Twenty-Year Outcome of Anomalous Origin of Left Coronary Artery From Pulmonary Artery: Management of Mitral Regurgitation

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Background. This study is a single-center experience with surgical repair of anomalous origin of left coronary artery from pulmonary artery (ALCAPA) with focus on the management of associated mitral regurgitation (MR).

Methods. We performed a retrospective analysis of cases presenting to a quaternary referral center between November 1990 and October 2011.

Results. In all, 25 patients (18 female) presented with a diagnosis of ALCAPA at a median age of 5 months (range, 1.5 to 102). Twenty-one patients (84%) had moderate to severe impairment of left ventricular function with median fractional shortening of 14% (range, 2% to 33%), and 19 patients (76%) had moderate to severe MR. Surgery was performed with direct coronary reimplantation in 16 patients (64%) and intrapulmonary tunnel (Takeuchi repair) in 9 (36%). Four patients had mitral valve repair at time of surgery, all for structural anomalies. Functional MR with a structurally normal mitral valve was not repaired. The median duration of postoperative follow-up was 93 months (range, 9 to 240). There were no early or late deaths, and no patient required mechanical support. At last follow-up, 24 of 25 patients were asymptomatic; the left ventricular function was normal in 22 patients. Moderate MR was present in 4 patients. There was significant improvement in left ventricular function and MR (p < 0.01) during follow-up.

Conclusions. Surgical repair of ALCAPA has good long-term results with low mortality and reintervention rates. The majority of MR is functional and will improve with reperfusion, but structural mitral valve abnormalities should be repaired at the time of surgery.


Anomalous origin of the left coronary artery from the pulmonary artery (ALCAPA) is a rare congenital cardiac lesion with an incidence of 1 in 300,000 live births [1]. It constitutes 0.25% to 0.5% of congenital heart disease [2]. It causes myocardial ischemia with left ventricular (LV) dysfunction and mitral regurgitation (MR). If untreated, survival beyond infancy is rare [2, 3]. The first clinical description of ALCAPA was reported by Edward Bland, Paul Dudley White, and Joseph Garland in 1933, so the anomaly is also called Bland-White-Garland syndrome [4]. ALCAPA was classified into infantile (early presentation) and adult (late presentation) types based on the age and mode of presentation [5]. Neonates are usually asymptomatic, as high pulmonary arterial pressure in the neonatal period maintains the antegrade flow into the left coronary artery (LCA). As the pulmonary vascular resistance drops, there is retrograde flow of blood from the LCA into the pulmonary artery, resulting in coronary steal and myocardial ischemia. If there is insufficient collateral blood supply to the left ventricle, patients present during early infancy with cardiac failure. The patients with extensive collateral blood supply can survive into adulthood. However, these patients are likely to present in later life with arrhythmias, chest pain, cardiac failure, and sudden death.

Surgical repair for establishing a two coronary artery system has evolved over a period of time with direct implantation being now the procedure of choice [9–15]. The early presentation group are usually patients in poor condition with impaired LV function. The late presentation group have preserved LV function with MR. Concomitant mitral valve (MV) surgery with ALCAPA repair has been the area of debate because the majority of MR is functional with a structurally normal MV. There are limited studies describing the long-term outcomes of ALCAPA [6–8, 16, 17], and the importance of addressing the MR remains unclear.
The purpose of this study was to evaluate a single pediatric cardiac surgical center’s experience in the diagnosis, management, and long-term outcome of ALCAPA with focus on the management of MR.

Material and Methods

A retrospective case record review was made of all patients with the diagnosis of ALCAPA presenting to our department over the period from November 1990 to October 2011 as identified by our departmental database. The study was reviewed and approved by the local research and clinical audit departments. The need for individual consent was waived.

Patient Demographics

Twenty-five patients (7 male and 18 female) with a diagnosis of ALCAPA were identified during the study period. The median age at presentation was 5 months (range, 1.5 to 102). Sixteen patients (64%) presented in infancy (early presentation group), and 9 (36%) presented after 1 year of life (late presentation group). Three patients presented with an asymptomatic murmur, 2 patients presented with episodes of screaming and sweating with feeds, and 20 patients presented with failure to thrive and clinical features of cardiac failure.

Echocardiography with color Doppler was used to make the diagnosis of ALCAPA and associated lesions. The LV systolic function was assessed and expressed as fractional shortening (FS). The degree of MR was expressed as mild, moderate, or severe on color Doppler. LV systolic function at the time of presentation (FS) was compared with the late presentation group with a median FS of 10% (range, 5% to 33%) when compared with the late presentation group with a median FS of 26% (range, 18% to 31%). There was no significant difference of FS between the groups. The median FS of 14% (range, 2% to 33%) was significantly lower compared with the early presentation group with a median FS of 26% (range, 18% to 31%).

Surgery

Surgery was performed for all 25 patients immediately after confirming the diagnosis of ALCAPA. The median age of surgery was 5.5 months (range, 1.80 to 102), with a median weight of 5.81 kg (range, 3.99 to 30.8 kg). Sixteen patients (64%) had direct implantation of LCA into aorta, and 9 patients (36%) had intrapulmonary tunnel (Takeuchi procedure). The patients included a 20-month-old girl who was diagnosed as having ALCAPA at 10 months of age and had a left internal mammary graft placed to the LCA in a different cardiac center, as the ostium of LCA was thought to be too far away to be reimplanted into the aorta. This patient continued to have moderate to severe MR, and cardiac catheter study had shown blocked internal mammary graft. She successfully underwent a Takeuchi procedure and MV cleft repair in our institution.

Five patients had associated MV structural abnormalities (three MV clefts, one MV prolapse, and one dysplastic double orifice MV), 1 patient had ventricular septal defect, 1 patient had atrial septal defect, and 1 patient had significant branch pulmonary artery stenosis. All the patients who had structural MV problems were in the late presentation group. Four patients had MV repair (all for structural anomalies), and 1 patient had pulmonary arterioplasty at the time of first surgery. Patients with functional MR but a structurally normal MV did not undergo any attempt at MV repair. The coronary anatomy of patients was as follows: arising from the left and posterior sinus of the main pulmonary artery (MPA) in 15 (60%; Figs 1A, 1B); left and lateral side of MPA in 8 (32%; Figs 1C, 1D); at the junction of the MPA and right pulmonary artery in 1 (4%; Figs 1E, 1F); and high up laterally in the ascending part of the MPA in 1 (4%).

The median bypass time was 94 minutes (range, 38 to 351), and the median cross-clamp time was 50 minutes (range, 33 to 97). There were no operative deaths. The median bypass time in the direct implantation group was 92 minutes (range, 38 to 351), and in the Takeuchi procedure group, it was 95 minutes (range, 64 to 141; \( p = 0.28 \)). The median cross-clamp time in the direct implantation group was 54 minutes (range, 33 to 88), and in the Takeuchi procedure group, it was 47 minutes (range, 38 to 97; \( p = 0.45 \)).

The data on follow-up with last clinical and echocardiographic evaluation and any further surgical or catheter intervention were noted for the purpose of study. The data were analyzed with the Mann-Whitney U test, Fisher’s exact test, and \( \chi^2 \) test with Yates’ correction for the statistical significance of variables. A \( p \) value of less than 0.05 was taken as the level of significance. Kaplan-Meier curves were used to analyze the reintervention rates.

Results

Nineteen of 25 patients with a median age of 4.5 months (range, 1.5 to 102) were diagnosed on initial presentation. Six of 25 patients (24%) with a median age of 40 months (range, 15 to 66) had a delay in diagnosis by 9 to 34 months (median 11.5). The latter were followed up for mitral regurgitation in 5 and presumed dilated cardiomyopathy (DCM) in 1.

At the time of presentation, 21 patients had moderate to severe impairment of LV systolic function with a median FS of 14% (range, 2% to 33%), and 19 patients (76%) had moderate to severe MR (Fig 2). The early presentation group of patients, however, were much sicker with poor LV systolic function at the time of presentation (\( p < 0.001 \)) and a median FS of 10% (range, 5% to 33%) when compared with the late presentation group with a median FS of 26% (range, 18% to 31%).
significant difference in the severity of MR between the early and late presentation groups.

Cardiac catheterization was undertaken in 13 of 25 of these patients to confirm the diagnosis. All patients (9 of 9) in the late presentation group needed catheterization as compared with 4 of 16 in the early presentation group ($p = 0.001$).

Early Postoperative Results

The median duration of intensive care unit stay was 6 days (range, 1 to 22). The median duration of postoperative stay in the hospital was 12 days (range, 6 to 87), with the early presentation group staying for a median of 18 days (range, 6 to 41) compared with patients in the late presentation group staying for a median of 8 days (range, 6 to 87; $p < 0.01$). None of our patients required a ventricular assist device or extracorporeal membrane oxygenation support on presentation or postoperatively. All 25 patients were discharged home after surgery.

Follow-Up

The median duration of postoperative follow-up was 93 months (range, 9 to 240). All patients are alive at the time of most recent follow-up, with 100% long-term survival. At the time of most recent follow-up, 24 of 25 patients were completely asymptomatic, and a 15-year-old patient had mild chest pain, 7 years after the surgery, and myocardial perfusion scan showed mild reversible perfusion defect in the anterior wall of the left ventricle on the stress images and normal appearance on the resting study. The LV systolic function was normal in 22 patients, mildly impaired in 2 patients, and moderately impaired in 1 patient with a median FS of 35% (range, 31% to 43%). There was significant improvement ($p < 0.001$) in the FS at most recent follow-up when compared with the FS at the time of presentation (Fig 2A).

At the recent follow-up, significant MR was present in only 4 patients. The improvement in MR after the ALCAPA surgery was significant ($p < 0.001$) when compared with the degree of MR at the time of presentation (Fig 2B). Of 19 patients who had moderate to severe MR at the time of presentation, 4 had MV repair. All these 4 patients had moderate or severe MR with FS of 25% to 32% and associated structural MV problems (MV cleft in 2

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**Fig 1.** (A, B) The left coronary artery (LCA) arising from the left and posterior sinus of the main pulmonary artery (MPA) in 15 patients (60%). (C, D) The LCA arising from left and lateral side of the MPA in 8 patients (32%). (E, F) The LCA arising at the junction of the MPA and right pulmonary artery in 1 patient.

**Fig 2.** (A) Horizontal axis shows duration of follow-up, with time of presentation as 0; vertical axis shows fractional shortening at time of presentation and at time of most recent follow-up. (B) Horizontal axis shows duration of follow-up, with time of presentation as 0; vertical axis shows severity of mitral regurgitation at time of presentation and at time of most recent follow-up.
patients, MV prolapse in 1 patient, and dysplastic double orifice MV in 1 patient). Two of these 4 patients had residual moderate MV regurgitation at the time of most recent follow-up. Interestingly, 1 patient with a structural valve problem who was not treated at the time of ALCAPA repair came back with severe MR and had MV repair at the time of reintervention (see below). This patient had moderate MR at the time of most recent follow-up. Of 14 ALCAPA patients with moderate or severe MR who did not have any MV repair (ie, “functional MR”), only 1 patient had moderate MR at the time of most recent follow-up, and the postoperative follow-up period for this patient is only 9 months. Figure 3 describes the time course of progression of MR in 21 patients (the remaining 4 patients did not have enough data to prepare a line diagram). Nine patients are receiving angiotensin-converting enzyme inhibitors, and 5 patients had exercise electrocardiograms, which were normal at the time of recent follow-up.

Reinterventions

One patient who had Takeuchi procedure had balloon dilation of the pulmonary trunk, 2 patients with Takeuchi procedure and 1 patient in direct implantation group had stenosis at the origin of the LCA, which were dealt with surgically. All the 3 patients who had stenosis of LCA origin were noted to have poor LV function in the echocardiogram after the initial surgery for ALCAPA, and the LCA origin stenosis was confirmed by cardiac catheterization. One patient needed MV intervention after the first surgery. This patient initially had direct implantation of the coronary artery as initial surgery and continued to have LV dysfunction and severe MR. Cardiac catheterization confirmed stenosis of LCA origin, which was repaired surgically. Intraoperatively, there was a cleft in the anterior MV leaflet, which was repaired. In our series, the patients with Takeuchi tunnel (3 of 9) tended to have more reinterventions when compared with the direct implantation group (1 of 16), but the difference is not statistically significant ($p = 0.65$; Figs 4 and 5).

Comment

Diagnosis of ALCAPA

The majority of infants with ALCAPA are diagnosed on initial presentation with symptoms of heart failure and echocardiography demonstrating impaired LV systolic function with flow reversal in LCA or diastolic flow seen in the MPA. They can be misdiagnosed as DCM [6]. We had 1 infant in our series who was misdiagnosed as having DCM.

In the older age group, some of the children were asymptomatic and were referred for a murmur. The diagnosis was overlooked with findings of MR seen on the
echocardiogram. As in other series reported in literature [6], we noted a delay in recognizing 5 cases that were followed up in the clinic with MR with structural MV problems like MV cleft, MV prolapse, or dysplastic double orifice MV. One of them also had MV repair for severe MR before the diagnosis of ALCAPA was made. In most of the patients who had delayed diagnosis, the visualization of prominent intercoronary collaterals in the ventricular septum on color Doppler echocardiography raised the suspicion of ALCAPA, which was confirmed later by coronary angiogram. Abnormal color Doppler signals in the ventricular septum representing intercoronary collaterals as a marker of ALCAPA is described in the literature [20]. Based on our experience, we also believe that this is an important sign that can help in diagnosing this challenging problem by echocardiography. In our patients, we did not evaluate the status of commissural alignment of the aorta and pulmonary valves, but it might help in the planning of surgery as direct transfer of the LCA may be more difficult in cases with commissural malalignment.

**Surgical Results**

The surgery for ALCAPA has evolved over time from the initial ligation of the LCA at the pulmonary artery origin by Sabiston and associates [9] in 1960. Later, different surgeries were described, such as placement of a Dacron interposition graft between the aorta and LCA and other bypass procedures using saphenous vein [10–13]. In 1974, Niches and coworkers [14] first described the direct reimplantation (translocation) of LCA into aorta with good results. At present, the direct translocation of LCA into aorta is universally accepted as the surgery of choice. In cases where direct reimplantation of LCA is not possible, Takeuchi and coworkers [15] described a surgery involving creation of an aortopulmonary window and intrapulmonary tunnel connecting the aorta to the LCA origin. In our center, there was a change in trend to the preference of surgery over time. Of a total of 25 patients who had surgical repair for ALCAPA in our center, 12 patients had surgery done from 1990 to 1999; 7 of 12 had the Takeuchi procedure, and 5 of 12 had direct reimplantation of LCA into aorta. Of 13 patients who had surgery from 2000 to 2011, 2 of 13 had the Takeuchi procedure and 11 of 13 had direct reimplantation of LCA (p = 0.04). As in other large series [16], direct implantation of LCA to aorta is very much the preferred technique at our institute. The only indication for the Takeuchi procedure would be if the LCA is arising at the extreme left lateral position on the MPA.

**Management of Mitral Regurgitation**

The management of associated MR at the time of initial surgery is controversial. In most cases of ALCAPA, the MR is due to MV annular dilation secondary to dilation of ischemic LV and ischemic dysfunction of papillary muscles. Some centers advocate routine surgical repair of the MV at the time of initial repair [7]. Many centers advocate MV repair only in selected cases as the coronary revascularization after the surgery should improve the LV function and decrease the MV annulus size, thereby decreasing the severity of MR [6, 8, 16, 18]. A recent paper by Alexi-Meskishvili and colleagues [17] suggested...
doing MV surgery in patients only with severe MR, especially in older children. However, in some cases of ALCAPA presenting with severe MR but preserved LV function, the mechanism of MR may be mainly due to ischemic damage of papillary muscle rather than MV annular dilation [6, 8, 16, 18]. In some cases, MR may be due to associated structural MV lesions, and one notable finding from this study is the relatively common occurrence of structural anomalies (5 of 25 patients [20%]), particularly in the late presenting group. We described previously 2 cases of cleft MV in association with ALCAPA that were treated by coronary transfer and MV repair [21].

Our policy has been only to repair structurally abnormal MVs, and not to repair functional MR in the belief that this will improve after revascularization. In this series, 19 of 25 patients (76%) had moderate or severe MR at the time of presentation. Our policy of selective MV repair was supported by our results. Of 14 ALCAPA patients with moderate or severe MR who did not have any MV repair, only 1 patient had moderate MR at the time of most recent follow-up. The postoperative follow-up period for this patient is only 9 months. The remainder of the patients had mild or no MR at the time of most recent follow-up. Only 1 patient needed MV repair during the follow-up, and this patient was noted to have a cleft in the anterior MV leaflet. These findings would suggest that ALCAPA patients with significant MR need very careful preoperative assessment of the MV to rule out any structural anomalies, especially in older patients with good LV function. The MV repair should be performed in all cases with structural MV problems. Associated structural MV problems in ALCAPA patients are also not uncommon, as in our series we noted this association in 5 of 25 patients (20%). We suggest careful echocardiographic evaluation of MV before the surgery as it plays an important role in planning the surgery.

Recovery of Myocardium
As suggested by previous studies in the literature [6–8, 16, 17], we also noticed excellent spontaneous recovery of cardiac function and MR in our group of patients after ALCAPA repair (Fig. 2). Chronic hypoperfusion of LV myocardium preoperatively results in a variable degree of LV dysfunction. Revascularization after surgery results in recovery of LV function. Myocardial histologic study of ALCAPA patients by Shivalkar and associates [22] has shown viable myocytes in the myocardium with some morphologic alterations without any degenerative characteristics that might represent structural adaptation to chronic ischemia. All the patients with the histologic changes preoperatively recovered well after the surgical correction of ALCAPA and showed normal myocardial function in the postoperative echocardiographic studies. In spite of excellent recovery of LV function after revascularization, a significant number of patients (57%) had myocardial scars on magnetic resonance imaging examination during follow-up in a recent study [17]. Some studies in the literature reported the usefulness of ventricular assist devices or extracorporeal membrane oxygenation in the immediate postoperative period in selected cases [6, 8, 16, 17, 19]. In our series, none of the patients required mechanical support before the surgery or in the postoperative period in spite of severe preoperative LV dysfunction and severe MR. We do, however, acknowledge that if our threshold for using extracorporeal membrane oxygenation support was lower, the sicker patients may have benefitted with potentially a shorter intensive care unit stay. However, the long-term results of LV function recovery supports our practice.

In conclusion, our study demonstrates the excellent short-term and long-term survival after the surgical correction of ALCAPA, with near complete recovery of LV function. Functional MR due to severe LV dysfunction improves significantly after coronary revascularization without the need of MV repair, but structural MV problems are relatively common and should be addressed at the time of initial revascularization surgery if there is significant MR. A high index of suspicion is required in evaluating children with DCM and isolated MR to prevent delay in diagnosis.

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References

ABTS Requirements for the 10-Year Milestone for Maintenance of Certification

Diplomates of the American Board of Thoracic Surgery (ABTS) who plan to participate in the 10-Year Milestone for the Maintenance of Certification (MOC) process as Certified-Active must hold an unrestricted medical license in the locale of their practice and privileges in a hospital accredited by the JCAHO (or other organization recognized by the ABTS). In addition, a valid ABTS certificate is an absolute requirement for entrance into the MOC process. If your certificate has expired, the only pathway for renewal of a certificate is to take and pass the Part I (written) and the Part II (oral) certifying examinations.

The CME requirements are 150 Category I credits over a five-year period. At least half of these CME hours need to be in the broad area of thoracic surgery. Category II credits are not accepted. Interested individuals should refer to the Board’s website (www.abts.org) for a complete description of acceptable CME credits.

Diplomates will be required to take and pass a secure exam after their application has been approved. Taking SESATS in lieu of the secured exam is not an option. The secured exam is administered over a two-week period in September of every year at Pearson Vue Testing Centers, which are located nationwide. Diplomates will have the opportunity to select the day and location of their exam. For the dates of the next MOC exam, visit the Board’s web site at www.abts.org.

Starting on July 1, 2014, the ABTS will require its Diplomates to participate in an outcomes database as fulfillment of Part IV (Performance in Practice) for the 10-year Milestone of Maintenance of Certification (MOC). For a list of approved outcomes databases or for more information on how to have a database approved by the Board, visit the Board’s website at www.abts.org. Participation in the Professional Portfolio will no longer be accepted as fulfillment of MOC Part IV after July 1, 2014.

Diplomates may apply for MOC in the year their certificate expires or, if they wish to do so, they may apply up to two years before it expires. However, the new certificate will be dated 10 years from the date of expiration of their original certificate or most recent MOC certificate. In other words, going through the MOC process early does not alter the 10-year validation. Diplomates certified prior to 1976 (the year that time-limited certificates were initiated) are also required to participate in MOC if they wish to maintain valid certificates.

The deadline for submitting an application for 10-year Milestone of MOC is March 15 of every year. Information outlining the rules, requirements, and dates for MOC in thoracic surgery is available on the Board’s website at www.abts.org. For additional information, please contact the American Board of Thoracic Surgery, 633 N St. Clair St, Ste 2320, Chicago, IL 60611; telephone (312) 202-5900; fax (312) 202-5960; e-mail: info@abts.org.