Diagnosis and prognosis of anomalous origin of the left coronary artery from the pulmonary artery

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ABSTRACT

INTRODUCTION: Anomalous origin of the left coronary artery from the pulmonary artery (ALCAPA) is an uncommon congenital heart abnormality. The aim of this study was to describe a single-centre experience with surgical repair of this condition.

METHODS: We performed a retrospective analysis of cases from February 2004 to January 2014.

RESULTS: Ten patients presented with the diagnosis of ALCAPA. A total of seven infants and three adults underwent surgical repair in our Department of Thoracic Surgery, Rigshospitalet, Denmark. The seven infants presented with symptoms of heart failure: dyspnoea, sweating or failure to thrive; two adults were asymptomatic and one adult presented with cardiac arrest. Six infants had moderate to severe mitral valve regurgitation and five of these patients had preoperative moderate to severely reduced left ventricular function. Nine patients underwent surgical repair by re-implantation of the left coronary artery to the aorta and one underwent surgical repair ad modus Takeuchi (an aortopulmonary window). None of the patients underwent re-operation and none died.

CONCLUSION: All ten patients survived with recovery of left ventricular function within 12 months. An early diagnosis and prompt surgical intervention is warranted in the treatment of ALCAPA.

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Anomalous origin of the left coronary artery (LCA) from the pulmonary artery (abnormal left coronary artery from pulmonary artery = ALCAPA) or Blade-White-Garland syndrome is a rare, but serious congenital cardiac malformation (**Figure 1**A and B). ALCAPA represents one of the most common causes of myocardial ischaemia and infarction in children. If left untreated, the mortality rate is up to 90% within the first year of life. ALCAPA accounts for 0.25-0.50% of all congenital heart diseases [1]. ALCAPA can be classified as infantile or adult presentation [1-6]. At birth, neonates are largely asymptomatic due to the high pulmonary arterial pressure in the neonatal period, and thereby sufficient perfusion to the left coronary system, although with a lower saturation. Symptoms arise within the first months of life when the

pulmonary vascular resistance decreases. This results in a reduced pulmonary artery pressure leading to retrograde flow from the LCA to the pulmonary artery which, in turn, leads to coronary steal and myocardial ischaemia [1-7]. If the collateral blood supply from the right coronary artery (RCA) to the left ventricular myocardium is insufficient, the patient will present with symptoms of heart failure, angina, left ventricular dysfunction and mitral valve regurgitation (MR).

If the patient has adequate collateral blood supply from the RCA, the patient may survive into adolescence or adulthood and present with dyspnoea, arrhythmias, chest pain, cardiac failure or sudden death [5, 8].

Prompt surgical intervention is the treatment of choice in children and adults with ALCAPA. In children, the aim is to re-establish coronary perfusion to salvage the myocardium and allow recovery of left ventricular function as soon as possible. In adults, the aim is to reduce the risk of malignant arrhythmias or sudden death [5, 8].

Today, the standard surgical method is to mobilise the LCA from the pulmonary artery and re-implant it into the aorta re-establishing a dual coronary system (Figure 1C) [9]. In cases in which re-implantation is not feasible, alternative techniques such as creation of an intrapulmonary baffle (the Takeuchi technique) have been used. This procedure uses a rolled flap of the main pulmonary artery (MPA) wall and an aorto-pulmonary window to create an intrapulmonary tunnel to connect the anomalous ostium to the aorta through the MPA itself (Figure 1D).

The aim of this study was to present cases of ALCAPA in our unit over a ten-year period from 2004 to 2014 including clinical findings, the surgical interventions, outcome and survival.

METHODS

Data were collected retrospectively by reviewing clinical records and the departmental database. Left ventricular function was expressed as ejection fraction (EF) as assessed by echocardiography. The degree of MR was expressed as mild, moderate or severe (grade I, II or III).

Trial registration: none.

The anatomy of the normal coronary arteries and of the anatomy in the ALCAPA. **A.** The normal anatomy of the coronary arteries, note the route of the LCA behind the MPA. Arrows indicate the direction of flow in the coronary arteries. **B.** Typical patho-anatomy of ALCAPA with the LCA arising from the MPA from the left most situated sinus. **C.** Re-implantation of the ALCAPA from the MPA to the aorta. **D.** Repair with the Takeuchi technique. Using a rolled flap of MPA-wall and an aorto-pulmonary window, an intrapulmonary tunnel is created to connect the anomalous ostium to the aorta through the MPA itself. The dotted line/arrow shows the direction of blood flow from the aorto-pulmonary window through the baffle to the anomalous coronary artery.
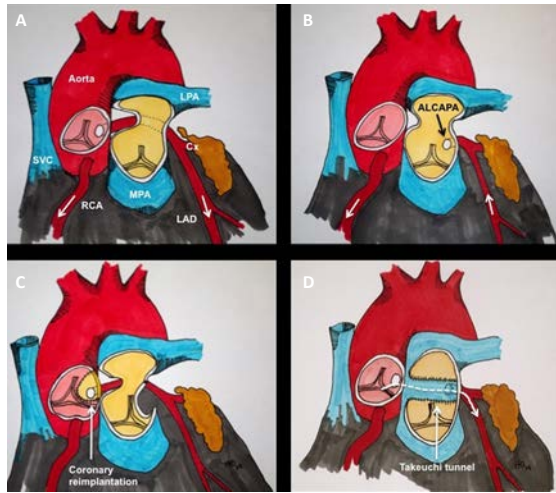
ALCAPA = abnormal left coronary artery from pulmonary artery; Cx = circumflex artery; LAD = left anterior descending artery; LCA = left coronary artery; LPA = left pulmonary artery; MPA = main pulmonary artery; RCA = right coronary artery; SVC = superior vena cava.

RESULTS

From February 2004 to January 2014, seven infants (two boys and five girls) and three adults (all female) aged from two months to 39 years had a diagnosis of ALCAPA in the Department of Thoracic Surgery, Rigshospitalet, Copenhagen, Denmark (**Table 1**).

The majority (70%) of ALCAPA patients in this cohort presented before or around six months of age with symptoms and signs of congestive heart failure (Table 1). Six of the seven patients presenting in infancy with isolated ALCAPA had severely depressed left ventricular systolic function, whereas the one patient with ALCAPA and ventricular septal defect (VSD) had preserved left ventricular function. Three of the six electrocardiograms (ECG) available for review were abnormal and suggestive of myocardial ischemia. Of particular note, in two patients (#6, #7 in Table 1), the ALCAPA diagnosis was initially overlooked despite repeated clinical and echocardiographical evaluation by different cardiologists. These two patients were referred for surgery because of VSD and MR, respectively, and the ALCAPA diagnosis was made perioperatively. Only two patients presented in adulthood; one with exertional dyspnoea at high alti-

tude, the other with sudden cardiac arrest. ALCAPA was demonstrated by transthoracic echocardiography in four patients (#1, #3, #4, #5), by cardiac catheterisation in two patients (#2, #9) and by computed tomography (CT) in one patient (#8).

Nine patients underwent surgical repair by re-implantation of the left main coronary artery into the naorta. One of the three adult patients (not shown in Table 1) had undergone surgical repair as a child 18 years earlier (three years old) with an intrapulmonary tunnel (ad modum Takeuchi) (Figure 1D) because direct re-implantation was not feasible. Tunnel leaks creating significant left-to-right shunting (Qp/Qs = 2.2) necessitated reoperation 18 years after the initial operation. Extracorporeal membrane oxygenation was required post-operatively in one patient.

All-cause mortality was zero in this small cohort with variable follow-up (six months to 22 years). Left ventricular function recovered and MR improved in all patients.

DISCUSSION

ALCAPA is an uncommon congenital abnormality with variable clinical presentation depending on the nature of the collateral coronary circulation and associated congenital heart malformations. Today, the surgical technique of choice to correct ALCAPA is direct aortic re-implantation, which is technically feasible in most children. Even in patients with a poor left ventricle function and significant MR, the post-operative recovery is remarkable [10]. Our nine patients, operated with coronary re-implantation, all had complete recovery of left ventricular systolic function and MR when assessed echocardiographically. The recovery-time varied from six months up to 12 months after surgery. To which extent the antero-lateral myocardium is subclinically scarred and fibrotic is unknown, and long-term follow-up of this patient group is warranted.

Clinical findings in late presenters (adults) with ALCAPA were investigated by Yau et al in a large review including 151 patients [8]. They found a predominance of females 2:1, 66% presented with angina, dyspnoea, palpitations or fatigue like our patient #8. A further 17% presented with ventricular arrhythmia, syncope or sudden death like our patient #9; and 62% of these had no antecedent symptoms. The average age for sudden death in untreated adult ALCAPA was 35 years, and the recommendation for all newly diagnosed adult ALCAPA is therefore to undergo surgical treatment as early as possible [8].

In the study by Yau et al, the ECG demonstrated Q-waves in 50%, left ventricular hypertrophy in 28% and left axis deviation in 15%. ECG was normal in 4%. In our study, one patient (#8) had left axis deviation and right

branch bundle block, and another patient (#9) had a normal ECG. In contrast, symptomatic infants with isolated ALCAPA all had ECG abnormalities with ST-depression, (pathological) Q-wave in V5-V6, and negative T-waves in V5 (#1, #2) (Table 1) [8].

ALCAPA is generally an isolated defect, but can co-exist with other abnormalities such as VSD (#6, Table 1) [10-12]. One of our patients was initially diagnosed with a VSD and had dilated left heart and symptoms of heart failure. However, because of the relatively well-preserved cardiac function (EF 72%), ALCAPA was not suspected prior to surgery. Intra-operatively, regional myocardial cyanosis of the left ventricle in the area supplied by LAD led the surgeon to suspect ALCAPA. In retro-

▤ TABLE 1

The nine patients with a diagnosis of ALCAPA in the Department of Thoracic Surgery, February-January 2014, had coronary reimplantation as their first surgical intervention. Patient no. 7 had concomitant closure of a VSD. The patient who initially had the Takeuchi tunnel surgery is not presented here.

Patient no.	Gender	Age	Presentation	Diagnostics and findings	Surgical findings	Recovery
1	Girl	2 mo.	Tachypnoea, sweating	Heart murmur[b] (2/6), hepatomegaly, ECG: left ischaemia, ECHO: EF 15%, MR grade II-III, ALCAPA, CT: ALCAPA	ALCAPA	ECHO 12 mo. post: EF 65%, MR grade I-II
2	Girl	3 mo.	Tachypnoea, sweating	ECG: Q-wave V5-V6, MR grade II ECHO: EF 30%, endocardial fibrosis, LCA not visible => cardiac catheterisation => ALCAPA + collateral	ALCAPA	ECHO 12 mo. post-op.: EF 74%[d], MR grade I
3	Boy	3,5 mo.	Failure to thrive, tachypnoea, cardiovascular collapse	Heart murmur[b], hepatomegaly, chest X-ray: enlarged heart, ECHO: EF 5-10%, dilated LV, MR grade II-III, ALCAPA	Lateral infarction, apical fibrosis, ALCAPA	ECHO 12 mo. post: EF 65%, MR grade I-II
4	Girl	4 mo.	Tachypnoea, sweating, failure to thrive No improvement with diuretics	ECHO: EF 10%, diastolic retrograde flow, MR grade II-III LM departed from position between MPA and RPA => cardiac catheterisation: ALCAPA	LM departed from position between MPA and RPA, ALCAPA	Post-op. ECMO ECHO 12 mo. post: EF 65%, MR grade I
5	Girl	6 mo.	Tachypnoea, sweating	ECHO: EF 20%, MR grade II-III, dilated LV	ALCAPA	ECHO 12 mo. post: EF 55%, MR grade I, papillary fibrosis
6	Boy	6 mo.	Tachypnoea, cough, sweating	Heart murmur (3/6), chest X-ray: enlarged heart ECG: no changes ECHO: EF 72%[d], MR grade 1, VSD, dilated LV	ALCAPA diagnosed per-op. Cyanosis of LV in LAD's area	ECHO 12 mo. post: EF normal, no MR
7	Girl	17 mo.	1-6 mo.: sweating, failure to thrive 6-12 mo.: infections, colic 12-17 mo.: intermittent dyspnoea, infections	Chest X-ray: enlarged heart, ECHO: EF 43%, MR grade III, mitral valve prolapse and PFO	ALCAPA diagnosed per-op. due to dilated heart, coronary collaterals, fibrosis of LAD region	ECHO 6 mo. post: EF: 58%[d] and MR grade II
8	Woman	20 yrs	2005: fatigue for 4 weeks during travelling in Tibet/Malaysia 2007/2008: dyspnoea in the mountains in Tibet	2005: heart murmur 3/6 Exercise tolerance test: ST-depression ECHO: septal hypertrophy and coronary fistula/sinusoids in the septum Observation 2005-2008, asymptomatic 2007/2008: ECG: incomplete RBBB, negative T-waves in V2, left axis ECHO: diastolic retrograde flow in septum like abnormal coronary arteries anatomy Exercise tolerance test ST depression CT angiography: ALCAPA ECHO: EF 66% and no MR	2-3 cm large fibrotic area (earlier infarction) apically in heart, ALCAPA	ECHO 12 mo. post: Normal EF 59% and MR grade I[c]
9	Woman	39 yrs	No symptoms before present, former athlete Sudden cardiac arrest VF at physical exercise, resusc. => hypothermia-CA: ALCAPA	ECHO: EF 50%, anterior hypokinesia and no MR	Dilated RCA, collaterals, extensive fibrotic changes in anterior and apical heart Ao implant, ALCAPA	Several ventricular tachy-cardia episodes => ablation, 2 episodes of CA, still alive[a], normal EF Living a normal live, does sports

ALCAPA = abnormal left coronary artery from pulmonary artery; Ao = aorta; CA = coronary angiography; CT = computed tomography; ECG = electrocardiogram; ECHO = transthoracic echocardiography; ECMO = extracorporeal membrane oxygenation; EF = ejection fraction; FS = fractional shortening; LAD = left anterior descending artery; LCA = left coronary artery; LM = left main coronary artery; LV = left ventricle; MI = myocardial infarction; MPA = main pulmonary artery; MR = mitral valve regurgitation; PFO = persistent foramen ovale; RBBB = right bundle branch block; RCA = right coronary artery; RPA = right pulmonary artery; VSD = ventricular septal defect.
a) She had been admitted to the hospital as a baby with findings of fibroelastosis without any further treatment at that time.
b) Due to MI.
c) As a child she diagnosed with colic (may have been due to ALCAPA).
d) FS is converted to EF (ref: www.ekkokardiografi.dk).

spect, this patient had echocardiographically visible regional hypokinesia of the antero-lateral left ventricular wall, which was not recognised before surgery. The co-existence of ALCAPA and VSD can be a dangerous combination. A large VSD may induce high pressure in the MPA, which preserves the left ventricular function due to reduced steal or even antegrade perfusion through the ALCAPA. If the VSD is closed and the ALCAPA is left unoperated, the subsequent drop in MPA pressure will increase coronary steal from the ALCAPA and result in myocardial ischaemia. This condition may result in acute heart failure or even death [8, 10-13].

Another patient (#7, Table 1) presented with failure to thrive at the age of 17 months and moderate-to-severe MR without ALCAPA being suspected. The patient had symptoms of heart failure with sweating and dyspnoea although the EF was only mildly reduced to 43%. Diuretics did not improve the patient's clinical condition.

Structural congenital mitral valve abnormalities are rare, like ALCAPA, and should be considered together with ALCAPA in children with early-onset MR. Echocardiography showed a normal anatomy of the mitral valve leaving the severe MR unexplained. ALCAPA was diagnosed intra-operatively due to dilated heart, coronary collaterals and fibrosis of the region supplied by the left anterior descending artery. Our cases demonstrate the diagnostic difficulty with ALCAPA. In some of our cases, the clinical presentation was not straightforward, and ALCAPA was first recognised during surgery. Standard clinical evaluation failed to detect the ALCAPA. This illustrates the importance of being aware of the varied clinical presentation of ALCAPA.

The nature and timing of presentation of ALCAPA is variable depending upon the adequacy of the collateralised LCA circulation and pulmonary artery pressure. Patients with poor collateral circulation are more likely to present in infancy like cases #1-6 and #9. One patient presented with severe heart failure and survived the first three years of life without surgery (the Takeuchi tunnel), which may have been owed to good collateral circulation.

Late presenting patients may be asymptomatic, suffer from exertional dyspnoea, arrhythmia or sudden death (#8, #9/Table 1) [14, 15].

CONCLUSION

ALCAPA should be suspected in infants presenting with symptoms of heart failure, abnormal ECG and reduced left ventricular systolic function (or MR) on echocardiography. In adults with unexplained exertional dyspnoea, documented ventricular arrhythmia or sudden cardiac arrest, ALCAPA should also be excluded. Even if echocardiography suggests normal coronary anatomy, further investigation with cardiac catheterisation and coronary

angiography may be warranted. In older patients with ALCAPA, a heart CT angiography or cardiac magnet resonance imaging may provide a non-invasive means of demonstrating ALCAPA. Structural abnormalities (such as VSD) with co-existing regional or global left ventricular hypokinesia should alert the cardiologist to the possibility of ALCAPA. Surgical treatment with coronary re-implantation provides good results even in the setting of severe left ventricular dysfunction and mitral regurgitation, often with complete recovery of the left ventricular-function and normalisation or marked improvement in mitral valve function.

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