ORIGINAL ARTICLE

Early Outcomes of Aortic Coarctation Repair in Children not Suitable for Percutaneous Catheter Intervention

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Abstract

Background: ***Aortic coarctation (CoA) is a congenital heart disease (CHD) marked by discrete or diffuse narrowing in the descending aorta at the juxta-ductal region.1 It represents 5-8% of all CHD. Surgical repair is an established technique, and it is used when catheter intervention is not suitable.***

The aim of the study: ***To analyse the impact of present anatomical characteristics and surgical performance (end-to-end and extended end-to-end anastomosis) on early outcomes, in children not suitable for percutaneous catheter intervention.***

Methods: ***This is a prospective study performed on 60 patients who underwent CoA repair from January 2022 to December 2024. The patients who had end-to-end repair (EEA) were group A, and the other who had extended end-to-end repair (EEEA) were group B.***

Results: ***In group A, 56.7% of the patients were females. The mean pre-operative PPG across CoArc was 64.9±6.2 mmHg. The mean cross-clamp time was 16.0±1.4 minutes. The mean post-operative PG was 16.5±2.1 mmHg. While in group B, 46.7% of the patients were females. The mean CoA length was 4.07±2.08 mm, and the mean CoA diameter was 2.89±0.56 mm. The mean cross-clamp time was 28.9±3.5 minutes. The mean post-operative PG was 4.2±2.8 mmHg. There were statistically significant differences regarding cross-clamp time and mean postoperative PG (P value <0.001 & <0.001, respectively).***

Conclusion: ***Our study reported that surgical repair of AoC in children is an alternative method to catheter intervention. It had good results, whatever the method of anastomosis was used.***

Keywords: Aortic coarctation (CoA); End to end ansatomosis (EEA); Extended end to end ansatomosis (EEEA); early mortality

1. Introduction

Aortic coarctation (CoA) is a congenital disease characterized by discrete or diffuse stenosis in the descending aorta at the juxtaductal area.[1] It represents 5% to 8% of all congenital heart disease (CHD), occurring in 0.4% of live births.[2,3] CoA may occur in isolation or in conjunction with other significant CHDs, including subaortic stenosis, mitral valve abnormalities, and ventricular or atrial septal defects.[4] Severe forms can manifest in the neonatal period, potentially leading to cardiogenic shock upon the closure of the ductus arteriosus. Conversely, less severe cases may remain asymptomatic until childhood or adulthood.[4]

Since Crafoord and Nylin's pioneering description of the end-to-end anastomosis (EEA) technique for CoA repair in 1945,[5] various surgical approaches have been developed, including isthmusplasty,[6] subclavian flap aortoplasty,[7] extended end-to-end anastomosis (EEEA),[8] end-to-side anastomosis (ESA),[9] and patch or conduit repair.[10]

Surgical approaches for aortic coarctation have evolved over time due to concerns regarding high rates of residual or recurrent narrowing and other complications, particularly in infants. Notably, early operative mortality is generally low across all surgical techniques, while late mortality is significantly influenced by the presence of concomitant intracardiac defects.[11]

Accepted 10 February 2025.
Available online 30 April 2025

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https://doi.org/10.21608/aimj.2025.446518

EEEA for aortic coarctation repair theoretically offers several advantages. These include complete resection of the stenotic segment, addressing potential tubular hypoplasia of the aortic arch, utilizing autologous aortic tissue for potential growth, and preserving the left subclavian artery. However, potential drawbacks of this technique may include increased operative risk due to the more extensive nature of the procedure, potential for suture line tension leading to bleeding complications, and a longer operative time compared to less extensive approaches.[12]

A shift towards earlier surgical intervention for CoA in infancy has occurred over time. Initially, CoA repair was often viewed as a complete cure, with limited emphasis on long-term monitoring.[13] However, subsequent research has revealed that individuals with a history of coarctation, even after successful repair, face an elevated risk of developing complications later in life, including recurrent recoarctation, systemic hypertension, stroke, atherosclerosis, and aortic aneurysms [14,15]

The aim of our study was to analyze the impact of present anatomical characteristics and surgical performance (EEA vs EEEA) on early outcomes after surgical treatment of aortic coarctation through left thoracotomy in children not suitable for percutaneous catheter intervention.

2. Patients and methods

This is a prospective study performed on 60 patients who underwent closed heart surgery through a left posterolateral thoracotomy for repair of aortic coarctation in Al-Azhar University Hospitals and National Heart Institute from January 2022 to December 2024. The patients were divided into 2 groups: Group A, which included 30 patients who underwent end-to-end repair

Group B: included 30 patients who underwent extended end-to-end repair.

This study included patients < 18 years at the time of operation who underwent aortic coarctation repair via a left posterolateral thoracotomy. We excluded patients who required median sternotomy for complete repair, patients who required pulmonary artery banding, patients with redo aortic coarctation, patients with significant proximal aortic arch hypoplasia and patients with associated other cardiac anomalies, rather than PDA and bicuspid aortic valve.

All the following data were collected for all patients: A. Preoperative data: Full history and clinical examination, manifestation of heart failure, body weight and height and New York Heart Association (NYHA) classes.

Investigations: Electrocardiogram (ECG), plain chest x-ray, echocardiography and CT aortography.

C. Operative data: Type of repair and cross-clamp time.

D. Post-operative data: Mechanical ventilation time, ICU stay, total hospital stay, complications (including pneumothorax, hemothorax, chylothorax, chest infection, wound infection, rebound hypertension, arrhythmias, neurological complications and residual stenosis), plain chest x-ray and echocardiography.

E. 6 months follow-up: Body weight, hemodynamics, plain chest x-ray and echocardiography.

Surgical technique

The patient was positioned on right lateral decubitus. A left posterolateral thoracotomy incision was done in the third intercostal space, sparing the serratus anterior muscle. The chest cavity was opened, and the lung was retracted forward to access the posterior mediastinum. The posterior mediastinal pleura was incised to reach the aorta.

The pleural reflection overlying the aortic arch and descending aorta was meticulously dissected, affording optimal visualization of the relevant anatomical structures. Meticulous care was exercised to avoid iatrogenic injury to the recurrent laryngeal nerve and the phrenic nerve. The aortic arch, the ligamentum arteriosum, and the descending thoracic aorta, inclusive of its intercostal arterial branches, underwent extensive mobilization.

During the surgical procedure, mild hypothermia was induced by allowing the patient's temperature to decrease to 35 degrees Celsius. Intravenous corticosteroids were administered. The ductus arteriosus was ligated with sutures. Systemic anticoagulation was initiated with intravenous unfractionated heparin at a dose of 100 IU/kg (1mg/kg).

In the EEEA technique, vascular clamps are strategically positioned: one distal to the brachiocephalic artery, left common carotid artery, and left subclavian artery on the aortic arch, and another on the descending aorta. Subsequently, a segment of the aorta is resected. This involves an incision on the undersurface of the aortic arch, initiated near the origin of the left common carotid artery. A corresponding incision is then made on the descending aorta to facilitate end-to-end anastomosis. A continuous running suture line, typically composed of polypropylene, is initiated at the apex of the aortic arch incision. This suture line is then meticulously extended posteriorly to align with the prepared margin on the descending aorta, establishing the end-to-end anastomosis.

In the EEA technique, vascular clamps were

applied: one to the distal portion of the aortic arch beyond the origin of the left subclavian artery, and another to the descending aorta. Subsequently, the stenotic segment of the aorta was resected. This was followed by the direct reapproximation of the aortic ends through an end-to-end anastomosis.

Following the completion of the anastomosis, the adequacy of blood flow restoration was assessed by measuring the blood pressure in the radial artery and the femoral artery. Meticulous hemostasis was ensured. The posterior mediastinal space was thoroughly irrigated with warm saline solution. The pleural cavity was then closed by reapproximating the pleural edges using a continuous running suture of polypropylene.

3. Results

Patients' demographic and pre-operative data are summarized in Table (1). In group A, 56.7% of the patients were females. 66.7% of the patients were less than 1 year old and 33.3% of them more than 1 year old. The average weight was 7.6±3.4 Kg, the average height was 69±16.3 cm and the average BSA was 0.38±0.13 M2. According to NYHA classification, there were 19 patients (63.3%) in class I, 6 patients (20%) in class II and 5 patients (16.7%) in class III. In group B, 46.7% of the patients were females. 66.7% of the patients were less than 1 year old and 33.3% of them more than 1 year old. The average weight was 8.0±3.9 Kg, the average height was 69±16.7 cm and the average BSA was 0.39±0.14 M2. According to NYHA classification, there were 18 patients (60%) in class I, 6 patients (20%) in class II, 5 patients (16.7%) in class III and 1 patient (3.3%) in class IV. There was not any statistical significant difference between the groups regarding these data.

The pre-operative echocardiogram [as shown in table (2)] revealed in group A that the average LVEDD was 25.7±4.1 mm, the average LVESD was 16.5±3.3 mm, the average EF was 57.1±6.9 %, the average IVS thickness was 5.2±0.8 mm, the average LA diameter was 21.6±4.2 mm, the average RV diameter was 14.6±2.6 mmHg, and the average PPG across the coarctation was 64.9±6.2 mmHg. The aortic valve was bicuspid in 5 patients (16.7%) and the PDA was present in 24 patients (80%). While in group B, the average LVEDD was 25.8±4.2 mm, the average LVESD was 16.5±3.3 mm, the average EF was 55.1±8.9 %, the average IVS thickness was 5.0±1.0 mm, the average LA diameter was 21.4±4.3 mm, the average RV diameter was 15.2±2.5 mmHg, and the average PPG across the coarctation was 66.3±9.5 mmHg. The aortic valve was bicuspid in 11 patients (36.7%) and the PDA was present in 23 patients (76.7%). There was not any statistical significant difference between the groups regarding these data.

Table 1. Demographic and pre-operative data.

		GROUP A (N = 30)	GROUP B (N = 30)	P VALUE
FEMALE GENDER (%)		17(56.7%)	14(46.7%)	0.438
AGE	< 1 year	20(66.7%)	20(66.7%)	1.000
	≥ 1 year	10(33.3%)	10(33.3%)	
WEIGHT (KG)		7.6±3.4	8.0±3.9	0.700
HEIGHT (CM)		69±16.3	69±16.7	0.994
BSA (M^2)		0.38±0.13	0.39±0.14	0.806
HYPERTENSION (%)		6(20%)	7(23.3%)	0.754
NYHA	I	19(63.3%)	18(60%)	0.794
	II	6(20%)	6(20%)	
	III	5(16.7%)	5(16.7%)	
	IV	0(0%)	1(3.3%)	

BSA=body surface area, NYHA=New York Heart Association.

Table 2. Pre-operative echocardiogram data.

	GROUP A (N = 30)	GROUP B (N = 30)	P VALUE
LVEDD (MM)	25.7±4.1	25.8±4.2	0.926
LVESD (MM)	16.5±3.3	16.5±3.3	0.937
EF (%)	57.1±6.9	55.1±8.9	0.334
IVS THICKNESS (MM)	5.2±0.8	5.0±1.0	0.372
LA DIAMETER (MM)	21.6±4.2	21.4±4.3	0.832
RV DIAMETER (MM)	14.6±2.6	15.2±2.5	0.372
PPG ACROSS COA (MMHG)	64.9±6.2	66.3±9.5	0.502
BICUSPID AORTIC VALVE (%)	5(16.7%)	11(36.7%)	0.080
PDA (%)	24(80%)	23(76.7%)	0.754

LVEDD=left ventricular end diastolic diameter, LVESD=left ventricular end systolic diameter, EF=ejection fraction, IVS=Interventricular septum, LA=left atrium , RV=Right ventricle, PPG=Peak pressure gradient, PDA=Patent ductus arteriosus.

Table (3) shows the pre-operative MSCT data. In group A, the average CoA length was 4.26±2.54 mm, the average CoA diameter was 2.85±0.84 mm, the average Z-score for isthmus was -5.52±2.32, the average ascending aorta diameter was 11.3±2.7 mm, the average distal transverse arch diameter was 9.7±2.2 mm, the average Z-score for distal transverse arch was 1.53±1.25, the average post stenotic segment diameter was 7.2±1.5 mm and the average aortic diameter at diaphragm was 9.6±11 mm. While in group B, the average CoA length was 4.07±2.08 mm, the average CoA diameter was 2.89±0.56 mm, the average Z-score for isthmus was -5.42±1.39, the average ascending aorta diameter was 11.4±2.6 mm, the average distal transverse arch diameter was 9.3±2.0 mm, the average Z-score for distal transverse arch was 1.18±1.03, the average post stenotic segment diameter was 7.2±1.7 mm and the average aortic diameter at diaphragm was 7.7±2.1 mm. There was not any statistical significant difference between the groups regarding these data.

Table (4) shows the operative and post-operative data. In group A, the average cross-clamping time was 16.0±1.4 minutes. The average intra-operative

PG was 15.5±3.3 mmHg. The average duration of mechanical ventilation was 6.0±2.6 hours, the average ICU stay was 4.2±4 days and the average total hospital stay was 11.4±8 days. The blood transfusion required in 1 patient (3.3%). Post-operative persistent hypertension and the need of antihypertensive treatment occurred in 2 patients (6.7%). The post-operative complications occurred in 7 patients (23.3%). The average post-operative PG was 16.5±2.1 mmHg. In group B, the average cross-clamping time was 28.9±3.5 minutes. The average intra-operative PG was 3.8±4.3 mmHg. The average duration of mechanical ventilation was 8.9±3.6 hours, the average ICU stay was 3.6±1.4 days and the average total hospital stay was 11.0±6.7 days. The blood transfusion required in 3 patient (10%) and the inotropes were used in 6 patients (20%). Post-operative persistent hypertension and the need of antihypertensive treatment occurred in 5 patients (16.7%). The post-operative complications occurred in 8 patients (26.7%). The early mortality rate was 3.3%. The average post-operative PG was 4.2±2.8 mmHg. There were statistical significant differences between both groups regarding the average cross-clamping time, the average intra-operative PG, the average duration of mechanical ventilation, the using of inotropic support and the average post-operative PG (P value <0.001, <0.001, =0.001, =0.010 & <0.001, respectively).

Table 3. Pre-operative MSCT data.

	GROUP A (N = 30)	GROUP B (N = 30)	P VALUE
COA LENGTH (MM)	4.26±2.54	4.07±2.08	0.748
COA DIAMETER (MM)	2.85±0.84	2.89±0.56	0.828
Z-SCORE FOR ISTHMUS	-5.52±2.32	-5.42±1.39	0.846
ASCENDING AORTA DIAMETER (MM)	11.3±2.7	11.4±2.6	0.954
DISTAL TRANSVERSE ARCH DIAMETER (MM)	9.7±2.2	9.3±2.0	0.471
Z-SCORE FOR DISTAL TRANSVERSE ARCH	1.53 ± 1.25	1.18±1.03	0.240
POST STENOTIC SEGMENT DIAMETER (MM)	7.2±1.5	7.2±1.7	0.900
AORTIC DIAMETER AT DIAPHRAGM (MM)	9.6±11	7.7±2.1	0.346

CoA=Coarctation.

There were statistical significant differences between the early post-operative and 6 months follow up pressure gradient in group A (P value < 0.001) and group B (P value < 0.001). [as shown in table (5)]

Regarding 6 months follow up data in group A, the average ejection fraction was 63.66±4.9% and the average weight gain was 9.66±3.08 Kg. 2 patients (6.7%) had persistent hypertension. While in group B, the average ejection fraction was 64.6±4.9% and the average weight gain was 10.07±3.57 Kg. 2 patients (6.9%) had persistent hypertension. There were statistical significant differences between the pre-operative and 6 months follow up in group A regarding ejection fraction, weight gain and NYHA classification (P value <0.001, =0.016 & <0.001, respectively). There were also statistical significant differences between the pre-operative and 6 months follow up in group B regarding ejection fraction, weight gain and NYHA classification (P value <0.001, =0.039 & =0.002, respectively).[as shown in table (6)]

Table 4. Operative and post-operative data.

		GROUP A (N = 30)	GROUP B (N = 30)	P VALUE
CROSS CLAMP TIME (MIN)		16.0±1.4	28.9±3.5	< 0.001*
INTRA-OPERATIVE PRESSURE GRADIENT (MMHG)		15.5±3.3	3.8±4.3	< 0.001*
VENTILATION TIME (HOURS)		6.0±2.6	8.9±3.6	0.001*
DURATION OF ICU ADMISSION (DAYS)		4.2±4	3.6±1.4	0.418
TOTAL HOSPITAL STAY (DAYS)		11.4±8	11±6.7	0.821
BLOOD NEED		1(3.3%)	3(10.0%)	0.301
PERSISTENT HTN		2(6.7%)	5(16.7%)	0.227
ANTI-HTN TREATMENT		2(6.7%)	5(16.7%)	0.228
INOTROPIC SUPPORT		0(0%)	6(20.0%)	0.010*
POST-OPERATIVE COMPLICATIONS	Total	7(23.3%)	8(26.7%)	0.765
	Reopening	0(0%)	2(25%)	0.155
	Chest infection	2(28.6%)	0(0%)	0.104
	Phrenic nerve injury	1(14.3%)	1(12.5%)	1.000
	Post-coarctation syndrome	1(14.3%)	0(0%)	0.268
	Vocal cord paresis	1(14.3%)	0(0%)	0.268
	Wound infection	1(14.3%)	0(0%)	0.268
	Heart failure	1(14.3%)	2(25%)	0.604
	Seizures	0(0%)	2(25%)	0.155
	Early mortality	0(0%)	1(12.5%)	0.332
POST-OPERATIVE PRESSURE GRADIENT (MMHG)		16.5±2.1	4.2±2.8	< 0.001*

* indicates statistically significant.
ICU=Intensive care unit, HTN=Hypertension.

Table 5. Comparison between early and 6-month post-operative pressure gradient in both groups.

		EARLY POST-OPRATIVE	6 MONTHS FOLLOW-UP	P VALUE
GROUP A (N = 30)	Pressure gradient (mmHg)	16.5±2.1	13.63±2.98	< 0.001*
GROUP B (N = 29)	Pressure gradient (mmHg)	4.8±2.1	1.55±2.35	< 0.001*

* indicates statistically significant.

Table 6. Comparison between pre-operative and 6-month post-operative data in both groups.

		PRE-OPRATIVE	6 MONTHS FOLLOW-UP	P VALUE
GROUP A	Ejection fraction (%)	57.1±6.9	63.66±4.9	< 0.001*
	Hypertension (%)	6(20%)	2(6.7%)	0.128
	Weight gain (Kg)	7.6±3.4	9.66±3.08	0.016*

(N = 30)	NYHA	I	19(63.3%)	30(100.0%)	<
		II	6(20.0%)	0(0%)	0.001*
		III	5(16.7%)	0(0%)	
	Ejection fraction (%)		55.1±8.9	64.6±4.9	< 0.001*
	Hypertension (%)		7(23.3%)	2(6.9%)	0.079
	Weight gain (Kg)		8±3.9	10.07±3.57	0.039*
GROUP B (N = 29)	NYHA	I	18(60.0%)	29(100.0%)	0.002*
		II	6(20.0%)	0(0%)	
		III	5(16.7%)	0(0%)	
		IV	1(3.3%)	0(0%)	

* indicates statistically significant.
NYHA=New York Heart Association.

4. Discussion

A definitive consensus regarding the optimal surgical approach for aortic coarctation repair remains elusive. Currently, EEA and EEEA constitute the most widely utilized surgical techniques.[16] However, given the inherent anatomical variability observed among patients, the optimal surgical strategy should be meticulously individualized. While several surgeons advocate for EEEA as the preferred approach due to its perceived enhanced safety profile, others believe that standard end-to-end anastomosis may facilitate improved hemodynamics and potentially stimulate more favorable aortic arch growth.[17]

The classical technique of EEA has demonstrated feasibility in the vast majority of cases. The EEEA has emerged as a safe and reproducible technique with favorable long-term outcomes, as evidenced by a significantly lower rate of re-intervention compared to standard EEA.[18] Extensive mobilization of the proximal and distal aortic segments is paramount. This necessitates meticulous dissection of the elastic neonatal aorta and the brachiocephalic vessels, ensuring adequate exposure of the proximal aortic arch to the ascending aorta. This comprehensive mobilization is crucial for achieving a technically sound aortic arch reconstruction. Moreover, it minimizes the risk of late scar tissue retraction and may contribute to a reduced incidence of recoarctation.[19]

In our study, the average cross-clamp time was 16.0±1.4 minutes in group A and 28.9±3.5 minutes in group B. Koç et al. reported that the average cross time was 16.7±5.8 minutes in the EEA technique and 23.4±7.7 minutes in the EEEA technique.[18] In Uguz et al, the average cross-clamp time was 19±7 minutes in the neonates and 14±4 minutes in the infants.[20] Also, Murakami and his colleagues stated that the average cross-clamp time was 16 minutes.[21]

In our study, the average ICU stay was 4.2±4 days in group A and 3.6±1.4 days in group B, and the average total hospital stay was 11.4±8 days in group A and 11±6.7 days in group B. In Farag et al., the median length of ICU stay was 2 days, and the median length of hospital stay was 7 days.[22] In Yilmaz et al, the average duration of ICU stay was 2.55±0.69 days in the neonate group and 2.14±0.97 days in the infant group, and the average total hospitalisation time was 14.23±5.03 days in the neonate group and 11.24±6.34 days in the infant group.[23]

The mortality rate in this study was 0% in group A and 3.3% in group B. In the literature, the mortality rate ranges between 1.4% and 9.7%.[20-24] Our results revealed that the average post-operative pressure gradient in the follow-up was 13.63±2.98 mmHg in group A and 1.55±2.35 mmHg in group B. In the literature, the median postoperative pressure gradient was 9.5±6.2 mmHg in Koç et al.,[18] 9±6 in Uguz et al.[20] and 17.08 mmHg in Murakami et al.[21].

Kotani et al. demonstrated that despite the presence of significant proximal aortic arch stenosis (Z-score <-6), EEEA can be associated with a low risk of reintervention, achieving a 90% freedom from reoperation at three years.[17] Furthermore, Tulzer et al. reported favorable outcomes with EEEA, demonstrating low perioperative morbidity and mortality rates. Notably, their study revealed an impressive 90.12% freedom from reintervention at the 10-year follow-up mark.[25]

Persistent hypertension occurred in 2 patients (6.7%) in group A and 5 patients (16.7%) in group B. Koç et al. reported 14 patients (22.9%) with persistent hypertension who used anti-hypertensive drugs.[18] Furthermore, Lillitos et al. demonstrated a significant temporal association between the timing of surgical repair and the subsequent risk of developing hypertension requiring medical management. Specifically, their study revealed a tenfold increase in this risk when surgical intervention was delayed until childhood compared to early neonatal repair.[26] Based on these collective observations, it is reasonable to hypothesize that early surgical intervention for coarctation may play a pivotal role in mitigating the long-term risk of developing hypertension requiring pharmacologic management.

Postoperative systemic hypertension is a frequent observation, particularly within the immediate postoperative period in pediatric patients undergoing coarctation repair.[27-29] This hypertensive state typically manifests as a biphasic phenomenon: Early-onset hypertension: Characterized primarily by an elevation in systolic blood pressure, this phase is generally self-limiting, resolving spontaneously within 48 hours. Late-onset hypertension: This phase is characterized by persistent elevation in both systolic and/or diastolic blood pressure beyond the initial 48 hours postoperative period. The persistence of hypertension beyond the initial 48 hours postoperatively is associated with an increased risk of developing post-coarctectomy

syndrome. This syndrome is clinically characterised by abdominal pain and is frequently associated with concurrent mesenteric arteritis.[20]

Numerous studies have compared patient characteristics, as well as preoperative and postoperative clinical and echocardiographic parameters, between patients requiring reintervention after aortic coarctation repair and those without the need for subsequent procedures. While several studies, including those by Adamson et al.,[30] Burch et al.,[31] and Liang et al.,[32] have observed a trend towards younger patient age at initial repair in those requiring reintervention, these findings did not reach statistical significance. Conversely, McElhinney et al.[33] reported a significant association between extremely early age at initial repair (less than 15 days of life) and an increased risk of reintervention.

4. Conclusion

The gold standard for coarctation repair is the surgical intervention with low morbidity and mortality. We compared resection with EEA and resection with EEEA. Our study reported that both surgical techniques improved the patient's weight, NYHA classification and ejection fraction.

Our results revealed that the resection with EEEA yields better results regarding lower residual pressure gradient immediately after the operation and 6 months post-operatively. However, it had a longer cross-clamp time and duration of mechanical ventilation and a higher need for post-operative inotropic support.

Disclosure

The authors have no financial interest to declare in relation to the content of this article.

Authorship

All authors have a substantial contribution to the article

Funding

No Funds : Yes

Conflicts of interest

There are no conflicts of interest.

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