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Directing a dispersion cannula tip toward the aortic root during thoracic aortic arch surgery does not adversely affect cardiac function

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Abstract

Introduction: Neurologic complications of open thoracic aortic surgery are devastating problems in patients with severely diseased aortas. This study aimed to clarify whether directing the aortic cannula tip toward the aortic root affects the postoperative cardiac function in patients undergoing open thoracic aortic surgery.

Methods: A total of 16 patients who underwent total or partial arch replacement between January 2014 and April 2019 were enrolled and divided into two groups. Ascending aorta perfusion was performed by placing the cannula tip toward the aortic root (reversed direction group, seven patients) or toward the aortic arch (standard direction group, nine patients). Intraoperative and perioperative data, including mortality, morbidity, and postoperative cardiac function, were compared between the groups.

Results: There were no hospital deaths or stroke events in either group. The aortic cross-clamping time was 102.4 ± 20.3 minutes in the reversed direction group and 87.1 ± 9.9 minutes in the standard direction group ($p = 0.049$). Furthermore, the intubation time was 28.4 ± 12.9 hours in the reversed direction group and 12.4 ± 6.8 hours in the standard direction group ($p = 0.022$). Both times were significantly longer in the reverse direction group. Postoperative serum creatine kinase-MB levels were significantly lower in the reversed direction group (6.2 ± 3.3 U/L vs 13.3 ± 4.8 U/L, respectively, $p = 0.006$). The cardiac output and cardiac index did not significantly differ.

Conclusions: Directing the aortic cannula tip toward the aortic root does not adversely affect the postoperative cardiac function after aortic arch surgery.

Keywords

aortic perfusion; atheroembolism; aortic arch surgery; cardiac function; cardiopulmonary bypass

Introduction

Stroke remains a crucial complication in cardiovascular surgery, with an incidence as high as 1% to 5% despite advances in surgical technique, cardiopulmonary bypass (CPB), and perioperative management.[1] The risk of atheroembolic stroke is elevated in patients with diffuse atherosclerotic disease,[2] and neurologic morbidity is about four times higher in open thoracic aorta surgery with a shaggy aorta.[3] Cerebral protection methods have progressed, and the incidence of cerebral complications can be reduced by techniques such as deep hypothermic circulatory arrest, antegrade selective cerebral perfusion (SCP), and retrograde cerebral perfusion.[4–7] Cannulation strategy has also improved. Axillary artery perfusion, femoral artery perfusion, and transapical aortic cannulation are alternatives to aortic cannulation in thoracic aortic surgery with a diffusely atherosclerotic aorta.[8–10] Directing a dispersion cannula toward the aortic root is one method to prevent atheroembolism. We call this unique perfusion method "reversed direction" in contrast to "standard direction" perfusion, where the cannula tip is directed toward the aortic arch. In an experimental study, we previously reported that the

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reversed direction method could prevent atheroembolism.[11] Several clinical studies have reported that placing a dispersion aortic cannula to point toward the aortic root can prevent atheroembolism.[11–13] However, it is still unknown whether this unique perfusion method affects postoperative cardiac function. The present retrospective study aimed to clarify whether this perfusion method affects postoperative cardiac function and to compare it with conventional perfusion with the dispersion cannula pointing toward the aortic arch.

Methods

Ethical approval

This study was approved by the Hirosaki University Graduate School of Medicine Institutional Review Board (2019-1154), and the need for individual consent was waived.

Patients

From January 2014 to April 2019, 144 thoracic aortic surgeries were performed at our institute. Of these, 79 cases of acute aortic dissection and 49 cases of endovascular repair were excluded. We analyzed the 16 patients who underwent total or partial arch replacement using ascending aorta perfusion. We divided the patients into two groups, one with the aortic perfusion cannula tip angled toward the aortic root (the reversed direction group, $n = 7$); the other had the aortic perfusion cannula tip facing toward the aortic arch (the standard direction group, $n = 9$). We evaluated the preoperative computed tomography (CT) to decide which perfusion method to use with each patient. Protruding atheromatous plaque in the aortic arch, extensive irregular intimal plaque in the aortic arch (so-called shaggy aorta; Figure 1), and fusiform aortic arch aneurysm with thick mural thrombus were indications for perfusion in the reverse direction. For the standard aortic direction group, we selected patients with a less diseased aortic arch and a saccular aneurysm in the lesser curvature.

Operations and CPB strategy

The chest was opened with a median sternotomy under general anesthesia. The ascending aorta was used as the aortic perfusion site in all cases. Atherosclerotic change of the ascending aorta and the transverse aortic arch were evaluated by epi-aortic ultrasonography using a hand-held ultrasound probe before aortic cannulation to determine an atherosclerotic plaque-free site for the cannulation. A 7-mm cannula (STEALTH FLOW®, Senko Medical Instrument, Tokyo, Japan) was used for all 16 patients. The arterial perfusion cannulas were inserted proximal to the aortic root, avoiding areas of plaque. Bicaval venous cannulation and left ventricular vents through the right superior pulmonary vein were used for all 16 patients. The flow of the CPB was set at 2.2–2.6 L/minutes/m^2. Color Doppler echocardiography with a hand-held ultrasound probe for the aortic root and ascending aorta was performed. The systemic circulatory arrest was achieved in a state of deep hypothermia (urinary bladder temperature, 25°C–28°C). To establish antegrade SCP, 15F, and 12F balloon-tipped cannulas (Senko Medical Instrument, Japan) were inserted into the brachiocephalic artery, the left common carotid artery, and the left subclavian artery. The temperature of the antegrade cerebral perfusate was the same as the systemic temperature during SCP. The total flow of SCP was set at 10–15 mL/kg/minutes with perfusion pressure and transcranial near-infrared oxygen saturation maintained above 40 mmHg and 60%, respectively. After completion of the distal anastomosis, the lower body perfusion was reinstituted through a branch of the four-branched graft. The proximal anastomosis was then performed, after which the arch vessels were reconstructed in the following order: left subclavian artery, left carotid artery, and brachiocephalic artery.

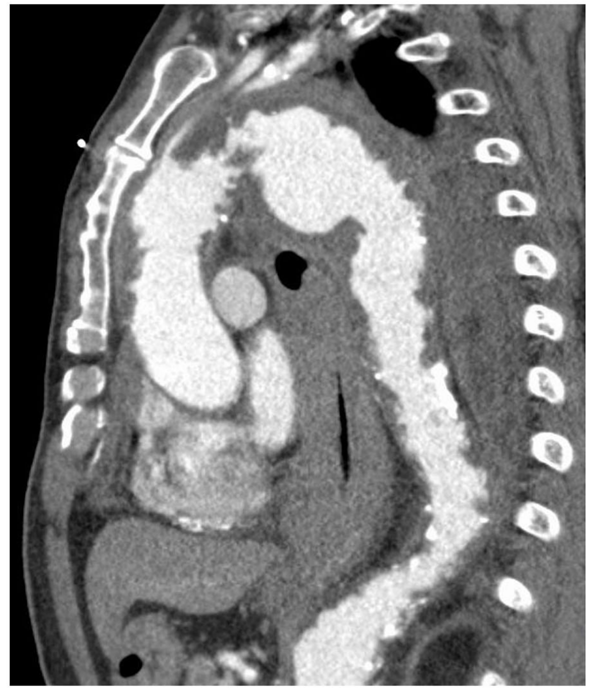

Figure 1. Typical computed tomography scan for perfusion in the reverse direction shows the typical protrusion of atheromatous plaque in the aortic arch, extensive irregular intimal plaque in the aortic arch, and fusiform aortic arch aneurysm with thick mural thrombus.

Table 1. Patient characteristics.

Variable	Reversed direction (*n* = 7)	Standard direction (*n* = 9)	p-Value
Male (sex)	4 (57.1)	4 (44.4)	0.47
Age (years)	73 ± 4	74 ± 6	0.64
Total arch replacement	6 (85.7)	6 (66.7)	0.417
Aortic insufficiency > mild	4 (57.1), mild: 3, moderate: 1	5 (55.6), mild: 5	0.545
LVDd (mm)	44.0 ± 3.9	44.4 ± 4.8	0.970
LVDs (mm)	27.1 ± 3.3	27.3 ± 3.7	0.902
LVEF (%)	66.2 ± 5.6	69.5 ± 9.7	0.421
LV mass (g)	149.6 ± 26.8	155.7 ± 58.1	0.814
LV mass index (g/m^2)	93.8 ± 11.7	108.0 ± 34.3	0.353

Data are presented as number (percentage) or mean ± standard deviation.
LVDd: left ventricular end-diastolic diameter; LVDs: left ventricular end-systolic diameter; LVEF: left ventricular ejection fraction; LV mass: left ventricular mass; LV mass index: left ventricular mass index.
*p < 0.05.

Myocardial protection

Antegrade cardioplegia using cold potassium crystalloid cardioplegic solution (STH2; Miotector®; Mochida Pharmaceutical Co., Tokyo, Japan) was performed through the aortic root or coronary ostium. An initial dose of 20 mL/kg was given immediately after circulatory arrest, followed by 10 mL/kg at 30-minute intervals.

Postoperative cardiac function and other variables

Postoperative cardiac function was evaluated using serum creatine kinase (CK) levels measured at 12 hours after reperfusion of the heart; serum creatine kinase-MB (CK-MB) levels measured at 12 hours after reperfusion of the heart; Swan-Ganz catheter data, including cardiac index (CI) and cardiac output (CO); and left ventricular end-diastolic diameter (LVDd), left ventricular end-systolic diameter (LVDs), left ventricular ejection fraction (LVEF), left ventricular mass (LV mass), and LV mass index measured by transthoracic echocardiogram. Permanent neurologic dysfunction was defined as the newly appeared neurological deficit after an operation, persisting at the time of discharge.

Statistical analysis

Data were processed using the IBM SPSS Statistics software, version 22 (IBM, Armonk, NY, USA). All continuous values are expressed as the mean ± standard deviation or the median with interquartile range. Categoric variables are expressed as the number (%) of the patients. Pearson's chi-square test or the Mann-Whitney *U* test was used to compare categoric variables. Differences were considered statistically significant at $p < 0.05$.

Results

Clinical studies

Table 1 shows patient characteristics. There was no difference in the proportion of mild or greater aortic insufficiency (AI) (57.1% vs 55.6%, respectively). There was no statistical difference between the two groups in terms of sex, age, type of procedures (total arch replacement), a grade of aortic valve regurgitation, LVDd, LVDs, LVEF, LV mass, and LV mass index. Table 2 shows the operative data. The operative time, CPB time, and SCP time were longer in the reversed direction group than in the standard direction group. Myocardial ischemic time was significantly longer in the reversed direction group than in the standard direction group, 102.4 ± 20.3 minutes versus 87.1 ± 9.9 minutes, respectively ($p = 0.049$). There were no statistical differences in the methods of cardioplegia.

Perfusion hemodynamics with Doppler echocardiography

Epiaortic echocardiography of a representative case in the reversed direction group is presented in Figures 2 and 3. Intraoperative color Doppler echocardiography findings indicated no retrograde flow toward the left ventricle (LV) (Figure 2). The mosaic pattern of reversed flow was observed in the aortic root (Figure 3(a)); however, this pattern was not present in the ascending aorta near the atheromatous plaque (Figure 3(a) and (b)).

Postoperative cardiac function

Table 3 shows the postoperative data. The postoperative serum CK-MB level was significantly lower in the reversed direction group than in the standard direction group (6.2 ± 3.3 U/L vs 13.3 ± 4.8 U/L, $p = 0.006$).

Table 2. Operative data.

Variable	Reversed direction, *n* = 7 (%)	Standard direction, *n* = 9 (%)	p-Value
Operative time (minutes)	415.4 ± 52.8	354 ± 66.1	0.06
Cardiopulmonary bypass time (minutes)	203.9 ± 26.0	177.3 ± 30.3	0.08
Myocardial ischemic time (minutes)	102.4 ± 20.3	87.1 ± 9.9	0.049*
Circulatory arrest time (minutes)	70.4 ± 25.1	56.0 ± 11.6	0.168
Selective cerebral perfusion time (minutes)	136.6 ± 13.9	116.3 ± 22.5	0.064
Minimum rectal temperature (°C)	24.4 ± 1.9	25.0 ± 1.3	0.525
Cardioplegia			
Antegrade through root	2 (28.6)	3 (33.3)	0.85
Antegrade through root + selective	2 (28.6)	0 (0)	0.098
Selective	3 (42.8)	6 (66.7)	0.375

Data are presented as mean ± standard deviation or number (percentage).
*$p < 0.05$.

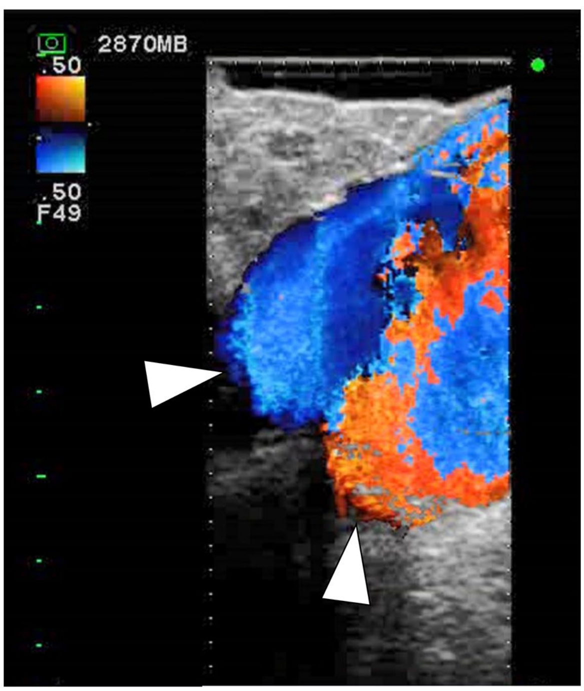

Figure 2. Epiaortic echocardiography during reversed perfusion (directing the aortic cannula toward the aortic root) reveals that the reversed blood flow turns around at the position of the aortic valve (arrowheads) and does not flow to the left ventricle.

There were no statistical differences between the two groups in the postoperative cardiac index during the intensive care unit stay and postoperative LVDd, LVDs, LVEF, LV mass, and LV mass index by transthoracic echocardiogram.

Intubation time was significantly longer in the reversed direction group (28.4 ± 12.9 hours vs 12.4 ± 6.8 hours, $p = 0.022$). There were no strokes or in-hospital deaths. Other postoperative complications included prolonged pericardial drainage (one patient in each group) and atrial fibrillation in one patient in the standard direction group.

Discussion

This study showed the clinical outcomes of 16 patients who underwent total or partial aortic arch replacement. There were no hospital deaths or strokes in all patients. This pilot study included the postoperative cardiac function of the reversed perfusion method (i.e. directing the aortic cannula tip toward the aortic root). Our results indicated that this unique perfusion method did not adversely affect the postoperative cardiac function.

Several operative techniques and preoperative and intraoperative management procedures were proposed to minimize neurological complications.[4–7,14] Arterial perfusion strategy is a critical point to prevent atheroembolism and perioperative neurologic dysfunction.[15,16] The efficacy of various kinds of arterial cannulation sites has been well documented. Ogino et al.[8] and Strauch et al.[17] reported that axillary artery perfusion had a protective effect against neurological complications. However, our flow dynamic study showed that the blood from the brachiocephalic artery in the right axillary artery perfusion flows toward the lesser curvature of the aortic arch.[18] Therefore, special care must be taken when the patient has a fragile atheroma around the arch vessels or lesser curvature of the aortic arch. In this study, there were no cases managed using the axillary perfusion method. Femoral artery perfusion is the classic alternative arterial perfusion site. The Yale University group reported a 1.8% incidence of permanent stroke in thoracic aortic surgery using femoral artery perfusion.[9] In contrast, Crooke et al.[19] reported that retrograde perfusion from the femoral artery is a risk factor for perioperative stroke in repeat cardiac surgery. Transapical aortic perfusion is a useful alternative perfusion method[10]; however, there are risks

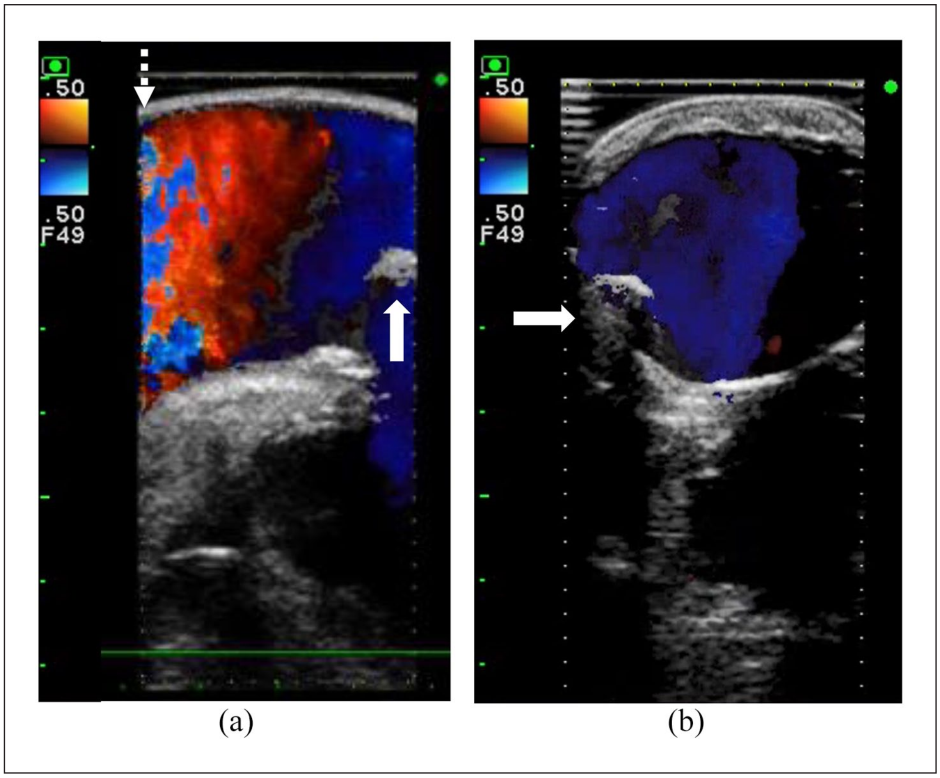

Figure 3. Epiaortic echocardiography during reversed perfusion shows a mosaic pattern into the aortic root, indicating wall shear stress and the sandblast effect of the aortic wall (a). A mosaic pattern cannot be observed in the ascending aorta near the atheromatous plaque (arrow) (a and b).
White dotted arrow indicates the site of the aortic cannula.

Table 3. Clinical outcomes.

Variable	Reversed direction ($n=7$)	Standard direction ($n=9$)	p-Value
Max CK (U/L)	386.8 ± 295.0	552.6 ± 462.5	0.081
Max CK-MB (U/L)	6.2 ± 3.3	13.3 ± 4.8	0.006*
Max CK-MB% (%)	2.2 ± 1.5	3.1 ± 0.3	0.043*
CI POD0 (L/minutes/m^2)	2.6 ± 1.2	2.9 ± 0.6	0.442
CI POD1 (L/minutes/m^2)	2.5 ± 1.1	2.8 ± 0.4	0.213
CI POD2 (L/minutes/m^2)	2.5 ± 1.4	3.6 ± 1.6	0.34
Intubation time (minutes)	28.4 ± 12.9	12.4 ± 6.8	0.022*
ICU stay (days)	3.4 ± 1.2	2.5 ± 0.8	0.184
LVDd (mm)	43.0 ± 1.9	42.4 ± 5.2	0.801
LVDs (mm)	29.5 ± 1.7	27.4 ± 2.1	0.187
LVEF (%)	63.6 ± 3.7	66.0 ± 4.9	0.468
LV mass (g)	136.8 ± 23.8	132.0 ± 55.9	0.895
LV mass index (g/m^2)	87.9 ± 20.6	93.3 ± 33.1	0.806
Stroke	0 (0)	0 (0)	
In-hospital mortality	0 (0)	0 (0)	
30-day mortality	0 (0)	0 (0)	

Data are presented as mean ± standard deviation or number (percentage).
CK: creatine kinase; CI: maximal cardiac index during the day; POD: postoperative day; ICU: intensive care unit; LVDd: left ventricular end-diastolic diameter; LVDs: left ventricular end-systolic diameter; LVEF: left ventricular ejection fraction; LV mass: left ventricular mass; LV mass index: left ventricular mass index.
*$p < 0.05$.

of bleeding and cardiac arrhythmias. On the contrary, the reversed direction method is a simple technique because surgeons can cannulate in the usual manner, except that they subsequently turn the cannula half-way around. Grooters et al.[13] reported satisfactory clinical outcomes of the reversed direction method in patients undergoing coronary artery bypass grafting. In an experimental study, we previously reported that directing the aortic cannula tip toward the aortic root generated slower and less turbulent flow in the transverse arch of the glass models of both healthy and aneurysmal aortic arches.[11] This method attenuated the sandblast effect caused by high flow velocity and shear stress from directing an aortic cannula tip toward the aortic arch. Yamana et al.[12] reported unique transesophageal echocardiogram data on the reversed direction method during a total aortic arch repair. They showed that perfusion toward the aortic root led to a significant decrease in peak forward flow velocity in the aortic arch during CPB. The findings of the present study support the results of our experimental study as well as those of the clinical study conducted by Yamana et al. because epiaortic echocardiography during the reversed direction method revealed that the mosaic pattern was present in the aortic root but not in the ascending aorta. Okada et al.[4] reported that the efficiency of using the same perfusion method reduced mortality and morbidity from neurological dysfunction in patients with a severely diseased ascending aorta/aortic arch. In the present study, the operative time, CPB time, SCP time, myocardial ischemic time, and intubation time were longer in the reversed direction group than in the standard direction group. All 16 patients underwent total or partial arch replacement without additional procedures. In the reversed direction group, secure anastomosis was required to prevent bleeding from the anastomotic site because the highly diseased aortas were at high risk for reintervention due to excessive bleeding. There was no difference in the patient background; nevertheless, one emergency case was included in the reversed direction group. Additionally, as a more secure anastomosis was necessary for the reversed direction group, longer operative time and selective cerebral perfusion time may contribute to this longer intubation time. However, no stroke events occurred even though the reversed perfusion group had highly diseased aortas.

Although previous reports have shown the efficacy of reducing neurological dysfunction using this unique perfusion method, little is known about its effect on postoperative cardiac function. Placing the aortic cannula tip toward the aortic root may increase afterload due to the reversed blood flow. The present study showed that the postoperative maximum of serum CK-MB levels was significantly lower in the reversed direction group, although myocardial ischemic time was significantly longer. No statistical differences in postoperative CI, LVDd, LVDs, LVEF, LV mass, and LV mass index were observed between the two groups. The postoperative clinical courses were good in both groups. These results indicate that the reversed direction perfusion method does not affect postoperative cardiac function despite direct flow toward the aortic root. Importantly, one of the concerns with this method is the effect of retrograde flow in the aorta toward the LV. In our previous experimental study, shear stress and turbulence were notably high in the aortic root by placing the cannula toward the aortic root.[11] In the present study, reversed flow toward the LV was not observed with mild or lesser AI. In the presence of AI, reversed flow toward the LV can worsen LV function due to an increase in LV volume overload and afterload. Although the present study included three patients with mild AI and one patient with moderate AI in the reversed direction group, the postoperative cardiac function did not deteriorate. Even with AI, left ventricular dilation could be controlled by left ventricular venting. We believe that the reversed direction perfusion method can be safely applied to patients with mild or lesser AI.

The present study has several limitations. This study was a single-center retrospective study with a small number of patients. The two groups were different in terms of aortic pathology, and patients in the reversed direction group had more highly diseased aortas than those in the standard direction group. The prevalence of "shaggy" or "hostile" aortic arch aneurysm is relatively low. This is because a high-volume study is difficult for this clinical entity. Further multicenter clinical studies for this method on patients with similar backgrounds are therefore warranted.

Conclusion

The reversed aortic perfusion method (that is, directing the aortic cannula tip toward the aortic root) does not affect the postoperative cardiac function after procedures for thoracic atherosclerotic ascending or arch aneurysm. This unique perfusion method could be applied to many cardiac procedures to prevent atheroembolism without worsening postoperative cardiac function. This perfusion method could have the possibility of a paradigm shift in the cannulation method.

Declaration of conflicting interests

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Author contributions

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by YI and RK. The first draft of the manuscript was written by YI and RK, and all authors commented on the previous versions of the manuscript. All authors read and approved the final manuscript.

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