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ORIGINAL ARTICLE

The Evolution of the Minimally Invasive Approach and Conventional Median Sternotomy for Coronary Artery Fistula Correction

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Background Minimally invasive cardiac surgery has become a safe and cosmetic alternative to standard median sternotomy. This retrospective study reviews our results and experience with the minimally invasive approach for congenital coronary artery fistula correction, compared with conventional approach.

Methods From February 2001 to June 2016, 110 patients with isolated coronary artery fistula (CAF) in our centre underwent correction through minimally invasive approach (MIA) (n = 65) or standard median sternotomy (SMS) (n = 45). Cardiopulmonary bypass (CPB) was used in 16 patients in the SMS group, and all the other patients underwent the procedure without CPB through a standard median sternotomy or minimally invasive approach.

Results There was no in-hospital mortality and no patients reverted to a median sternotomy in the MIA group. Subxiphoid incision (32 cases) and parasternal incision (28 cases) were the most common approaches used for the procedure. The operative time was 67.82 ± 14.4 minutes in MIA group and 107.04 ± 27.91 minutes (p = 0.0001) in the SMS group. The intubation time was 3.58 ± 2.33 hours in the MIA group and 6.1 ± 3.26 hours in the SMS group (p = 0.0001); the intensive care unit (ICU) stay was 10.04 ± 7.95 hours in the MIA group and 19.74 ± 7.81 hours in the SMS group (p = 0.0001). Three patients (two in MIA Group vs one in SMS Group, p = 0.787) were identified with a trivial residual shunt during the procedure, which had disappeared by discharge.

Conclusions Minimally invasive approach can provide an excellent surgical exposure for CAF ligation in selective patients compared with SMS. It is a safe and cosmetic alternative to conventional treatment and minimised the length of stay.

Keywords Minimally invasive surgery • Congenital heart disease • Coronary artery fistula

Abbreviations: CAF, Coronary artery fistula; RCA, Right coronary artery; RV, Right ventricular; LAD, Left anterior descending artery; MSCT, Multi-slice spiral computed tomography angiography; TEE, Transoesophageal echocardiography

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Introduction

Coronary artery fistulas (CAF) are rare congenital anomalies, which are defined as abnormal communications between any coronary artery and any cardiac chambers or any great vessel. The incidence of CAF is approximately 0.2% in patients undergoing cardiac catheterisation [1]. Most of these patients are asymptomatic, but symptoms of breathlessness and congestive cardiac failure may occur in infancy or children with a large left-to-right shunt, and symptoms of myocardial ischaemia including angina, myocardial infarction, and coronary steal may occur in older patients [2]. Current treatment includes surgical correction alone or accompanied by coronary artery bypass grafting, with or without cardiopulmonary bypass support, or, alternatively, transcatheter closure [3,4]. Conventionally, a median sternotomy was performed for CAF correction. The minimally invasive approach for CAF correction has been performed in our centre for several years. Thus, this article reviews our single institution experience over the past 15 years, and compares two different approaches for congenital CAF correction, minimally invasive approach (MIA) vs standard median sternotomy (SMS).

Patients and Methods

This study was approved by the Institutional Review Board of Wuhan Asia Heart Hospital and was in compliance with Health Insurance Portability and Accountability Act regulations and the Declaration of Helsinki. The Institutional Review Board waived the need for individual patient consent. From February 2001 to June 2016, 110 cases with CAF underwent surgical correction. Sixty-six (66) patients were asymptomatic in this series of patients. For patients under 20 years of age, almost all were asymptomatic. Ten (10) infant patients had a ''recurrent history of respiratory infections''. The other 44 patients had various symptoms including dyspnoea, angina, syncope, and palpitations. Heart murmurs were audible in 88 patients (80%) and most of these were continuous murmurs. Abnormal electrocardiographic findings were observed in 58 patients (52.72%), including evidence of ventricular hypertrophy in 22, ST changes suggesting ischaemic disease in 18, and rhythm and conduction disturbances in 18. In accordance with the patient's preference, and after discussion in our cardiologic/surgical conference, surgical access was made using either a minimally invasive approach (including subxiphoid approach, parasternal approach and lower mini-sternotomy approach (MIA Group, n = 65)) or standard median sternotomy (SMS Group, n = 45).

Patient Characteristics

General data concerning age, sex, and weight, were collected for analysis of any differences between the two groups prior to the operation (Table 1).

Surgical Planning

Multi-slice spiral computed tomography angiography (MSCT) and three-dimensional reconstruction were routinely performed in all patients. MSCT provides an accurate location of the fistula including the relationship with peripheral structures, which is of great value for the surgical strategy (Figures 1–3). The incision should be very accurate in position with excellent exposure for ligating the fistula. The surgical strategy including cardiopulmonary bypass (CPB) and the minimally invasive approach depended on the location and diameter of the CAF. Previously, SMS +/− CPB was used in patients with CAFs. With the availability of MSCT imaging for preoperative planning and with accumulative experience, the MIA approach has been gradually used in

Table 1 **Clinical characteristic of patients.**

Variables	MIA Group (n = 65)	SMS Group (n = 45)	t/χ2 Value	P-value
Mean age (y) (D ± SD)	13.34 ± 18.16	29.64 ± 23.31	3.937	0.001
Weight (kg)	27.25 ± 21.14	44.49 ± 21.88	4.144	0.001
Gender(M/F)	35/30	21/24	0.548	0.459
Location of Fistula			0.673	0.999
RCA-RV	25	17		
RCA-LV	8	6		
RCA-RA	8	6		
RCA-LA	2	1		
RCA-PA	4	3		
LCA-RA	7	3		
LCA-RV	5	5		
LCA-PA	6	4		

Abbreviations: SD, standard deviation; RCA, right coronary artery; RV, right ventricle; LV, left ventricle; PA, pulmonary artery; LCA, left coronary artery; SMS, standard median sternotomy; MIA, minimally invasive approach

Figure 1 A 2-year-old girl with CAF from RCA-AM to RV. A MSCT image. The giant aneurysm and fistula was beneath the xiphoid, which indicated the minimally invasive subxiphoid approach for CAF correction was the appropriate route.
Abbreviations: CAF, coronary artery fistula; RCA, right coronary artery; AM, acute marginal; RV, right ventricular; MSCT, multi-slice spiral computed tomography angiography.

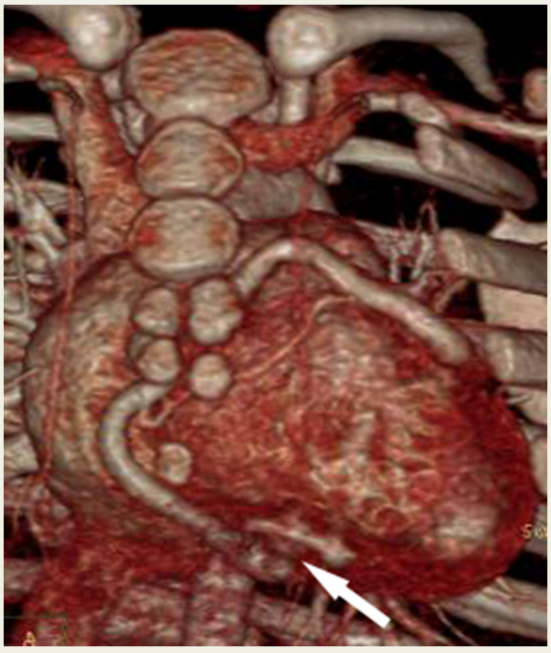

Figure 2 A 1-year-old boy with CAF from RCA to RV. The MSCT volume-rendered image shows that the giant aneurysm and fistula was under the sternum, which indicated the minimally invasive substernal approach for CAF correction.
Abbreviations: CAF, coronary artery fistula; RCA, right coronary artery; RV, right ventricular; MSCT, multi-slice spiral computed tomography angiography.

patients with CAFs. However, patients with multiple CAFs and/or large cardiac chambers associated with other cardiac anomalies should undergo correction with CPB through a median sternotomy. Cardiopulmonary bypass was used in

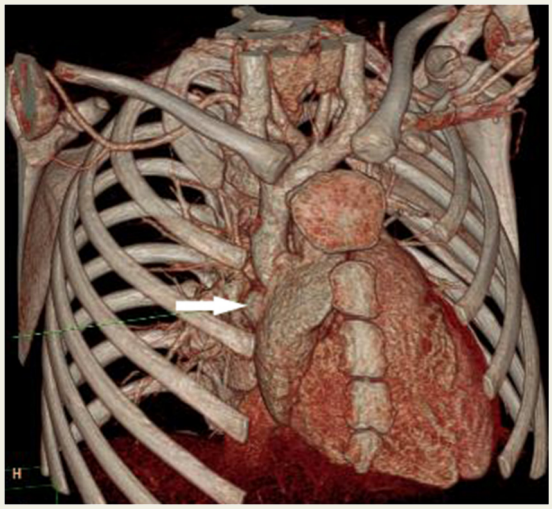

Figure 3 An 8-month-old female patient with CAF from LCX to RA. The MSCT volume-rendered image shows that the giant aneurysm and fistula from circumflex branch of left coronary artery to right atrium was at the third intercostal space, which indicated the right anterolateral thoracotomy approach for CAF correction.
Abbreviations: CAF, coronary artery fistula; LCX, left circumflex artery; RCA, right coronary artery; MSCT, multi-slice spiral computed tomography angiography.

16 patients in the SMS group and all the other patients underwent the procedure without CPB through standard median sternotomy or minimally invasive approach.

Operative Technique

Surgical Techniques in MIA Group

All patients were placed in a supine position and a roll was used to elevate the surgical portion of the chest to improve exposure. For safety reasons, external defibrillator pads were placed on the patient's back and anterior left chest. A transoesophageal echocardiographic (TEE) probe was inserted routinely to provide continuous intraoperative monitoring as well as to assess the surgical result. The technique of minimally invasive approach for CAF correction has been described previously [5]. A minimally invasive approach (2–3.5 cm) including subxiphoid mini-thoracotomy, (right or left) parasternal mini-thoracotomy, or partial inferior sternotomy was performed as the surgical strategy. The pericardium was then incised and suspended to the margins of the incision. The exposure was excellent and the fistulous tracts were identified. A giant aneurysm or ectatic coronary artery was identified and significant thrill was palpated at the fistula, which could be detected without shunt by TEE when it was firmly compressed. The dilated coronary artery was dissected before the fistula and double sutures were used to perform a test occlusion for about 5 minutes. Electrocardiograph (ECG), TEE and haemodynamic scans were observed to determine whether the fistula could be obliterated. Five

(5) minutes later, if the patient was stable, the double sutures were litigated. A 5-0 polypropylene suture was used to reinforce the obliteration. Transoesophageal echocardiography confirmed the successful closure of the fistula with no residual shunt and no wall motion abnormalities. Almost all patients were extubated 2 hours after the procedure in the intensive care unit (ICU).

Surgical Techniques in SMS Group

A standard midline sternotomy with a short skin incision was performed in the SMS Group. The pericardium was then incised and suspended to the margins of the incision. A giant aneurysm or ectatic coronary artery was identified and the fistulous tracts were identified with significant thrill at the fistula. Coronary artery fistula closure was the same as described in the MIA Group. In patients who underwent SMS plus CPB, standard cardiopulmonary bypass was instituted with bicaval and aortic cannulation. Cardiac arrest was achieved by intermittent infusion of cold blood cardioplegic solution. Then the CAF was corrected by ligating or suturing and other cardiac anomalies were corrected simultaneous including ventricular septal defect (VSD) closure, or atrial septal defect (ASD) closure. After the successful CAF closure, the pericardium is closed and all skin incisions are closed intracutaneously.

Patients were not given anticoagulation therapy after the operation. The measurement of cTnI was routinely done to identify any myocardial infarction. Transthoracic echocardiography was used to determine a residual shunt and wall motion abnormalities.

Patients' Follow-Up

All patients should be followed-up in the first year after discharge. The patients were assessed for the presence of a residual shunt and for wall motion abnormalities with transthoracic echocardiography. Transthoracic echocardiography was performed at follow-up at 3 months, 6 months and 1 year after surgery.

Data Management and Statistical Analysis

The data were managed and analysed by using SPSS 19.0 (IBM, Armonk, NY, USA). All continuous variables were expressed as mean ± SD and were compared using t-test analysis of variance. Categorical variables were analysed with Fisher or chi-square χ^2 test. All statistical tests are two-tailed. A p-value of <0.05 was considered statistically significant.

Results

Demographic and Clinical Characteristics

Sixty-five (65) patients (mean age: 13.34 ± 18.16 years) were assigned to the MIA Group; 45 patients (mean age: 29.64 ± 23.31 years) to the SMS Group. The age of patients in MIA Group was younger than the patients in SMS Group ($p = 0.001$) (Figure 4). The weight in the SMS Group was heavier than the MIA Group, and the difference was significant ($p = 0.001$). There were no significant differences between the groups in gender and CAF locations (Table 1).

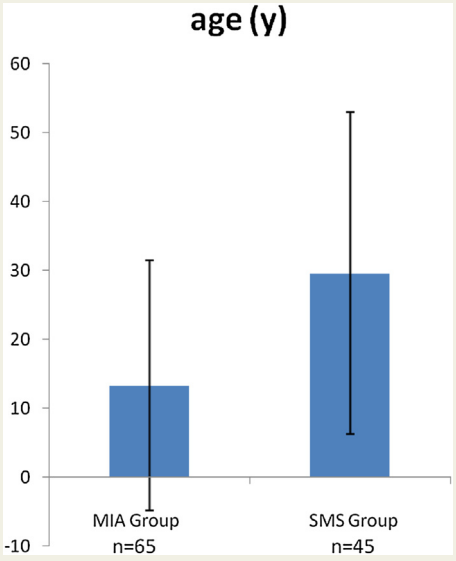

Figure 4 The age of patients in MIA Group was younger than the patients in SMS Group (13.34 ± 18.16 years vs. 29.64 ± 23.31 years, $p = 0.001$).
Abbreviations: MIA, minimally invasive approach; SMS, standard median sternotomy.

Perioperative Profiles

Procedures were performed successfully in all patients and there was no in-hospital mortality. No patient in the MIA Group was converted to standard median sternotomy. In the MIA Group, subxiphoid incision (32 cases) and parasternal incision (23 cases) were the most common approaches used for the procedure. The operative time was 67.82 ± 14.4 minutes in the MIA Group and 107.04 ± 27.91 minutes in the SMS Group, and the difference was significant. The intubation time in the MIA Group was shorter than the SMS Group and the difference was significant (3.58 ± 2.33 h vs 6.1 ± 3.26 h, $p = 0.0001$). Compared with SMS Group, the postoperative drainage was less (75.32 ± 22.12 ml vs 151.28 ± 74.5 ml, $p = 0.0001$). Patients in the SMS Group needed a longer stay in ICU and hospital. Two (2) patients in the MIA Group and one patient in the SMS Group were identified with a trivial residual shunt after the procedure, however, the shunt disappeared by discharge (Table 2). Postoperative cTnI was normal in all patients with no evidence of myocardial infarction.

Sixteen (16) patients in the SMS group underwent CAF correction with CPB. The CPB time was 71.93 ± 31.89 minutes and the cross-clamp time was 41.54 ± 23.65 minutes respectively.

Table 2 **Perioperative Data.**

Variables	MIA Group (n = 65)	SMS Group (n = 45)	t/χ2 Value	P-value
Operative time (min)	67.82 ± 14.4	107.04 ± 27.91	8.662	0.0001
Drainage (mL)	75.32 ± 22.12	151.28 ± 74.5	6.64	0.0001
Intubation time (hours)	3.58 ± 2.33	6.1 ± 3.26	4.733	0.0001
Intensive care unit (ICU) stay (hours)	10.04 ± 7.95	19.74 ± 7.81	6.339	0.0001
Incision length (cm)	3.77 ± 1.08	7.04 ± 1.21	14.855	0.0001
Complications				
Reoperation	0	1(2.22%)	–	NS
Wound infection	0	1(2.22%)	–	NS
Residual shunt	2	1	0.073	0.787
Hospital stay (days)	5.25 ± 1.42	6.58 ± 1.73	4.276	0.0001
Mortality	0	0	–	–

The median follow-up was 9.6 years (range: 1 year to 16 years). All patients were free from symptoms and signs related to CAF during follow-up and no patient required reoperation. Follow-up echocardiograms revealed satisfactory correction without residual shunt and abnormal cardiac wall motion.

Discussion

Coronary artery fistula is a rare channel that communicates between the coronary artery and any cardiac chamber or vessel. The most common sites of drainage are low-pressure structures including pulmonary artery (PA), right ventricle (RV), and right atrium (RA). The most common shunt may be left anterior descending artery (LAD) to PA, which accounts for 40% [6,7]. However, in this study, the shunt from right coronary artery (RCA) was the most frequent (38.18%), which was different from the published reports. Coronary angiography (CAG) is the gold standard technique for CAF diagnosis. However, MSCT has been an alternative diagnostic tool for CAF, which can precisely show the location of the fistula and provide more details than CAG including the relations with peripheral structures, which is of great value for surgical strategy.

Indications for surgery include symptomatic cases and asymptomatic cases with a volume overload from a large shunt blood flow. Urrutia-S et al. [8]. emphasised that CAF correction should be undertaken when the diagnosis is made. They reported that early treatment could prevent later symptoms or complications such as angina pectoris, congestive heart failure, myocardial infarction, subacute endocarditis, aneurysm formation with rupture or embolisation, or pulmonary hypertension. With the development of diagnostic tools including echocardiography and computed tomography angiography, more patients are identified at an early age. In this study, the age of patients in the MIA Group was younger than the SMS Group, because more patients underwent the SMS approach for CAF correction in the early period and, in recent years, more patients underwent the MIA approach at an early age. Compared with the SMS approach for CAF correction, the MIA approach is safe and cosmetic without an increased risk of operative complications. Thus, we advocate that surgical treatment should be given even in asymptomatic patients and the MIA approach may be the optimal treatment for early age patients.

Catheter treatment of CAF is a fairly complicated intervention and requires an experienced operator and interventional specialist with expertise in both CAG and embolisation techniques. There are only case reports or reports with small series of patients [9]. One main advantage of the catheter-closure technique is that, after coil placement and occlusion of the fistula, other feeding vessels can be identified and at the same time [10]. This advantage may reduce its use in patients with CAF, especially in younger patients. Thus, surgical treatment for CAF still is the preferred procedure for cardiac surgeons and patients. With the development of minimally invasive cardiac surgery, the MIA approach for CAF correction may have the same outcome as the conventional approach. In our centre, the MIA approach has been used for several years with excellent results [5].

A median sternotomy is a fairly conventional procedure for CAF surgical treatment with or without CPB. With the development of minimally invasive cardiac surgery, the procedure of CAF correction may be undertaken using this technique. However, reports of MIA for correcting CAF are rare. The first case reported was presented by Mitropoulos and colleagues [11]. In the case report, a 38-year-old woman with CAF (left circumflex [LCX] to pulmonary artery [PA]) underwent successful ligation via a left anterior mini-thoracotomy. Other MIAs including subxiphoid mini-thoracotomy (right or left), parasternal mini-thoracotomy, and partial inferior sternotomy can also be performed and provide excellent surgical exposure for CAF correction. In our study, subxiphoid incision (32 cases) and parasternal incision (23 cases) were the most commonly used approaches for the procedure. The MIA for CAF correction not only reduced the operative time (67.82 ± 14.4 min in MIA Group and 107.04 ± 27.91 min in SMS Group), but also significantly reduced the postoperative intubation time and the postoperative drainage avoiding blood transfusion. However, it is

important to choose the optimal minimally invasive approach for the cardiac surgeon before the procedure. Analysis of the MSCT, including reconstruction of the relationship between the CAF and the sternum or ribs, guides the approach for the cardiac surgeon.

Earlier, the SMS approach with or without CPB was the routine surgical treatment for CAF correction in our centre. However, with the development of the technique and knowledge of cardiac abnormalities, MIA has been an alternative to SMS for CAF correction in recent years. Especially in infancy or children, a minimally invasive approach can provide excellent surgical exposure for CAF correction , and the patients recovered uneventfully and quickly. Not only has it avoided the impairment of CPB, but also the radiation exposure from catheter treatment. Recently, MIA has been the preferred surgical strategy for CAF except for multiple CAFs or concomitant other intracardiac anomalies. This technique reduced the ICU stay and post-drainage with satisfactory results.

Limitations of the Study

There are several limitations to this study. This is a retrospective study at a single centre and thus it is inevitably biased by issues of patient selection and the technique used. In addition, our report includes our initial experience. In the earlier years, sternotomy with or without CPB was the conventional strategy for patients with CAFs, but with improvements in preoperative imaging and surgical techniques, almost all isolated CAFs underwent minimally invasive approach correction in our centre. Thus, in this study, it produces distinct patient cohorts with the sternotomy (SMS) group being older and larger patients at an earlier time in our experience.

Conclusions

A minimally invasive approach can provide an excellent surgical exposure for CAF ligation in selective patients compared with standard median sternotomy. It is a safe and cosmetic alternative to conventional treatment and minimises the length of stay.

Disclosure

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