Techniques and Pitfalls of Coronary Arterial Reimplantation in Anatomical Correction of Transposition

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Abstract

Background and Aim: We assessed the anatomical variations in coronary arterial patterns relative to the techniques of reimplantation in the setting of the arterial switch operation, relating the variations to influences on outcomes. **Methods:** We reviewed pertinent published investigations, assessing events reported following varied surgical techniques for reimplantation of the coronary arteries in the setting of the arterial switch procedure. **Results:** The prevalence of reported adverse events, subsequent to reimplantation, varied from 2% to 11%, with a bimodal presentation of high early and low late incidence. The intramural pattern continues to contribute to mortality, with some reports of 28% fatality. The presence of abnormal course relative to the arterial pedicles in the setting of single sinus origin was associated with a three-fold increase in mortality. Abnormal looping with bisinusal origin of arteries was not associated with increased risk. **Conclusion:** The techniques of transfer of the coronary arteries can be individually adapted to cater for the anatomical variations. Cardiac surgeons, therefore, need to be familiar with the myriad creative options available to achieve successful repair when there is challenging anatomy. Long-term follow-up will be required to affirm the superiority of any specific individual technique. Detailed multiplanar computed-tomographic scanning can now reveal all the variants, and elucidate the mechanisms of late complications. Coronary angioplasty or surgical revascularization may be considered in selected cases subsequent to the switch procedure.

Introduction

Numerous studies have assessed the complexity and variability in origin and course of the coronary arteries when discordant ventriculo-arterial connections are found in the setting of concordant atrioventricular, the arrangement usually described as transposition.[1-12]Prior to the introduction of the arterial switch procedure, such variability was mainly of academic interest. Knowledge of the variability is now of paramount surgical importance, with certain variations presaging a poor outcome.[8,12-14]Understanding of the variations, and their significance, has been complicated thus far by lack of uniform descriptions. Classifications have tended either to be incomplete,[8] or excessively complex.[4] The Leiden approach is most universally applicable.[8,9] The system does not, however, account for all the potentially significant variables, such as looping.[12] The course of the artery to the sinus node may also be of significance.[3,15] Among the multiple patterns, the presence of a solitary artery, the intramural variant, and looping, have been associated with an increased risk of complications in some surgical series, but not all.[1-28] With this in mind, we have evaluated the varied patterns relative to the early and late outcomes of the arterial switch procedure.

Methods

We searched the extant literature using the Mesh term "Transposition of the great vessels", and the key word "arterial switch", to identify the variations in the coronary arterial anatomy as published from 1966 through

2021. The search engines used were PubMed , Google Scholar, Cochrane Database for Systematic Reviews, Cochrane Central Register of Controlled Trials, Ovid MEDLINE (all; 31.12.2019), ACP Journal Club, Ovid EMBASE (1974 to 31.12.2019), Database of Abstracts of Review of Effectiveness. We searched the literature in all languages, including reports of mortality subsequent to the switch procedure when coronary arterial patterns had been described. When overlapping series were published from a single institution, we selected the studies providing data on the largest number of patients.

Surgical Anatomy

With the exception of the Leiden convention,[8] attempts categorising the variations in coronary arterial patterns have foundered either because of incompleteness or undue complexity. The Leiden convention itself is less than perfect, failing to account for the course of the coronary arterial stems relative to the arterial roots. Nor does it recognise that, on occasion, the coronary arteries themselves may be absent or duplicated. This does not mean that it should be discarded. Nor does it necessitate the addition of new codes.[9] On the contrary, it retains its major value in accounting adequately for the origin of the coronary arteries from the aortic valvar sinuses. It is an easy matter then to account for additional features in descriptive fashion.

The convention is based on the anticipated presence of the three major coronary arteries, each with well-recognised areas of myocardial supply. The right coronary artery supplies the right ventricular myocardium and, when dominant, a variable portion of the diaphragmatic wall of the left ventricle. The circumflex artery supplies the obtuse marginal wall of the left ventricle. If dominant, this artery can supply part of the diaphragmatic wall of the right ventricle. The anterior interventricular artery supplies the anterior walls of both ventricles, along with the anterior part of the ventricular septum. The variations found in the setting of transposition can then almost always be understood on the basis of "marriage of convenience" between the arteries and the aortic valvar sinuses.[6] Thus, the coronary arteries typically arise from one or other, but usually both, of the aortic sinuses adjacent to the pulmonary trunk (Figure 1A). The Leiden approach distinguishes between these sinuses irrespective of the variations in relationship between the roots themselves, and irrespective of which sinus gives rise to which particular artery or arteries. The observer, figuratively speaking, stands upright in the non-adjacent sinus of the aortic root and looks towards the pulmonary root. One of the adjacent aortic valvar sinuses is then to the right hand of the observer, and the other to the left hand (Figure 1A). These positions are retained irrespective of the relationships of the arterial roots (Figure 1B).

In the commonest pattern found in transposition, the right coronary artery arises from the left-handed sinus, while the main stem of the left coronary artery, branching into anterior interventricular and circumflex arteries, arises from the right-handed sinus (Figure 2A). In the second commonest pattern, the circumflex artery arises from the left-handed sinus, taking a retro-pulmonary course (Figure 2B). Distinguishing the sinuses in handed fashion might seem to be illogical because the right coronary artery often arises from the left-handed sinus. The convention, however, does no more than distinguish between the adjacent sinuses. The approach popular amongst cardiac surgeons is to nominate the right-handed sinus as #1, and the left-handed sinus as #2. In a minority of cases, furthermore, the main stem of the left coronary artery does arise from the left-handed sinus (#2). It then passes behind the pulmonary trunk to branch and fulfil its marriages of convenience (Figure 2C). The right coronary artery in this pattern arises from the right-handed sinus (#1), taking an antero-aortic course to reach the right atrioventricular groove.

When all three major arteries are present, assuming they arise from the adjacent sinuses, there are only eight potential patterns of sinusal origin. All have now been described. One is particularly rare, since it breaks the concept of marriage of convenience. In this rarest variant, two of the major arteries cross from their sinusal origin as they extend to supply their myocardial territory.[7] In all the other variants, the arteries course from the most appropriate sinus to their myocardial territory. On occasion, however, as shown, the arterial stems course loop the pulmonary root, or else loop in front of the aortic root. Such looping is a constant feature when all the coronary arteries arise from one or other of the adjacent sinuses, with the other adjacent sinus bereft of a coronary arterial origin (Figures 2 E,F).[5] Such looping, tethering the coronary arteries to the arterial roots, can create significant problems for the surgeon. In presence of a significant arterial stem, however, such looping does not necessarily produce problems (Figure 2C). A greater surgical problem is encountered when single sinus origin (Figure 3A) is the consequence of an intramural course of one or more of the major arteries.[16] Intramural arteries pass between the arterial roots, extending through the wall of the aortic valvar sinus, and usually cross the valvar commissure adjacent to the pulmonary trunk (Figure 3B). Also of potential significance is whether the arteries take individual origin from the valvar sinuses, or whether there is a confluent origin and stem for two of the major branches, or for all three in the setting of a solitary coronary artery.[5]Additional features of potential significance are the origins of the artery to the sinus node and the infundibular artery (Figure 2). Any of the three major coronary arteries can also be absent or duplicated. Exceedingly rarely, one or more of the coronary arteries can arise from the non-adjacent sinus of the aortic root. This can be a contra-indication to the arterial switch procedure.[29]A further variation is mismatch between the commissures of the arterial valves (Figures 2A, F).[30] If extreme, this variation can complicate safe transfer during the arterial switch.

Surgical techniques of transfer for usual and complex coronary arteries

Multiple individual modifications have been reported to allow adequate transfer depending on the origins, branching pattern, looping course, and intramural variations of the arteries.

The preferred current techniques for the usual patterns

- *Coronary reimplantation following neoaortic reconstruction:*This was the original approach used by Jatene and associates,[31] and subsequently advocated during the 1980s (Figure 4A).[32,E1]
- *The Melbourne medial flap technique:* This technique transfers the coronary arterial buttons to medially hinged neoaortic trapdoors (Figure 4B).[33] The technical details of anatomical correction of transposition with usual coronary arrangement and Dacron patch closure of ventricular septal defect have been enumerated in the video presentation (Electronic Video 1). The coronaries were transferred to the neoaorta using the medially hinged neoaortic trapdoor.
- *Modified trapdoor technique:* In this modification, two buttons are created, each adopting the role of the trapdoor flap for the other button.[34]

Complex coronary arteries with anterior and/or retro-pulmonary looping

The medial trapdoor technique: A medially hinged neoaortic trapdoor is useful in cases of significant looping.[33,39] With anterior looping, the coronary button can be positioned at or above the neoaortic anastomosis.[33,35]

Yacoub technique: This technique is used to relocate the right coronary artery associated with retropulmonary looping of the circumflex artery (Figure 4C).[4]

Single sinus coronary arteries, juxtacommissural coronary arteries, and/or intramural coronary arteries

- *Yacoub technique:* A single arterial button is turned upside down, and anastomosed to the neoaorta (Figure 4D).[4]
- *Planche technique:* This modifies the "upside-down" technique, adding a U-shaped incision in the neoaortic wall and avoiding the use of a pericardial patch (Figure 5A).[12]
- *Bay-window technique:* The inner half of U-shaped coronary cuffs are sewn into trapdoor incisions made on the neoaortic stump. (Figure 5B).[36]
- *Pouch technique:* This technique involves commissural detachment, unroofing of intramural coronary arteries, and creation of a long aortic pouch (Figure 5C).[37,38,40]
- *The Double Button Melbourne technique:* This involves commissural detachment and unroofing of the coronary arterial orifices (Figure 6A).[17,39]
- *The pericardial hood technique:* The upper edge of the coronary arterial button is implanted to the neoaorta at an appropriate level when the arterial orifices are inseparable, confluent, or juxtacommissural.[39]

- *In-situ transolocation:* An aortopulmonary window is created, with the anastomosis completed using a tongue of aortic wall (Figure 6B).[40]
- *Aubert procedure:* An aortopulmonary window is completed with a patch to the neoaorta (Figure 7A).[41]
- *Moat's procedure:* The aortopulmonary window is completed using a bovine pericardial baffle (Figure 7B).[42]
- *Imai procedure:* The window approach for intramural arteries is modified by suturing a D-shaped hinged aortic cuff of the non-adjacent sinus. (Figure 7C).[43]
- *In-situ arterial reallocation:* Hockey-stick-shaped incisions are used to transfer the coronary arteries without distortion of their original anatomic position (Figure 8A).[44]
- *Reimplantation after neoaortic anastomosis:* Separate intramural coronary arterial buttons are transferred after completion of the neoaortic anastomosis.[45]
- *Anastomosis with pericardial hoods:* The trapdoor approach is combined with use of pericardial hoods (Figure 8B).[46]
- *Cetin technique:* Coronary arterial buttons are transferred to the neoaorta using pericardial or pulmonary arterial hoods (Figure 8C).[47]

Results

Since the turn of the 21st century, patients undergoing the arterial switch operation have been reported with perioperative mortalities ranging between nil and 6%.[19,48,49] In the data analysed by NICOR, for example, which collates overall results for all centers in the United Kingdom, 118 procedures were reported for 2019 through 2020, with 4 deaths within 30 days of the procedure.[50] Some patterns, such as the intramural variants, or those with single sinus origin, continue to be associated with a significantly increased risk of death, which persists over time.[19-55] Even with the commonest types of coronary arterial anatomy, transfer is not always straight forward. In Melbourne, for example, where results have been excellent in terms of mortality and overall outcomes, some manipulation of the coronary arteries subsequent to transfer was required in one-fifth of cases.[33] It has emerged, nonetheless, that certain patterns are likely to create problems. Most worrying is the intramural arrangement. Individuals with these patterns continue to suffer increased mortality, reported by some at 28%, compared to 3% in those with usual patterns in the same hands. These individuals also suffer an increased incidence of overall lethal and non-lethal coronary events, at 41% as opposed to 4.7% for the remaining patterns.[26-28,48,51-55] The risk for single sinus origin has decreased in institutions dealing with large volumes, such as Marie-Lannelongue Hospital in Paris.[12] These investigators established the risk factors for coronary arterial events in a large cohort,[12,26,53,56] noting 7.2% incidence of events in those individuals with single sinus origin. Complex patterns were associated with a 6.5 fold increased risk of death.[53,54] Others have also reported problems with loooing arteries in the setting of single sinus origin, noting significant mortality (OR 2.9, 95% CI: 1.3-6.8). It was the intramural arrangement, nonetheless, that still induced the greatest mortality (OR 6.5, 95% CI: 2.9-14.2). Overall, patients with any coronary pattern other than the usual one had nearly twice the mortality.[26]

Better indications can be found on the basis of meta-analysis. In one large analysis,[26] results were combined from 9 independent case series, providing details of almost 2,000 patients.[12,13,25,26,54,56-59] Most studies had used the Leiden classification. Complex arterial patterns were again associated with a 6.5 fold increased risk of death. Another meta-analysis of results from 20 institutions also showed single sinus origin and the intramural variants to be associated with problems, in this instance postoperative myocardial ischemia.[60]Results, perhaps not surprisingly, however, vary markedly in difference centers. Metton and associates, for example, described their experience with 46 patients having the intramural arrangement from an overall cohort 919 patients.[51] They reported 11 deaths prior to discharge from hospital, with 2 additional deaths at 51 and 105 days, giving overall mortality of 28%.[51] In three other series, mortalities have been reported at 14% and 5%.[49,55] The Melbourne group, nonetheless, repaired 28 individuals having the intramural pattern, with no deaths.[48] Thus, even the intramural variant is not necessarily a risk factor in experienced hands.

Discussion

Accurate reimplantation of the coronary arteries is the key component in the success of the arterial switch procedure. This must be achieved without creating undue tension, torsion, or kinking of the stems of the coronary arteries or their proximal branches. During the evolution of the procedure, certain patterns have been identified as problematic. Of particular concern are the so-called intramural variants, and the arrangements when all arteries arise from a single sinus. During the evolution of the operative procedure, so-called "looping" was considered a potential problem, as was juxta-commissural origin of the arterial orifices. Presence of associated defects also created additional problems, as did side-by-side arterial trunks in the so-called Taussig-Bing variant.[4,12,31,47] With ongoing experience, many of these potential problems have been mitigated. It is now generally considered that translocation is feasible for all variable patterns, although origin from the nonadjacent sinus may now be considered a contra-indication.[29]

In the initial technique as described by Jatene, the coronary arteries were not transferred to the new aorta until after anastomosis of the aorta to the initial pulmonary root.[31] Translocation to a distended root was then recognised as helpful in avoiding the need for prolonged myocardial ischemia, preventing recurrent reperfusion injuries, and permitting visualization of the newly implanted buttons and suture lines prior to reconstructing the new pulmonary trunk.[21,22,31,47,E1-E4] The approach, however, posed the risk of damaging the neoaortic valvar leaflets when creating the required openings in the neoaortic root. Placement of a marking stitch at the facing neoaortic commissure was proposed to mitigate this difficulty.[E5] The essence of the technique is to punch appropriately sized holes, and then to anastomose the mobilized buttons to these openings.[13] A key point is to bring the initial pulmonary root towards the buttons, rather than stretching the buttons towards the new root.[E6] Good midterm results were reported using this strategy.[59]

Despite the success of the initial technique,[31] advantages came to be recognised of the trapdoor technique.[33,39] In this modification, the arterial buttons are translocated to the neoaortic root prior to reconstruction of the neoaorta. This approach was considered of particular value in the setting of retropulmonary looping of the circumflex artery, which is the second commonest pattern, or the main stem of the left coronary artery. These variations create a shorter distance, and an acute turn, between the coronary artery and its new sinus, with potential kinking or distortion during translocation. Similar advantages were suggested for the trapdoor approach in the setting of anterior looping,[12] which has the potential risk of stretching or bowstringing during translocation .[4,13,E4] Further advantages were suggested if the arterial buttons were placed at or above the neoaortic anastomosis.[33,35] Since reports of its success were published by the group working at Marie Lannelongue during the mid-1990s, the technique has gained significant popularity.[12,52,54,E6] Some suggested changes, however, were not without their own problems. In the modification proposed by Vouhe, for example, with each button playing the role of the trapdoor flap for the other button, arterial obstruction within one year occurred in over one-quarter of patients. These findings understandably led to the abandonment of the modification.[34] Another modification was to create trapdoor flaps in both arterial roots.[44] Good short-term results then accrued for five consecutive individuals found to have looping in the setting of single sinus origin.[44] Yet another successful modification was to augment the relocated coronary artery using a patch of autologous or treated pericardium or pulmonary artery.[4,46] All of these modifications are designed to avoid kinking or stretching subsequent to transfer. It follows that identification of the optimal location for each anastomosis remains crucial. As yet, however, long-term results of these individual techniques are not available so as to determine which might be preferable.[4,34,36,44,46]

Problems were encountered initially when looping patterns were found in the setting of origin of coronary arteries from each of the adjacent sinuses. The techniques as described above have resolved most of the difficulties. Problems still remain when all arteries arise from the same aortic sinus,[6] a finding in up to one-sixth of individuals in some series.[40-43] The difficulties relate to the limited mobility when a short main stem feeds the looping artery or arteries. Comparable limited mobility is found should the arteries arise from the same sinus through double or triple orfices.[2,4,5,8,10,12,19,27,28,52] Specific techniques have also been proposed to mitigate these problems. Thus, when arising from a solitary main stem, a button can be detached and inverted using the technique proposed by Yacoub,[4] or else anastomosed to the neoaortic root using the trapdoor technique.[33,39] When there are multiple orifices within the sinus, then as is the case for juxtacommissural origin from both adjacent sinuses, creation of an aortopulmonary window is a good option.[40-43] The group working at Marie Lannelongue, however, had initially modified the technique of

Yacoub as suggested above, only to abandon it because of kinking. Instead, they promoted the dual button trapdoor transfer as described by Asou and Mee.[11,12,17,33,39] An additional high risk of direct implantation had been identified in specific situations when the angle between a line drawn between the centres of the arterial roots and that drawn from the neoaorta to the coronary arterial orifice exceeds 75 degree.[20] In this setting, augmentation using a pericardial hood was shown to maintain a natural lie of the transferred coronary artery, and to produce a good long-term result.[46] Others had suggested using a short autologous pericardial tube,[E3] but this risks the formation of thrombus, as well as extrinsic compression by the newly constructed pulmonary pathways. Problems also occurred subsequent to augmentation using a pulmonary arterial flap, with the coronary artery being abnormally positioned even after successful translocation.[21,44,E2,E3]

It is the intramural arrangement, nonetheless, that still poses the greatest risk to the patient. If undetected prior to the procedure, the artery may inadvertently be transected during the initial aortotomy. The aortotomy should be performed in a safe area, revealing the location of all the arterial orifices before the aorta is transected.[E7,E8] If the intramural artery is para-commissural, or inseparable from the other arterial orifice arising from the same sinus, the commissure itself should be detached, permitting harvesting of the button as a single disc. If the intramural component is stenotic, it must be completely unroofed prior to resuspending and reconstructing the neopulmonary valve.[11,17,39,46,47,E7-E9]

Once recognised, two methods have evolved to mitigate the problems of the intramural arrangement. The first is to separate the orifice of the intramural artery from its sinus, either as a confluent button containing the other artery, or as separate buttons. The second method is to leave both arteries within the sinus, and to create an aortopulmonary window roofed by a patch or autologous tissue. Each technique has advantages and disadvantages.[11,17,39,46,47,E7-E9] If two buttons are to be successfully created, there should be more than 2 millimeters between the orifices. Each button can then be handled using the trapdoor approach.[33,39] This technique, however, is technically demanding. An insufficient cuff of sinusal wall has been found to lead to more angled rotation of one or both buttons.[11,17,33,39,48] Transfer of a confluent button can be achieved using a medially based trapdoor supplemented by pericardial or pulmonary hood augmentation, with this approach avoiding turbulent flow within the neopulmonary system.[47]Creation of an aortopulmonary window, in contrast, by maintaining the native geometry, is claimed to reduce the possibility of tension, torsion, kinking or overstretching.[37,38,40-44] Use of a hinged aortic sinus pouch and flap in the latter approach is also claimed, irrespective of the location of the arteries, to reduce the risks of thrombosis, shrinkage, distortion, late obstruction, compression, and neopulmonary arterial stenosis.[37,38,40-44]

The commonest reason for early mortality following anatomical correction has proved to be postoperative ventricular dysfunction.[19,48,49,60] Reports on etiology, however, are limited and conflicting.[E8-E10] Studies conducted to date have been hindered by the small number of included patients, and hence their limited statistical power ranging between 20% to 35%.[25,26,53,54] We were able to identify nine retrospective, one prospective, and one meta-analysis specifically addressing the relationship between coronary arterial patterns and short and long-term outcomes.[12,13,25,26,30,34,36,57-59,E11-E13] Reported events have varied from 2% to 11%, with a high early and low late incidence. Most have been related to kinking, torsion, or stretching.[12,13,25,26,30,34,36,57-59,E11-E13] As with the operative problems, the events are associated with the intramural arrangement, retropulmonary looping, and single sinus origin with multiple orifices. Residual stenosis due to intimal proliferation is commonly reported.[47,51-54,57,E14,E15] Complications occurring with favourable arterial patterns have been less well explained. One meta-analysis,[26] for example,[26] found looping in the setting of a single sinus origin to be associated with a 3 fold increase in mortality, whereas looping when each adjacent sinus supported a coronary artery was not associated with increased risk. The underlying problem is again considered to be kinking or stretching of the looping coronary arteries.[26,53,E13-E15] In up to one-tenth of cases, evidence has been found of extensive lengths of stenosis, or even occlusion, explaining well some catastrophic clinical consequences.[12,33,39] A small number of individuals suffer late events, either death or myocardial infarction, following anatomical correction,[54,56,59,E4,E12] with myocardial revascularization reported at periods of between three months and three years after the switch.[53,54,E15,E16] The causes were again mostly related to stretching of the translocated coronary arteries with ongoing somatic growth, and progressive fibrocellular-intimal hyperplasia..[E12,E14,E15] Studies assessing the capacity of non-invasive methods to predict such obstruction have thus far been inconclusive.[E12-E20] With the increased resolution of three-dimensional clinical techniques, nonetheless, it is becoming much easier specifically to identify the postoperative coronary arterial anatomy, thus offering hope that the reasons for complications will soon become obvious.[E21-E23] Already, when using coronary angiography, the group working at Marie Lannelongue had identified postoperative lesions in two-thirds of their patients at a median of 7 years of follow-up.[53] Another angiographic study, however, identified problems in less than one-twentieth of their patients after a median follow-up of just over one year.[E12] Others have demonstrated long term problems in between one-twelth and one fifth of patients, mostly in the setting of single sinus origin, with the findings considered an important cause of late death.[E13-E15] The optimal management of the lesions, once identified, remains to be determined. Percutaneous coronary angioplasty, or surgical revascularization, have thus far been performed with satisfactory mid-term results.[51-53,E13,E15,E17-E19,E24,E25]

Conclusions

Even in the current era, an intramural arrangement, or origin of the three major arteries from the same sinus, remains associated with adverse events following the arterial switch procedure. Optimizing the technique for translocation of these challenging variants be crucial to reducing these ongoing problems. The creation of the International Congenital Heart Surgery Registry to address the issues of reimplantation, having categorised the patterns present used an all-inclusive system such as the original Leiden convention,[8] may now provide the data needed to answer the persisting questions.

Authors' contributionS

Author's name	Concept/ design	Data analysis/ interpretation	Drafting article	Critical revision	Appro
Ujjwal Kumar Chowdhury	?	?	?	?	?
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Figure Legends

Figure 1 : If the observer stands in the non-adjacent sinus of the aortic root, and looks towards the pulmonary root (Panel A), one of the sinuses of the aortic root is to the right hand of the observer (#1), whilst the other is to the left hand (#2). The system retains its ability to distinguish between the sinuses being right handed and left handed irrespective of the relationship between the arterial trunks (Panel B).

Figure 2 : The commonest variant is for the right coronary artery to arise from the left-handed sinus, and the main stem of the left coronary artery from the right-handed sinus (Panel A). In the second most common pattern, the retropulmonary circumflex artery also arises from sinus #2. The main stem of the left coronary artery can arise from sinus #2 (Panel C), with the antero-aortic right coronary artery arising from sinus #1. All coronary arteries can arise either from sinus #1 (Panel E) or from sinus #2 (Panel F). Panels A and F also show commissural mismatch (white arrows with red borders).

Figure 3 : Panel A shows the sinus #2 in a heart in which the main stem of the left coronary artery is intramural. An intramural anterior interventricular artery originating from sinus #2 is shown in panel B, with a retropulmonary circumflex artery also arising from this sinus.

Figure 4 : The steps, I and II, showing coronary reimplantation after neoaortic reconstruction in panel A. Panel B showing transfer to medially hinged trapdoors with panel C showing the technique of for transfer of the retropulmonary circumflex artery. Panel D shows steps I and II for transfer of a single coronary artery.

Figure 5 : In Panel A, steps I and II show a technique of relocation of a single coronary artery. In Panel B, the two steps are shown for the "bay window" transfer. Panel C shows the two steps of the aortic sinus pouch technique for transfer of an intramural coronary artery.

Figure 6 : In Panel A, steps I through IV illustrate the two-button technique for transfer of intramural coronary arteries. Steps I through III in Panel B show the modification of the initial creation of an aortopulmonary window.

Figure 7 : In Panel A, steps I through III show the initial technique proposed for anatomical correction without arterial translocation.[41] Steps I and II in panel B show the modification using a bovine pericardial patch,[42] while steps I and II in panel C show the modification using a D-shaped hinged aortic cuff from the aortic non-adjacent sinus.[43]

Figure 8 : Panel A shows steps I and II of in-situ relocation using hockey-stick incisions.[44] Panel B shows steps I and II of the augmentation of the button using a pericardial hood.[46] Panel C shows steps I and II of the technique using a pulmonary arterial patch.[47]

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Legend of Video Presentation (Electronics)

We report here-in a 20 days-old male child diagnosed with D-transposition of the great arteries of the ventricular septal defect, Yacoub's type A coronary arterial pattern undergoing anatomical correction at the arterial level using medially hinged trapdoor technique with Dacron patch closure of the ventricular septal defect under moderately hypothermic cardiopulmonary bypass and St. Thomas (II) based cold blood cardioplegia. Postoperative recovery was uneventful.

Surgical Techniques

The operation: Surgical planning and the position

- Following median sternotomy, the thymus was subtotally excised taking care not to expose the brachiocephalic vein. The pericardium was incised about 5-6 mm in front of and parallel to the phrenic nerve, thus exposing the two great arteries, the right atrium and the superior vena cava. The pericardium was opened using scissors and not cautery to avoid inadvertent cautery-induced ventricular fibrillation. A rectangular segment of pericardium was harvested and fixed in 10% glutaraldehyde for 10 minutes for later use of right ventricular outflow tract reconstruction.

- The position and size of the great arteries, as well as the site of origin and distribution of the coronary arteries was determined. All four chambers were inspected and pressures recorded. Note the antero-posterior disposition of the aorta and the main pulmonary artery with the left main coronary artery arising from the left posterior aortic sinus and the right coronary artery arising from the right posterior aortic sinus. The left main coronary artery giving origin to the left anterior interventricular coronary artery and circumflex coronary artery.
- The operation was performed with moderately hypothermic cardiopulmonary bypass at 32°C. Angled venous cannulas were inserted into the superior and inferior caval veins and with distal aortic cannulation. Measures were taken to avoid excessive manipulation.

Dissection and division of the ductus arteriosus

The persistent ductus arteriosus was dissected on the superior surface of the pulmonary artery by McGoon's technique, transfixed at both aortic and pulmonary arterial ends using 6-0 polypropylene suture (Johnson and Johnson Ltd., Ethicon, LLC, San Lorenzo, USA) and was divided.

Mobilization of the aorta and the pulmonary arteries

The two great arteries were separated from each other by dividing the pericardial reflection and between them, starting from the level of the top of the commissures and pulmonary artery till the level of pulmonary arterial branching on either side. Low voltage cautery (10-15 mv) was used during dissection. The aorta, right and left pulmonary arteries were looped using elastomer vessel loops.

Placement of marking sutures at the proposed neoaortic location of coronary transfer

Two marking sutures were placed over the pulmonary artery at the proposed neoaortic location. Note the site of neoaortic coronary button, little above the sinuses to avoid waisting/kinking of the coronaries.

Cross-clamping of the ascending aorta and administration of cardioplegia

The aorta was cross-clamped. Antegrade St. Thomas based (1:4) cold blood cardioplegia and topical cooling was used for myocardial preservation.

Venting of the left ventricle

Right atriotomy was done after snugging the inferior caval vein and left heart was vented through the atrial septal defect using a No.13 DLP suction vent (Medtronic Inc., Medtronic Parkway N.E., Minneapolis, MN, USA).

Dacron patch closure of the ventricular septal defect

The ventricular septal defect was closed using an appropriately sized Dacron polyester patch (Bard® Savage® filamentous knitted polyester fabric, Bard Peripheral Vascular Inc., Tempe, AZ, USA) and pledgeted 5-0 polypropylene sutures (Johnson and Johnson Ltd., Ethicon, LLC, San Lorenzo, USA). The tricuspid valve was checked for competence injecting cold saline through the tricuspid valve into the right ventricle.

Administration of second dose of cardioplegia

Second dose of antegrade root cardioplegia was administered after closing the ventricular septal defect.

Dissection of the aorta and pulmonary trunk

The aorta was divided in between stay sutures at the level of pulmonary arterial bifurcation. Two stay sutures of 6-0 polypropylene were placed on the top of each coronary buttons for retraction and mobilization. The transected distal aortic end was retracted superiorly for optimal visualization and uncluttering of surgical field.

The pulmonary trunk was next divided about 1-2 mm below the level of pulmonary arterial bifurcation. The vessel loops on right and left pulmonary arteries were placed on traction for the LeCompte manoeuvre.

Inspection of the pulmonary valve

The pulmonary valve and subpulmonary region were inspected through the transected end of the pulmonary artery.

Identification of the coronary arteries

The position of the coronary ostia and their relation to the sinuses of valsalva of the aortic and pulmonary valves were determined. Note the origin of both coronary arteries from the left and right posterior sinuses respectively. Additionally, the course and mode of branching of the proximal 5-6mm of each artery was inspected.

Mobilization of coronary buttons

The left and right coronary ostia were mobilized with a surrounding rim of aortic wall including almost the full thickness wall of the sinus of valsalva without causing injury to the valve leaflets. The process was started at the edge of the transected aortic wall for the left coronary ostium followed by the right coronary ostium. Low voltage cautery (5-6 mv) was used for hemostasis at the harvested site.

Creation of medially-based arterial flaps for coronary artery translocation

A site on the pulmonary artery for the left and right coronary anastomoses were chosen. This neoaortic location was higher than the top of the sinus of valsalva, to avoid tension/kinking/waisting of the coronary arteries and to avoid distortion of the aortic valve. Two medially based pulmonary arterial flaps as described by Roger Mee were created accordingly. The sites chosen allowed for rotation of the mobilized coronary buttons through an angle not more than 30°. No portion of the pulmonary arterial wall was excised.

Coronary anastomoses

The coronary anastomoses were performed using 6-0 polypropylene suture, taking care not to injure the coronary ostia and distortion of the mobilized disc.

The LeCompte manoeuvre

The pulmonary arterial bifurcation, right and left pulmonary arteries were mobilized beyond the site of the divided ductus into the pulmonary hilum on the left side and behind the superior vena cava to the branching of the right pulmonary artery on the right side. The distal transected end of the aorta was then threaded behind the mobilized pulmonary arterial bifurcation by LeCompte manoeuvre and the second aortic controlling clamp was transferred onto the aorta at its new site behind the pulmonary artery bifurcation.

Reconstruction of the aorta

The small distal end of the aorta was matched to the larger proximal end for anastomosis using 6-0 polypropylene suture.

Repair of the defects in the aortic sinus

Two defects which was produced in the facing sinuses of the pulmonary trunk were repaired using a single patch of the autologous pericardium and 6-0 polypropylene suture. The size of the patch is approximately one and a half times the size of the defect, thus enlarging the diameter of the proximal aorta to match the size of the distal pulmonary artery.

Release of the aortic cross-clamp and restoration of myocardial perfusion

The aortic cross-clamp was released, thus restoring myocardial perfusion. Note the distended left and right coronary arteries perfusing the myocardium without any kinking or torsion.

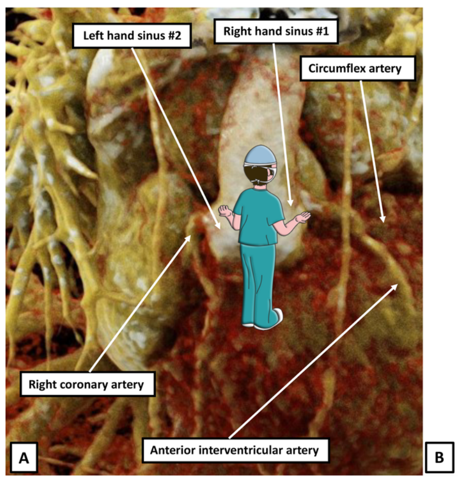
Reconstruction of the pulmonary artery

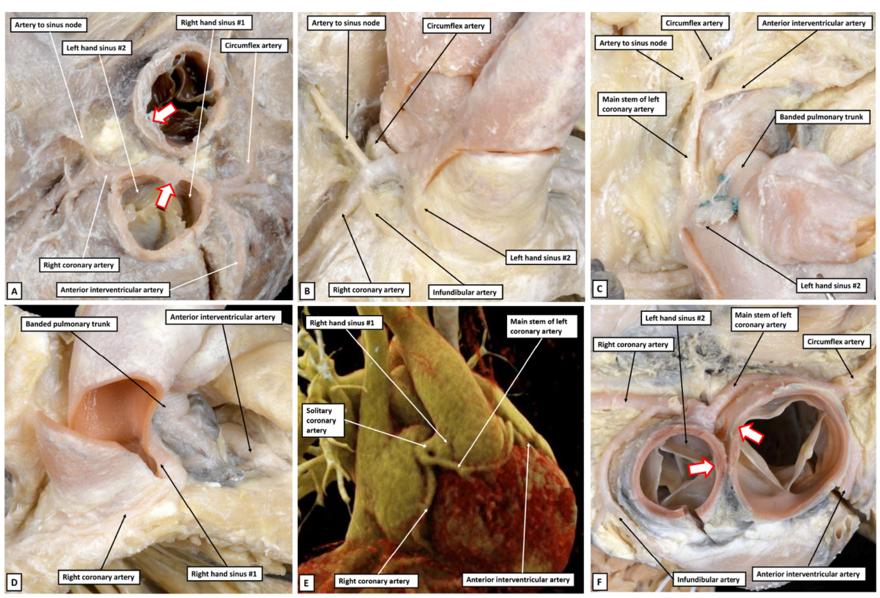
The last stage of the LeCompte manoeuvre consists of direct anastomosis between the reconstructed proximal aorta and the distal pulmonary artery using a 6-0 polypropylene suture. Precautions were taken to anastomose the two ends without compressing the proximal parts of the coronary arteries, without causing narrowing of the right and left pulmonary ostia and without stretching the branches of both pulmonary arteries.

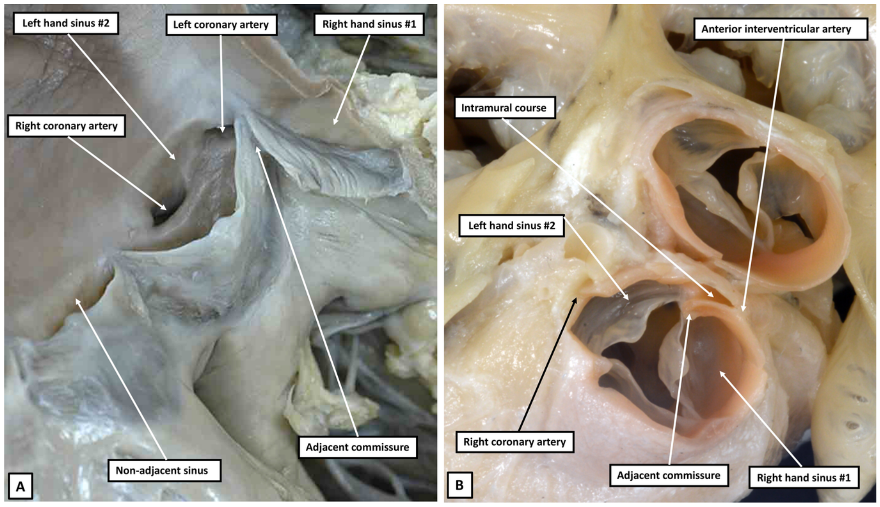
Closure of the right atriotomy

The atrial septal defect was directly closed using 5-0 polypropylene suture. The right atrium was closed in two layers using 5-0 polypropylene suture. The child was weaned-off cardiopulmonary bypass with stable hemodynamics on dobutamine and nitroglycerine infusion.

Postoperatively, the child was in normal sinus rhythm, and recovery was uneventful. At the 24-months follow-up, the child was asymptomatic, in normal sinus rhythm, normal ventricular function with no echo-cardiographic evidence of regional wall motion abnormality.



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Left coronary artery
Right hand sinus #1
Right coronary artery
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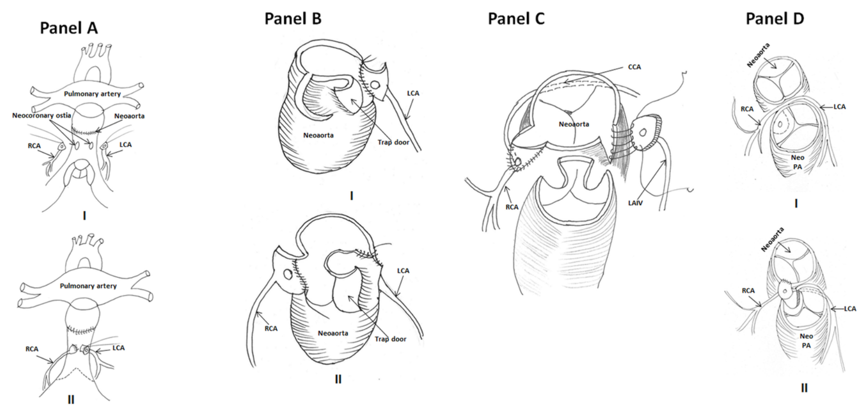
Anterior interventricular artery
Intramural course
Left hand sinus #2
Right coronary artery
Adjacent commissure
Right hand sinus #1
B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Neocoronary ostia
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Pulmonary artery
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Neoaorta
Trap door
I
LCA
RCA
Neoaorta
Trap door
II
Panel C
CCA
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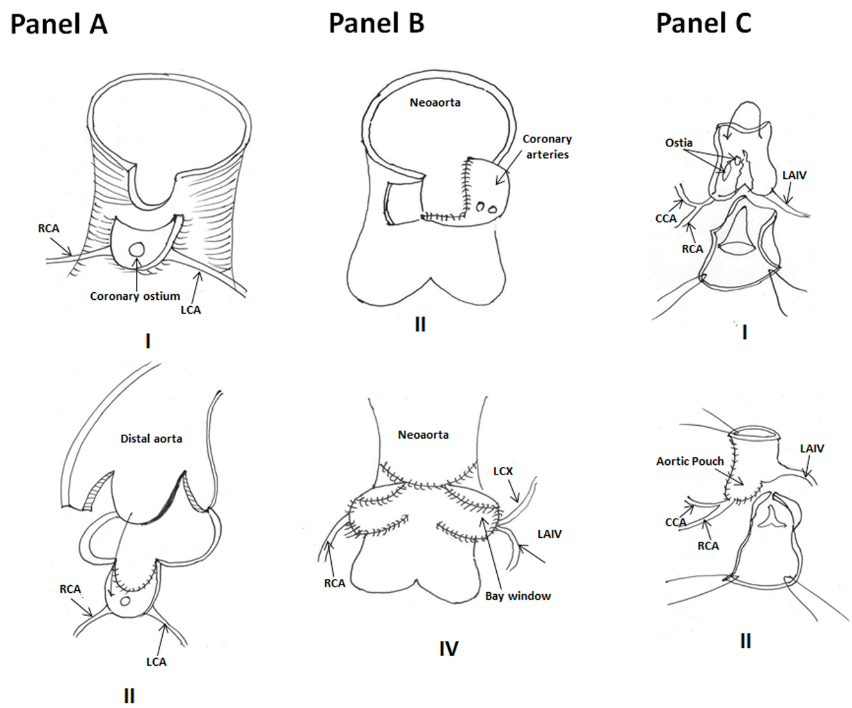
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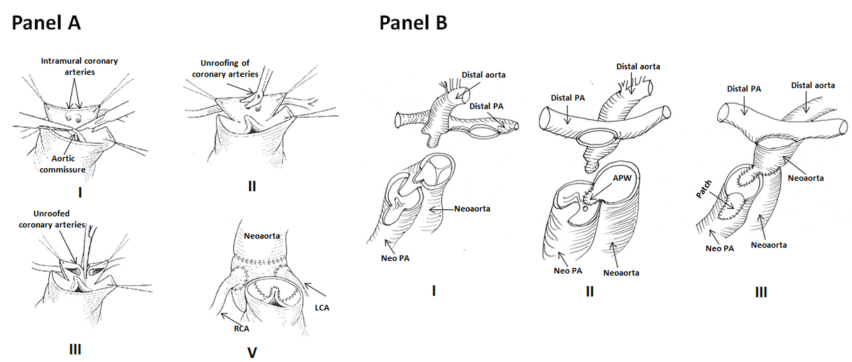
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III
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Distal aorta
Distal PA
Neoaorta
Neo PA
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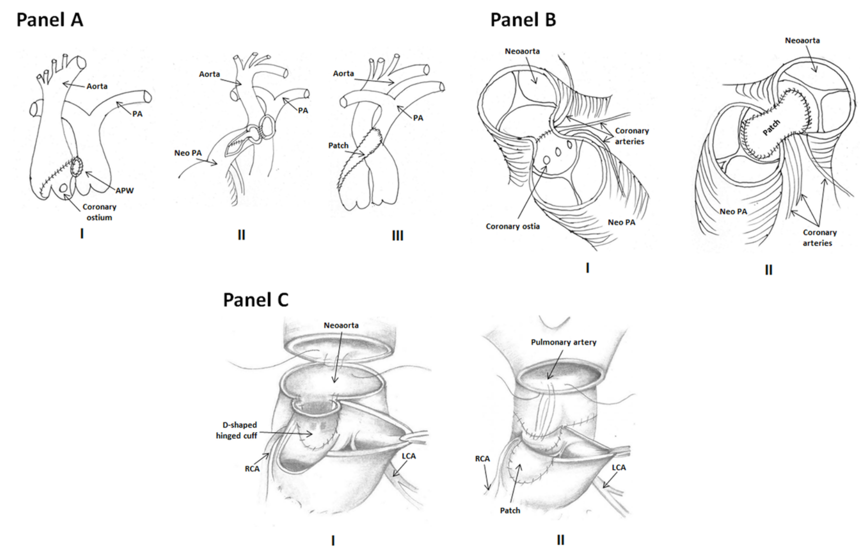
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Coronary ostia
Neo PA
I
Neoaorta
Patch
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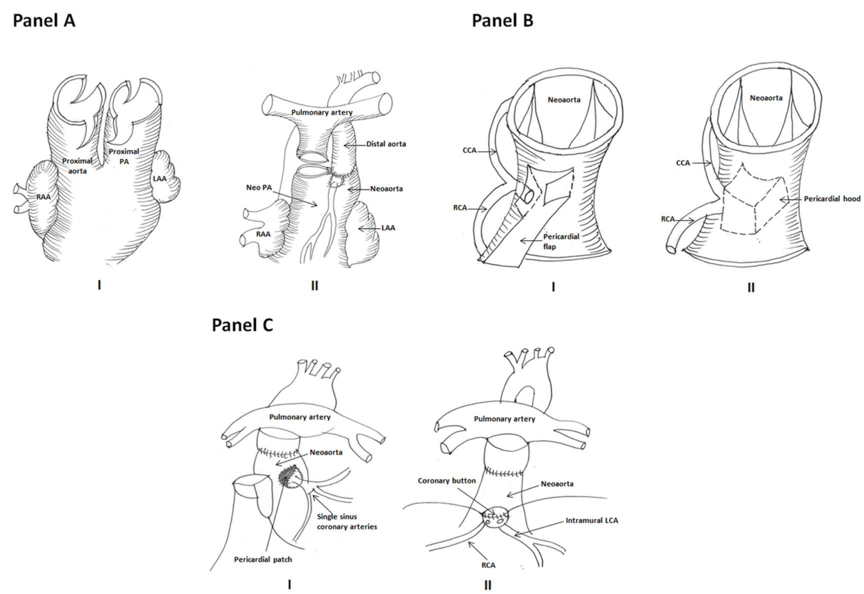
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Panel B
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CCA
RCA
Pericardial flap
I
Neoaorta
CCA
RCA
Pericardial hood
II
Panel C
Pulmonary artery
Neoaorta
Single sinus coronary arteries
Pericardial patch
I
Pulmonary artery
Coronary button
Neoaorta
Intramural LCA
RCA
II