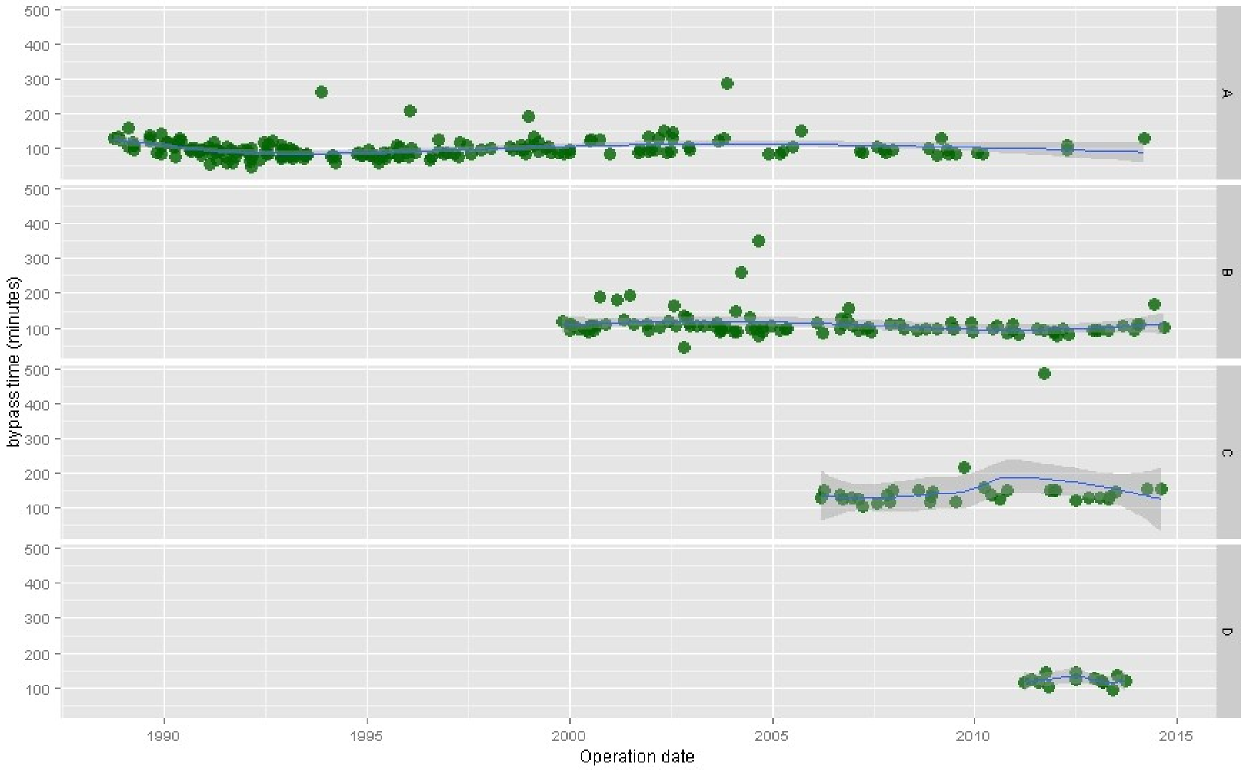


Figure 3. Survival following arterial switch operation (TGA-IVS and TGA-VSD), by individual surgeon.

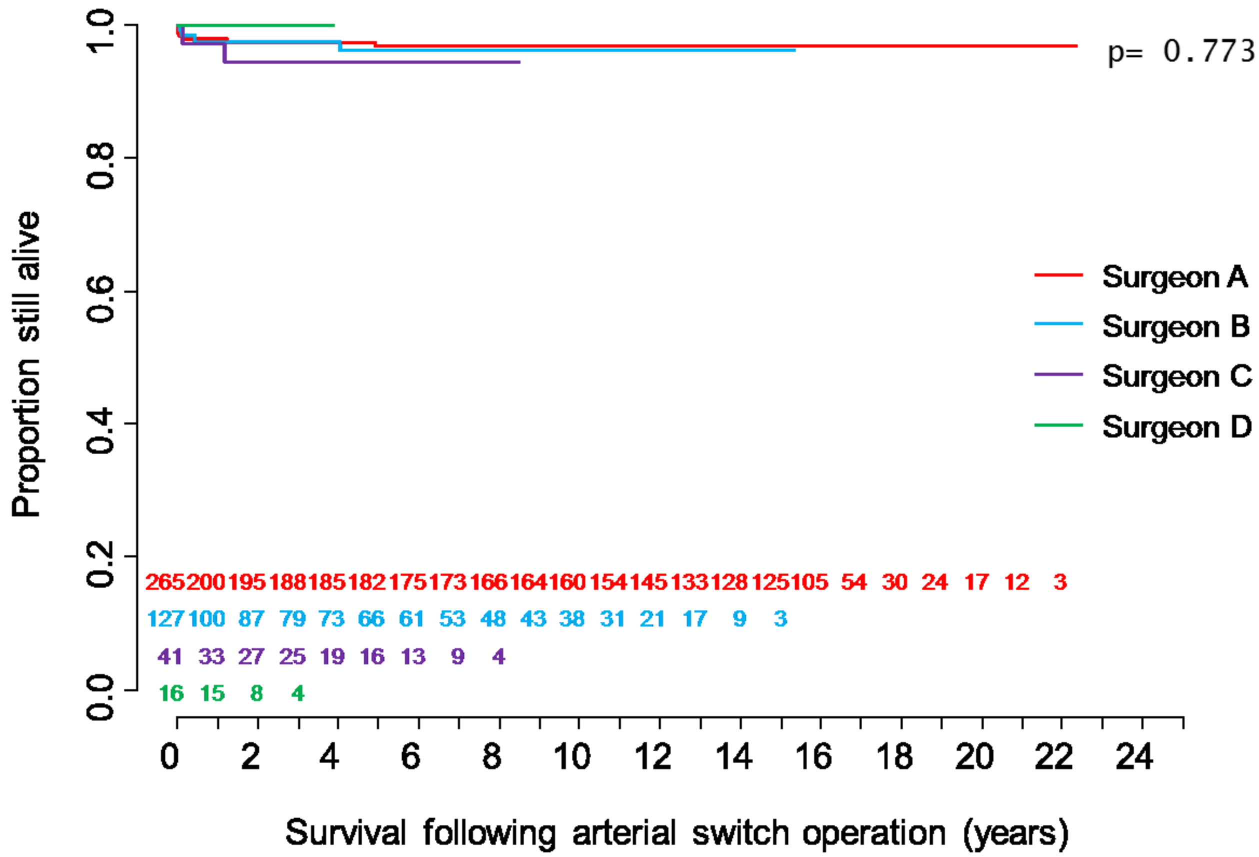


Figure 4. Survival following arterial switch operation over time.

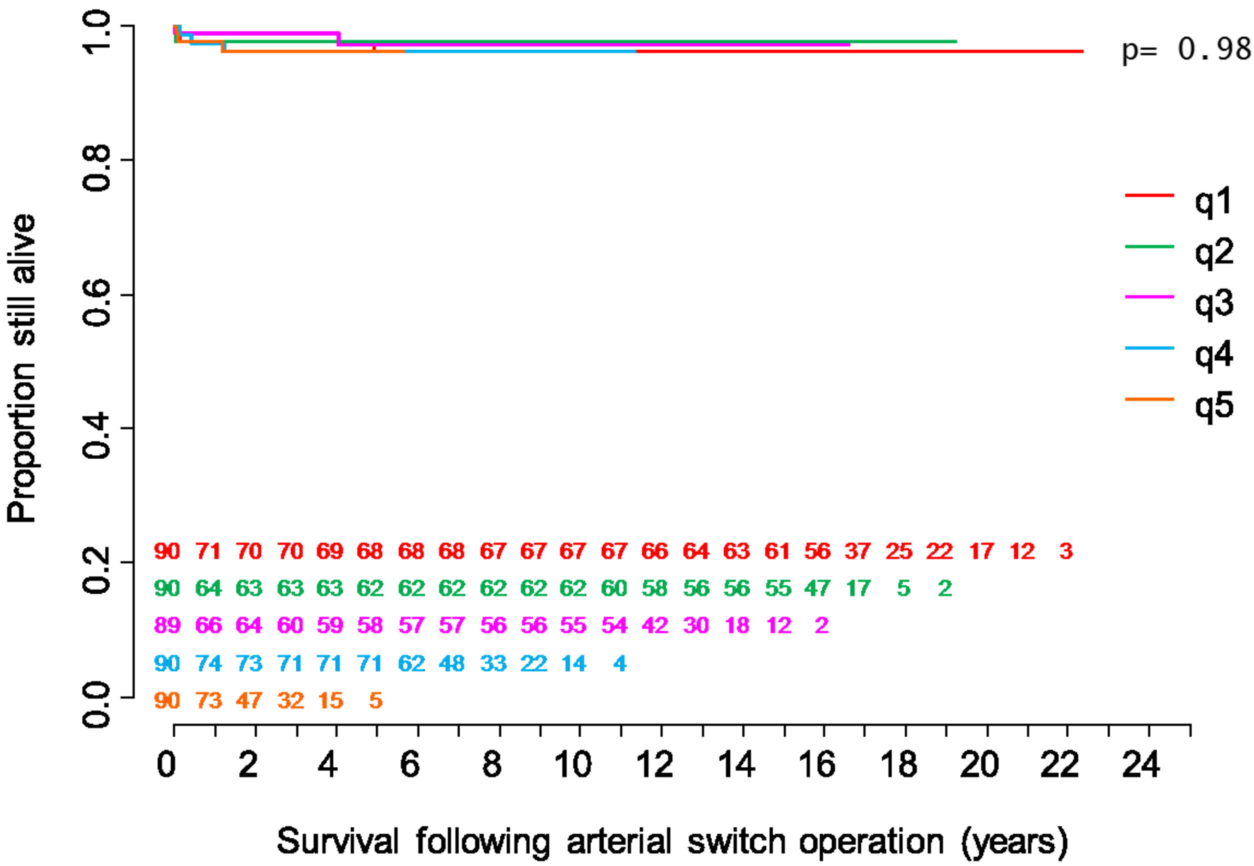


Figure 5. Freedom from re-intervention following arterial switch operation, by individual surgeon.