



Long-Term Coronary Artery Complications Following the Arterial Switch Operation for Transposition of the Great Arteries—A Scoping Review

World Journal for Pediatric and
Congenital Heart Surgery
2025, Vol. 16(3) 402-408
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DOI: 10.1177/21501351241311280
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Abstract

Coronary artery complications following the arterial switch operation (ASO) for transposition of the great arteries have become increasingly relevant as those affected are exposed to the comorbidities of later years. A scoping review was undertaken to explore the incidence, clinical features, and management of the long-term coronary complications after the ASO. The selection criteria yielded 73 articles. They recorded few long-term coronary artery complications following the ASO, which were difficult to recognize as most affected patients' symptoms were absent or nonspecific. In patients with suspected coronary artery involvement, coronary angiography or computed tomography provided confirmation, with significant stenosis generally managed by percutaneous trans-catheter interventions.

Keywords

adult congenital heart, arterial switch operation, transposition the great vessels, coronary artery complications, outcomes

Submitted August 5, 2024; Accepted December 11, 2024.

Introduction

Transposition of the great arteries (TGA) is a common cause of cyanosis in the newborn.¹⁻³ It is a serious congenital abnormality which if left untreated has a significant morbidity and mortality arising from increasing hypoxia as the systemic and pulmonary circulations function side by side in parallel rather than in series.⁴ However, if diagnosed in a timely fashion and managed appropriately, the immediate and long-term outlooks are excellent.⁵ Many patients in skilled hands are diagnosed prenatally by a morphological scan at 20 to 22 weeks.⁶

In Australia, the incidence of TGA is 0.3 to 0.6 per 1,000 live births, accounting for 4% to 5% of all congenital heart disease (CHD).³ Prenatal diagnosis via detailed fetal echocardiogram has improved over the years,⁶⁻⁸ allowing for planned perinatal care at specialist centers. As part of the immediate management, neonates generally require a balloon atrial septostomy to improve systemic oxygenation.⁹ This catheter intervention is followed by an arterial switch operation (ASO) ideally within the first two weeks of life to preempt left ventricular atrophy following the drop in the pulmonary vascular resistance.¹⁰ With major improvements in surgical techniques, the ASO currently has a low operative mortality of 2%.¹¹ It has excellent long-term outcomes compared with the atrial switch operation¹² as the left ventricle assumes its role as the systemic ventricle. In addition, unlike the atrial diversion procedure, there is less atrial manipulation resulting in fewer atrial arrhythmias.¹³

A crucial part of the ASO involves the translocation of the coronary arteries from the previous aortic root to the pulmonary root, which becomes the neo-aortic root. The translocation can lead to

mechanical kinking, distortion, compression, and scarring of the coronary arteries, which can also be damaged during the surgery.¹⁴ Over the years, surgeons have mastered the technique, with successful outcomes even for those newborns with TGA and intramural coronary arteries.¹⁵ However, later complications of the coronary arteries may develop and include local stenosis and occlusions, still without clear recommendations as their early diagnosis and subsequent management.¹⁶

The medium and long-term complications of the coronary artery translocation in the ASO is less well documented, and become especially important in the light of an increasing population of successfully treated aging patients who are at risk of developing atherosclerotic (atheromatous) cardiovascular disease.¹⁷ This review aims to identify and synthesize the reported findings of the prevalence, clinical presentation, investigations, and management of coronary artery complications following the

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Abbreviations	
ASO	arterial switch operation
CHD	congenital heart disease
CTCA	computed tomography coronary angiography
PRISMA-ScR	Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews
TGA	transposition of the great arteries

ASO. It will not comment on other complications of the ASO which include dilation of the aortic root, development of neo-aortic valve incompetence, and the now less frequent pulmonary artery stenosis, currently being addressed at the Royal Children’s Hospital, Melbourne, which is studying the long-term ASO survivors.

Materials and Methods

A scoping review was undertaken based on the principles of Arksey and O’Malley,¹⁸ and which followed the scoping review checklist of the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR).¹⁹ This methodology involved four steps: identifying the research question, systematically searching for relevant studies, screening and selecting studies which met the inclusion criteria, and summarizing their findings. Ethics approval was not deemed necessary as only published data were reviewed.

Research question: What do we know about the medium and long-term coronary artery complications following the ASO for TGA?

Systematic search: A systematic search was done during the months of April and May 2024 using two databases: PubMed/Medline and Embase. All identified studies were transferred to EndNote for analysis.

Selection of studies: Studies were selected by the following inclusion criteria:

1. Studies that reported patient populations that underwent the ASO for TGA
2. Studies that addressed coronary artery complications such as coronary artery–related lesions including stenosis, occlusions, and/or involved interventions, the development of ischemia, including the morbidity and mortality that occurred 30 days or later following the ASO.

These exclusion criteria were applied:

1. Articles for which a full text was not available or not reported in the English language
2. Case reports, commentaries, editorials, and preprints

The first screening involved removing duplicate articles. Next was scanning the titles and abstracts to see if they fit with the inclusion criteria. Once selected, the article’s full text was reviewed, and a summary was extracted and analyzed¹⁹ (See Figure. 1).

Data extraction: A data extraction table was set up in an Excel 2010 spreadsheet with the following information included from each study: authors, year of publication, study location, objectives, methodology, participants, and findings. A summary of the findings are included within the body of the paper and in the tables.

Results

The initial search of two databases yielded a total of 205 articles. Duplicate articles were discarded (n = 30). Further articles were excluded after the title and abstract were studied (n = 115). Following review of the references, 13 additional articles were included, resulting in a total of 73 articles to be analyzed (Figure 2). Table S1 provides a summary of the 73 studies—the references, objectives, methods, participants, and results. A summary of the main findings is provided in Table 1.

Table 1. Summary of Main Findings.

Coronary artery complications	Main findings from articles studied
Prevalence	Depends on method used to investigate, generally 3% to 11% though studies involving CT coronary angiography and intravascular ultrasound have found higher prevalences
Clinical presentation	Nonspecific symptoms such as mild chest pain or no symptoms due to surgical denervation and manipulation of the coronary arteries
Investigations	Multimodal imaging is required to adequately investigate complications: CT coronary angiography may be performed to assess coronary artery anatomy and guide the need for selective coronary angiography, stress echocardiography and cardiac magnetic resonance imaging may be useful to detect issues with myocardial perfusion; nuclear scintigraphy and cross-sectional echocardiography are less useful.
Management	If complications are found, patients should be managed with the assistance of an adult interventional cardiologist as these patients may be candidates for percutaneous coronary intervention or less commonly, internal thoracic artery coronary bypass. Preventative health measures such as aggressive screening and management of cardiovascular risk factors should be instituted and include obesity, smoking, systemic hypertension, a sedentary lifestyle and hypercholesterolemia.

Abbreviation: CT, computed tomography.

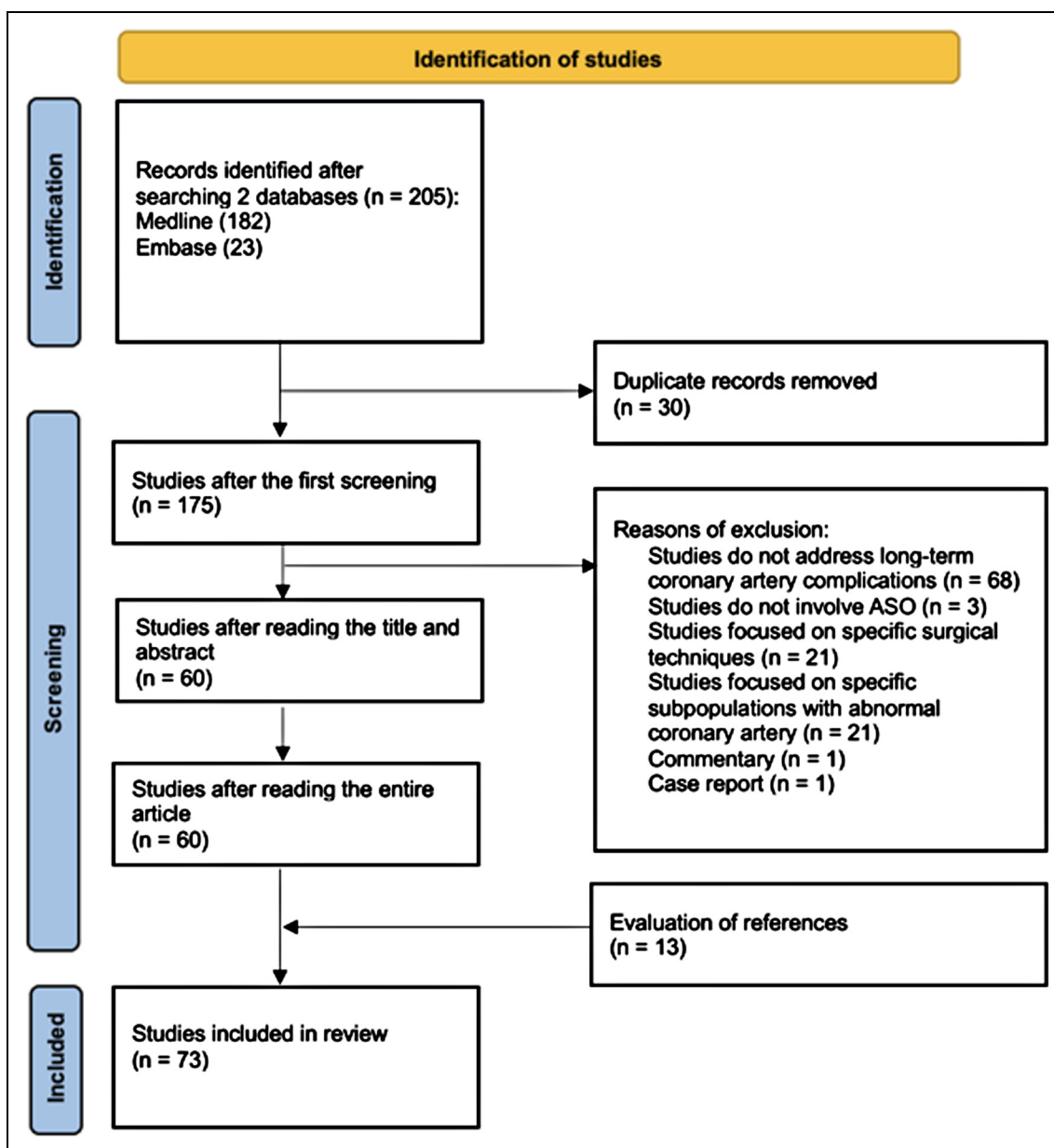


Figure 1. Study flowchart. Adapted from Page et al¹⁹.

Medium to Long-Term Coronary Artery Complications

The prevalence of late coronary artery abnormalities in large cohort retrospective studies is found to be between 3% and 11%.²⁰ This prevalence may be an underestimate as most patients do not routinely undergo diagnostic coronary angiography. Indeed, studies involving cardiac imaging of asymptomatic ASO patients found a much higher prevalence. One study observed that 43% of their patients who underwent coronary angiography had abnormal coronary findings.²¹ A further study utilizing intravascular ultrasound noted 89% of their patients had some degree of intimal thickening in at least one major coronary artery.²² This prevalence was significantly higher when compared with an intravascular ultrasound study of “normal hearts” where significant intimal thickening

suggestive of atherosclerosis was found in only 17% of those under 20 years and 37% in those who were 20 to 29 years of age.²³ Additionally, studies comparing adults with CHD which included patients with TGA with those without CHD, have found the former group had a 1.6-fold increased risk of myocardial infarction,²⁴ and double the risk of comorbidities such as coronary artery disease.²⁵ These findings are especially important for the adults who have had an ASO as they age, where the shift toward acquired heart disease such as atherosclerotic cardiovascular disease becomes increasingly relevant.¹⁷

Symptoms of Coronary Artery Involvement

Arterial switch operation patients with coronary artery complications often have nonspecific or no symptoms.²⁶ In part, these

observations may be due to surgical denervation of the coronary arteries during their translocation in the ASO.²⁷ Studies have reported a significant proportion of patients who are asymptomatic but still found to have coronary artery obstruction via computed tomography (CT) or direct coronary angiography.²⁸ Others have noted patients with mild chest pain during exertion to be indicative of myocardial ischemia.¹⁶ These observations add to the difficulty of diagnosing coronary artery obstruction and ischemic heart disease based on the history, supporting the need for routine coronary artery evaluation.

Investigation of Coronary Artery Complications

Current American and European guidelines for the management of adult patients post ASO-TGA recommend that investigation and management of suspected coronary abnormalities should be symptom driven.^{29,30} However, symptoms as noted above are often nonspecific or absent. Various imaging modalities are used to investigate coronary artery complications and are summarized in Table 2.

Noninvasive investigations include a simple electrocardiogram (ECG), an exercise stress test, echocardiography extending to a stress echocardiogram, and myocardial nuclear perfusion scans. However, studies have documented that CT coronary angiography (CTCA) or direct coronary angiography yield more accurate results.^{31,32} Stress echocardiography results were found to concur with stress myocardial perfusion studies,³³ CTCA as well as direct coronary angiography.^{34,35} Out of the 73 papers reviewed, 50 investigated the prevalence of coronary artery lesions following the ASO and specified the imaging methods used. The majority of these studies utilized CTCA or direct coronary angiography as the confirmatory method of diagnosis. A third of these studies involved a

combination of imaging methods. Very few studies utilized nuclear scintigraphy, cardiac magnetic resonance imaging, and/or coronary intravascular ultrasound as their only method of investigation. The overall consensus from these studies suggested echocardiograms and/or myocardial perfusion studies as routine investigations for coronary artery involvement followed by CTCA and/or direct coronary angiography in select patients as the gold diagnostic standard.³⁶ However, further study is required to provide clear guidelines as to which patients require coronary angiography. That is in addition to determining what tests should be done routinely as well as their timing in a generally asymptomatic population.

Management of Coronary Artery Complications

Coronary artery interventions. The input of an adult coronary interventional cardiologist is generally required in the management of medium to long-term coronary artery complications following the ASO. They have the experience in understanding the anatomy of the coronary arteries, the significance of any abnormality, and the outcome of the various revascularization procedures available.²⁶ Angiography will determine the severity of coronary artery stenosis and the presence or absence of collateral blood flow to determine if coronary intervention is necessary.^{28,37} Percutaneous coronary interventions can be performed in most cases with good results of up to 95% reduction in the degree of stenosis five years after intervention.¹⁴ Coronary artery bypass surgery may occasionally be necessary in 2% to 9% of patients.^{38,39} In general overall, freedom from coronary artery intervention at 20 years after the ASO ranges from 75% to 99%, depending on the reporting center.^{5,40–42}

Table 2. Summary of Investigations for Coronary Artery Complications.

Imaging modality	Indications	Benefits	Limitations
Cross-sectional transthoracic echocardiogram	Screening test to review cardiac anatomy and function and to recognize obvious myocardial dysfunction	- Noninvasive - Inexpensive	- Acoustic windows may limit imaging of coronary arteries - Insufficient to diagnose coronary artery complications
Stress echocardiogram	Detect problems with myocardial perfusion	Assesses myocardial perfusion and contractile reserve	Image quality especially during exercise may be inadequate for diagnosis
Intravascular ultrasound	Assess the walls of the coronary arteries in vivo	- Allows for transmural imaging - Generally correlated with angiography findings	- Invasive - May cause transient coronary spasm
Cardiac magnetic resonance imaging	- Assess cardiac anatomy and function - Assess myocardial perfusion - Image proximal coronary arteries	- Noninvasive - Radiation-free - Image quality not limited by patient size or previous surgery	- Long cycle times - Implanted metallic clips or devices may cause image artifact
Nuclear imaging	May be used as an adjunct to detect myocardial perfusion issues	SPECT can be combined with maximal exercise to assess perfusion with high stress	Exposure to ionizing radiation
CT coronary angiography	- Coronary artery imaging - To guide indication for direct coronary angiography	- Short acquisition times - Detailed image quality	- Radiation involved - Intravenous contrast needed
Direct coronary angiography	Evaluate coronary artery patency	- Gold standard for diagnosis of coronary artery lesions - Detailed image quality	- Invasive - May be difficult to perform because of altered site of ostia

Abbreviation: CT, computed tomography; SPECT, single photon emission computer tomography.

Cardiovascular risk factors. The development of atherosclerotic cardiovascular disease increases with the increasing age of the ASO survivors. It is recommended that this at-risk population undergo more intense screening and management of modifiable cardiovascular risk factors, including diet, physical activity, tobacco smoking, hypertension, obesity, and dyslipidemia.⁴³ In particular, proactive prevention of the dyslipidemic atherogenic triad of elevated triglycerides, low high-density lipoprotein cholesterol, and high low-density lipoprotein cholesterol can help prevent the development and/or reduce the risk of atherosclerotic cardiovascular disease.⁴⁴ Should a statin be prescribed routinely for all ASO patients remains unclear.

Comment

This study used a structured scoping review methodology to ensure a systematic search of the literature. It involved the analysis of a large number of relevant articles with results from the first successful ASO in 1975 to the present. It attempted to synthesize emerging evidence pertaining to an evolving and now aging population of adult ASO-TGA survivors.

Limitations include a lack of randomized control studies involving TGA patients following ASO due to their relatively small numbers, further burdened by ethical considerations.⁴⁵ There is also limited research on the long-term outcomes of the ASO for TGA beyond 20 years as the numbers to date are few but continue to grow.⁴⁶

Our Current Practice

With the absence of clear guidelines, our patients, if well, have yearly clinical reviews with a routine ECG, an echocardiogram together with seeking out and managing cardiovascular risk factors such as obesity, hypertension, and hypercholesterolemia. Any suggestion of possible ischemic symptoms including nonspecific chest pain warrant a stress echocardiogram and/or exercise stress test, generally followed by a CTCA. If the latter shows any abnormalities, the advice of an adult interventional cardiologist is obtained to determine the need for percutaneous and/or surgical coronary artery intervention. Once ischemia develops, our approach to revascularization is in line with international guidelines for the management of atherosclerotic cardiovascular disease, which recommends coronary revascularization in the presence of significant ischemia. Treatment decisions are patient centered, with an individualized approach that considers features such as collateralization or absence of ischemia and patient preferences and goals.

Suggested Future Research

Further study remains paramount to decide what investigations are required, whether routinely or following the development of symptoms so as to guide the need for more invasive investigations such as a CTCA and/or selective coronary angiography. In addition should such affected patients be treated differently from the

general adult population who develop coronary artery disease, and should there be a lower threshold for interventions and/or medication such as a statin and antihypertensive treatment? The answers to these questions will further aid the long-term management of our patients.

Conclusions

Medium to long-term coronary artery complications following the ASO for TGA may have significant health implications for the aging TGA population. This review found that such complications are infrequent, and difficult to diagnose clinically as many of the patients have nonspecific or no symptoms. A plethora of investigations are available but with limited guidelines as to what is best and whether one or more should be done routinely or in selected patients. The results of any interventions are also limited as the numbers affected are small. In addition, the full impact of atherosclerosis with increasing age of this at-risk population still needs to be determined—a study in progress.

Acknowledgments

Ms Poh Chua, librarian at the Royal Children's Hospital, Melbourne, assisted in the search strategy.

Authors' Statement

RSL researched and summarized the studies arising from this review. She wrote up the first draft of this paper, addressed any issues arising from discussion between the authors, and revised this paper accordingly. JL reviewed the manuscript and made pertinent comments related to the investigations and management of coronary artery complications in the adult population, a major component of his practice. SM conceived the study and guided its development, design, and progress. He critically reviewed the multiple drafts and helped prepare the final submission.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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Supplemental Material

Supplemental material for this article is available online.

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