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ORIGINAL ARTICLE

Congenital Anomalies of Coronary Arteries in Children: The Evaluation of 22 Patients

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Abstract Although congenital coronary artery anomalies are seen in 0.6–1 % of adult patients undergoing coronary angiography, the data for the pediatric population are few. This study of 22 children with coronary artery anomalies evaluated them in terms of demographic and clinical features and analyzed their angiographic findings and surgical results. Databases in the Department of Pediatric Cardiology at the University of Uludag were searched for all the patients with a diagnosis of congenital coronary artery anomaly who underwent coronary angiography between 1993 and 2013. Patients with coexistent congenital heart disease were excluded from the study. The study noted 22 patients (0.9 %; 10 boys and 11 girls) with coronary artery anomalies. The mean age of these patients was 58.77 ± 52.04 months (range, 1 month–16 years). Coronary arteriovenous fistula (50 %) and anomalous left coronary artery from the pulmonary artery (ALCAPA) (36 %) were the most common anomalies. In addition, the study included one patient with diffuse coronary artery hypoplasia, one patient with muscular bridge, and one patient with left main coronary artery originating from the right aortic sinus valsalva. Of the 11 patients who had coronary atrioventricular fistula, 7 were asymptomatic, whereas 75 % of the patients with ALCAPA syndrome were admitted because of heart failure. Although 13 patients had an exact diagnosis by echocardiography, 50 % of the patients with ALCAPA syndrome had their diagnosis determined by catheter angiography performed because of severe mitral regurgitation or dilated cardiomyopathy. The mortality rate for all the patients was found to be 18.1 %. Eight patients with coronary arteriovenous fistula have been followed up without surgery to the present. In contrast, seven patients with ALCAPA syndrome have undergone surgery, and three have died. Two of these patients died during the postoperative period, and the remaining patient died suddenly during the preoperative period at home. Isolated congenital coronary artery anomalies are very rare in the pediatric population. Although most congenital coronary artery anomalies are clinically silent, they may be associated with severe symptoms in children. Recognition of potentially serious anomalies such as ALCAPA syndrome is mandatory so that early surgical treatment can be prescribed.

Keywords ALCAPA · Children · Coronary arteriovenous fistulas · Dilated cardiomyopathy

Introduction

Coronary artery anomaly (CAA) refers to a wide range of congenital abnormalities involving the origin, course, and structure of coronary arteries. Although congenital CAAs are rarely symptomatic and patients enjoy a normal quality of life, they may induce sudden death or cause myocardial ischemia and cardiac failure.

Coronary artery anomalies can be associated with complex congenital heart disease, but they also occur as isolated anomalies. Identification of CAAs can be

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documented by autopsy, echocardiography, diagnostic coronary angiography, multislice coronary computed tomography (CT) angiography, or cardiac magnetic resonance imaging.

The reported incidence of CAAs in coronary angiographic series of adults is 0.6–1 % [19, 21, 33]. But childhood studies of CCAs are limited. This study aimed to illustrate the incidence, clinical features, diagnosis, surgical treatment, and prognosis of children with isolated congenital CCAs. In addition, the angiographic findings of coronary atrioventricular fistulas and the surgical outcomes of anomalous left coronary artery from the pulmonary artery (ALCAPA) syndrome were noted.

Materials and Methods

Subjects

From September 1993 to April 2013, 22 children (12 girls and 11 boys) ranging in age from 1 month to 16 years had a diagnosis of congenital CAA determined in the Department of Pediatric Cardiology at the University of Uludag, a tertiary medical center in Turkey. Databases were collected retrospectively by analyzing the angiographic data of 2,400 pediatric patients undergoing catheter angiography. The data retrieved from the clinical records included gender, age at diagnosis, symptoms, physical examination, and electrocardiographic measurements.

Echocardiography

Routine two-dimensional echocardiographic evaluation was performed using an ultrasound system provided with pulsed, continuous, and color Doppler (Vivid–6 GE and HP Sonos 5500). Left ventricular dimensions, ejection fraction, wall motion, septum, and posterior wall thickness were noted. Coronary arteries were evaluated in the parasternal short-axis view at the level of the great arteries. The diameters and the abnormal origin of the right and left coronary arteries as well as abnormal shunting into any cavity were noted.

Catheterization and Angiography

Aortic angiography was performed for all the children under sedoanalgesia. Selective coronary angiography was performed when required. Written informed consent was obtained from the parents of every child participating in the study.

Detected CAAs were categorized into four major groups using Angelini's classification [2]:

1. Anomalies of origination and course
2. Anomalies of intrinsic coronary arterial anatomy
3. Anomalies of coronary termination
4. Anomalous collateral vessels.

Patients who had CAAs associated with other congenital heart diseases were excluded from the study.

Statistical Analysis

Statistical analysis was performed using a computer-based program (SPSS for Windows, version 17; SPSS, Chicago, IL, USA). Quantitative variables were expressed as means and qualitative variables as percentage (%) values. Univariate comparison between continuous variables was performed with Student's t test or the Mann–Whitney U test, and comparison of categorical data was performed using the Chi square test or Fisher's exact test. A $p < 0.05$ was considered statistically significant.

Results

Coronary artery anomalies were found in 22 patients (0.9 %: 11 females and 10 males). The mean age of these patients was 58.77 ± 52.04 months. According to the classification used, 9 patients had anomalies of origination, 11 patients had anomalies of termination, and 2 patients had anomalies of the intrinsic coronary artery anatomy (Table 1).

Anomalies of Origination and Course

ALCAPA Syndrome

Eight patients (five females and three males) were shown to have ALCAPA syndrome. For five of them, the ALCAPA

Table 1 Frequency of coronary artery anomalies among 2,400 coronary angiographies

Coronary artery anomalies	Patients ($n = 22$)	Angiographic incidence (%)	Anomaly incidence (%)
Origination anomalies	9	0.37	40.9
ALCAPA	8	0.33	36.3
LAD from right aortic sinus	1	0.04	4.5
Anomalies of termination			
Coronary AV fistulas	11	0.45	50
Anomalies of intrinsic coronary anatomy	2	0.08	9
Coronary hypoplasia	1	0.04	4.5
Muscular bridge	1	0.04	4.5

Table 2 Characteristics of patients with anomalous left coronary artery from the pulmonary artery (ALCAPA) syndrome who underwent surgery

Gender	
Males	2
Females	5
Age at operation (months)	14.14 ± 13.17
Symptom	
Heart failure	5
Murmur	2
Specific ECG findings	
+	6
–	1
Accurate diagnosis by echocardiography	
+	4
–	3
Abnormalities of mitral valve	
+	6
–	1
Type of surgery	
Takeuchi procedure	5
Reimplantation of left coronary artery directly onto the aorta	2
Mortality	
+	2
–	5
Morbidity	
Spastic diplegia	1

diagnosis had been determined before the age of 6 months, and the initial symptoms were acute heart failure for all of them. Two of the patients, ages 2 and 2.5 years, were asymptomatic and referred for detection of a cardiac murmur during their physical examination.

Electrocardiography (ECG) found anterolateral myocardial ischemia in six of the patients. Echocardiography often showed various degrees of left ventricular dilation and mitral insufficiency with enhanced echogenicity of papillary muscles. Neverthless, for half of the patients with ALCAPA syndrome, the diagnosis could not be determined precisely by echocardiography, and catheter angiography was performed for these patients due to severe mitral regurgitation and dilated cardiomyopathy. Increased coronary artery collaterals within the septum were visualized in only two patients (25 %). Angiography confirmed the suspected diagnosis in all cases.

Seven patients underwent cardiac surgery, with the Takeuchi procedure performed for five patients and left coronary artery (LCA) reimplantation performed for two patients (Table 2). Two patients died in the hospital postoperatively due to low cardiac output (the Takeuchi operation was performed for the one patient and LCA reimplantation for the other), and one patient died suddenly at home while preparing for surgery. Also, spastic diplegia in one patient was reported postoperatively. A significant correlation was found between ejection fraction and mortality (Table 3). No association was found between age, gender, initial symptoms, electrocardiographic findings, echogenity of the mitral valve, and mortality.

Table 3 The association between preoperative ejection fraction and postoperative mortality in anomalous left coronary artery from the pulmonary artery (ALCAPA) syndrome

	Patients (*n*)	EF (%)	*p* Value
Postoperative mortality			0.01
+	2	19.5 ± 2.12	
–	5	47.5 ± 10.83	

Left Anterior Descending (LAD)

Coronary artery from the right aortic sinus. This diagnosis was determined for a 6-month-old child who incidentally presented with heart failure. The patient underwent coronary angiography to clarify the etiology of the dilated cardiomyopathy and died due to septic and cardiogenic shock after catheter angiography.

Anomalies of Coronary Termination

Coronary Arteriovenous Fistula (CAVF)

In our study, CAVF was the most common anomaly (50 %). Among the 11 CAVF patients, 6 were boys and 5 were girls, Their mean age at the diagnosis of CAVF was 69.9 ± 49.9 months (range, 1 month to 13 years). The majority (63 %) of these patients were asymptomatic and referred due to cardiac murmur. Two of the patients had nonspecific chest pain. None of the patients had heart failure. The ECG results were always within the normal range.

Echocardiography showed CAVF in nine children, with coronary angiography confirming the diagnosis. The angiographic characteristics of CAVFs are shown in Fig. 1. Three patients had been treated surgically. For two of these patients, percutaneous closure before surgical ligation was planned, but this was not possible due to the coronary artery structure. Although eight patients with CAVF did not require any treatment because of their small size, they all were followed up annually in terms of heart failure and ischemia.

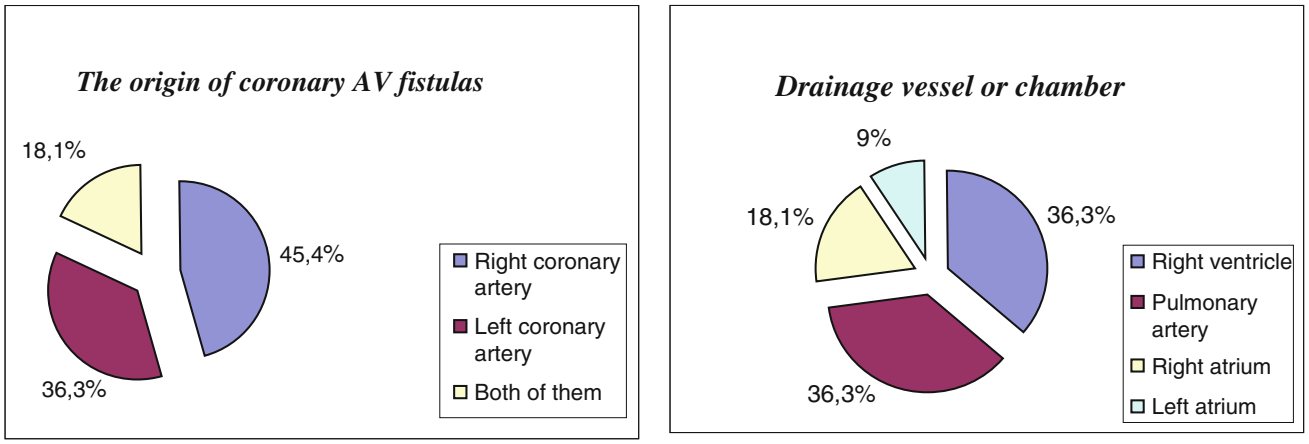

Fig. 1 Angiographic features of coronary arteriovenous fistulas

Anomalies of Intrinsic Coronary Arterial Anatomy

Coronary Hypoplasia

The coronary hypoplasia diagnosis was determined for a 10-month-old patient who presented with severe heart failure that was drug resistant. The echocardiogram was normal for coronary artery origin and courses. Coronary angiography showed hypoplasia of the left main coronary artery and a missing circumflex coronary artery. Transplantation was planned for this patient.

Muscular Bridge

The muscular bridge diagnosis was determined for a 16-year-old professional football player who had an exercise-related chest pain. His physical examination, electrocardiogram, exercise test, and echocardiography were normal. Coronary angiography showed a muscular bridge, which caused 30 % stenosis in LAD during systole. This patient was followed up clinically.

Discussion

Coronary artery anomalies are generally asymptomatic, with a benign prognosis in adults, so most of them are encountered as incidental findings during coronary angiography [1, 3]. Few studies have investigated CAAs in the pediatric population, and the incidence of CAA is reported to be 0.9–1.4 % [9, 24]. In our study, the incidence of CAA was found to be 0.9 %.

Anomalous origin of the LCA from the pulmonary artery is a rare anomaly that occurs in approximately 1 per 300,000 live births and represents 0.5 % of all congenital heart defects [6]. Our cohort had eight patients with ALCAPA syndrome, and five of them had the diagnosis of acute heart failure determined before the age of 6 months. In only two asymptomatic patients older than 2 years had collateral arteries developed between the normal right coronary artery (RCA) and the anomalous LCA.

It is extremely important to distinguish dilated cardiomyopathy from ALCAPA because early surgical treatment is essential for the latter. Electrocardiographic findings such as abnormal Q waves with T wave inversion in leads I, avL, and V5–6 are common in ALCAPA [13]. One study reported that a Q wave depth of 3 mm or more with T wave inversion in lead avL was helpful in the differential diagnosis of ALCAPA and dilated cardiomyopathy [7]. Similarly, six of the eight patients with ALCAPA syndrome had deep Q waves in leads avL and V5–6 in our series.

A dilated RCA, enhanced echogenicity of papillary muscles in two-dimensional echocardiography, and multiple collateral flows at the interventricular septum with color Doppler flow imaging may indicate the presence of ALCAPA [10, 14, 34]. Unfortunately, the findings showed that the incidence of all these findings decreases in infants [35]. Likewise, we also recommend diagnostic catheterization for all patients younger than 1 year who have dilated cardiomyopathy and specific ECG findings due to the low sensitivity of echocardiography in this age group.

The mortality rate for ALCAPA is high, with nearly 90 % of untreated patients dying in the first 12 months of life [8, 11]. Two patients in our population were older than 2 years, and echocardiography was pathognomonic for these children.

Many surgical methods are used for ALCAPA [23]. Conservation of the two-coronary artery system is preferred at nearly all centers. Two techniques ensure the two-coronary artery system. The Takeuchi procedure was performed for five patients, whereas our surgeon preferred to reimplant the anomalous LCA directly onto the aorta for two patients.

Two of the seven patients who underwent surgery died postoperatively. The remainder of the cohort proved to

have no late mortality during the follow-up period after discharge. Previous studies report that a left ventricular ejection fraction of 35 % or less is highly predictive of mortality [17]. In parallel with these studies, the report also noted a significant association between the ejection fraction and postoperative death. One patient experienced spastic diplegia after the Takeuchi procedure. The same patient experienced supravalvular pulmonary stenosis after 5 years and required reoperation.

The most common CAA encountered in our trial was CAVF, with an overall incidence of 0.4 %. The incidence of CAVF among adults was reported to be 0.3–0.7 % in previous studies [12].

The natural history and clinical course of congenital CAVF vary significantly among affected patients [18, 22, 31]. The disorder tends to manifest in infants younger than 2 years of age with congestive heart failure and in young adults with angina, dyspnea at exertion, and myocardial ischemia [15].

Seven patients in our series had no symptoms, and two patients had a noncardiac chest pain. Unlike the adult population, our cohort had no heart failure. This might have been due to the fact that the CAVFs detected in our patients were small and hemodynamically insignificant at the time of this study. However, these patients may have heart failure in the future with age due to increased left-to-right shunting, so regular follow-up assessment is mandatory.

For pediatric patients with CAVF, echocardiography would be sufficient in most circumstances [30]. Although multislice CT confirmed the presence of fistula in nearly all the patients, it could not visualize the origin and drainage of CAVF definitely [5]. Coronary angiography is the gold standard method for diagnosis. We identified CAVF by echocardiography in nine patients (81 %), and we performed coronary angiography for all the patients to define the precise origin and drainage site and to detect possible coil embolization.

The most common vessel of origin for CAVF is the RCA (50–55 %), followed by the LCA (35–42 %) and both combined (5 %) [12, 32]. They predominantly drain into low-pressure structures: 92 % to the right side of the heart [20, 29].

We found in our study that five of the CAVFs were derived from RCA, whereas four originated from LCA and two from both coronary arteries. As found in other studies, the majority of patients with CAVFs had drainage into the right side of the heart, whereas only one patient had drainage into the left atrium.

Coronary fistulas should be treated in the presence of large fistulas, progressive left-to-right shunting, myocardial ischemia, and congestive heart failure [5]. Most authors recommend occlusion of all CAVFs to avoid possible subsequent complications such as bacterial endocarditis. However, no patients experienced endocarditis complications during the follow-up period in our study.

An increasing number of case reports and studies show spontaneous congenital CAVFs. Schleich et al. [28] presented six children with complete closure of CAVFs. Similarly, spontaneous closure of CAVFs was reported for 23 % of the patients in the study of Sherwood et al. [31]. In contrast, no patient had a CAVF that closed spontaneously in our study. Therefore, long-term follow-up evaluation is needed to determine the rate for spontaneous closure of CAVFs.

Two treatment alternatives can be used for CAVF: surgery or closure by catheter. Transcatheter methods are reported to have similar efficacy, mortality, and morbidity rates [25].

Coil embolization was attempted for two of three patients treated surgically, but it was impossible due to the tortuous structure of coronary arteries and unsuitable catheters. No mortality or morbidity occurred after surgery in our study.

As demonstrated earlier, the anomalous origin of the coronary ostium from the opposite sinus of Valsalva is an incidental finding at coronary angiography most of the time. Among coronary anomalies of origination, those with an intramural or intraarterial initial course are considered the most dangerous because they may be compressed with secondary lumen reduction during systole and may cause sudden death [4, 26, 27].

In our series, only one patient had LAD from the right aortic sinus of Valsalva with a retroaortic course. Although we performed coronary angiography due to dilated cardiomyopathy, we thought it was only a coincident finding. The same patient died on the 2nd day because of septic and cardiogenic shock after coronary angiography.

Muscular bridge is seen much more frequently in adults, characterized by the intramyocardial course of the coronary artery. Whether it is associated with sudden death or merely represents a normal benign variation remains controversial [16].

We report a 16-year-old patient who had chest pain during exercise. Coronary angiography showed the intramyocardial bridge that caused 30 % stenosis of LAD during systole, so competitive sports were forbidden, and exercise was restricted for this patient.

Coronary artery hypoplasia is a very rare and nearly almost fatal anomaly that mostly results in dilated cardiomyopathy and usually requires heart transplantation [36].

Although it was reported as single case reports in the other studies, Ogden et al. [24] found the incidence of proximal coronary artery hypoplasia to be 0.022 % in a necropsy study with a large cohort. Coronary bypass grafting is the surgery of choice for some selected patients.

However, we followed up our case with medical treatment only because it was not feasible to perform coronary bypass grafting due to the diffuse hypoplasia of the coronary arteries.

Study Limitation

Because this was a catheter-based study, the incidence of CAAs in children could have been underestimated.

Conclusion

In conclusion, congenital CAAs are rarely identified in children. Although they usually are asymptomatic, they can cause significant mortality and morbidity. Echocardiography is an excellent imaging method for diagnosing these anomalies, but catheter angiography may be recommended for all infants with refractory dilated cardiomyopathy. It is emphasized that all coronary arteriovenous fistulas that are symptomatic and large should be closed either surgically or percutaneously. In contrast, it is reasonable to follow up small and asymptomatic coronary arteriovenous fistulas at regular intervals in the pediatric population.

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