Impact of closed minimal extracorporeal circulation on microvascular tissue perfusion during surgical aortic valve replacement: intravital imaging in a prospective randomized study

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Abstract

OBJECTIVES: Closed minimal extracorporeal circulation (MECC) systems currently do not represent the standard of surgical care for open-heart surgery. Yet, considering the beneficial results reported for coronary artery bypass graft (CABG) surgery, we used an MECC system in aortic valve replacement (AVR) and analysed the effects on intraoperative microvascular perfusion in comparison with conventional open extracorporeal circulation (CECC).

METHODS: In the current study, we analysed alterations in microvascular perfusion at 4 predefined time points (T1–T4) during surgical AVR utilizing orthogonal polarization spectral (OPS) imaging. Twenty patients were randomized for being operated on utilizing either MECC or CECC. Changes in functional capillary density (FCD, cm/cm²), microvascular blood flow velocity (mm/s) and vessel diameter (μm) were analysed by a blinded investigator.

RESULTS: After the start of extracorporeal circulation and aortic cross-clamping (T2), both groups showed a significant drop in FCD, but with a significantly higher FCD in the MECC group (153.1 ± 15.0 cm/cm² in the CECC group vs 160.8 ± 12.2 cm/cm² in the MECC group, P = 0.034). During the late phase of the cardiopulmonary bypass (CPB) (T3), the FCD was still significantly depressed in both treatment groups (153.5 ± 14.6 cm/cm² in the CECC group, P <0.05 vs T1; 159.5 ± 12.4 cm/cm² in the MECC group, P <0.05 versus T1). After termination of CPB (T4), the FCD recovered in both groups to baseline values. Microvascular blood flow velocity tended to remain at a higher level in the MECC group, whereas haemodilution during CPB was significantly reduced in the MECC group.

CONCLUSIONS: The use of MECC in AVR did not affect procedural safety and, resulted in beneficial preservation of microvascular blood flow velocity and significantly reduced haemodilution during CPB. In contrast to CABG surgery, the use of MECC did not improve FCD during surgical AVR. Clinical advantages possibly resulting from attenuated haemodilution and preservation of microvascular blood flow velocity require further validation in larger patient cohorts.

Keywords: Aortic valve replacement • Minimal extracorporeal circulation • Microcirculation • Haemodilution

INTRODUCTION

Despite a constantly ageing patient population, the rate of perioperative complications in surgical aortic valve replacement (AVR) has constantly decreased during the past 3 decades. However, minor perioperative organ complications are still common, especially in patient cohorts exhibiting medium or high perioperative risk. These complications are primarily considered as consequences of microemboli, air bubbles [1] and ischaemia–reperfusion injury. However, changes particularly in microvascular perfusion might also have a relevant role in causing these complications owing to the known relevance of microcirculation in perioperative organ dysfunction [2, 3]. To minimize cardiopulmonary bypass (CPB)-related adverse effects, and thereby to further reduce perioperative morbidity associated with on-pump cardiac surgery, minimal extracorporeal circulation (MECC) systems have been developed and introduced successfully in the clinical routine, primarily in the setting of on-pump coronary artery bypass (CABG) surgery. The concept is based on the idea of a closed low-volume circuit comprising only a rotary blood pump and a modern low-volume membrane oxygenator (MO). The venous blood returns through active drainage. Neither a venous reservoir nor a cardiotomy suction device is used. The shed blood is separated from the systemic circulation. The components, including
METHODS

Patient selection

Twenty patients scheduled for urgent or elective surgical AVR surgery because of aortic valve stenosis or regurgitation were enrolled between November 2012 and March 2013. Exclusion criteria were carotid artery stenosis greater than 60%, age >80 years, atrial fibrillation, left ventricular ejection fraction of less than 30%, coronary artery disease, emergency operation, endocarditis, reoperation or multiple valve surgery. Patients were randomized into two groups [conventional open extracorporeal circulation (CECC) and MECC groups] by using computer-generated random allocation. The study was approved by the institutional ethics committee and all patients provided their written informed consent.

Perfusion technology

Conventional open extracorporeal circulation group. A standard open bypass circuit was used, comprising a heparin-coated (Bioline Coating, Maquet Cardiopulmonary) tubing system, a hard-shell venous reservoir, a microporous MO (Quadrox-i Adult; Maquet Cardiopulmonary), with an integrated arterial line blood filter and a roller pump (RP 150, Maquet Cardiopulmonary). The circuit was primed with 1500 ml (mean 1488 ± 33 ml) of a balanced crystalloid/collodion solution (1000 ml of collodion and 500 ml of crystalloid solution).

Minimal extracorporeal circulation group. The MECC system (Maquet Cardiopulmonary) comprised a preconnected closed CPB circuit containing a RotaFlow centrifugal pump and a Quadrox™ diffusion MO. A flowmeter was integrated in the drive unit of the centrifugal pump. The MO contained a heat exchanger. Furthermore, the system featured a tip-to-tip heparin coating (Bioline Coating, Maquet Cardiopulmonary). Except a venous bubble trap, no arterial or venous line filters were included. A cell saver was used for intraoperative blood suction. The priming volume of the system was 1000 ml (mean 1010 ± 66 ml) crystalloid solution. The extracorporeal flow rate for both systems was set at 2.4 l min⁻¹ m⁻².

Anticoagulation was attained by administration of 300 IU/kg heparin, to achieve an activated clotting time of longer than 400 s. For both groups, alpha-stat blood gas management was used.

Anaesthesia

A standardized anaesthetic protocol was used for all patients. After obtaining intravenous (iv) access, the left arterial artery was cannulated with a 20-G arterial catheter (Leadercath Vygon, Eucon, France) for continuous monitoring of the arterial blood pressure. Afterwards, anaesthesia was induced with sufentanil (0.25 μg kg⁻¹, Janssen-Cilag GmbH, Neuss, Germany) and etomidate (0.2 mg kg⁻¹, B. Braun Melsungen AG, Melsungen, Germany). After relaxation with rocuronium (0.6 mg kg⁻¹, ORGANON GmbH, Oberschleißheim, Germany), patients were orally intubated with an otrorhal tube (Covidien, Mansfield, MA, USA). Anaesthesia was maintained with continuous infusion of propofol (4 mg kg⁻¹ h⁻¹, B. Braun, Melsungen AG), sufentanil (1 μg kg⁻¹, Janssen-Cilag GmbH) and cisatracurium (Glaxo Smithkline GmbH & Co. KG, Munich, Germany). Pressure-controlled mechanical ventilation was provided by a Primus® anaesthesia ventilator (Draeger, Lubeck, Germany). The respiratory rate and pressure were adjusted to maintain an arterial partial pressure of carbon dioxide (PaCO₂) of 4.8–5.6 kPa. A positive end-expiratory airway pressure of up to 5 cm H₂O was applied to maintain an arterial partial pressure of oxygen (PaO₂) of 12–15 kPa.

A triple-lumen catheter (7F Triple-Lumen CVC 3, 7 Fr, 20 cm, Arrow, Reading, PA, USA) and an 8.5-Fr introducer (Percutaneous Sheath Introducer Set; Arrow) were inserted into the right internal jugular vein. Body temperature was monitored continuously with a thermistor in the urinary catheter (16 Fr, Teleflex Medical GmbH, Kernen, Germany).

Surgical intervention and cardioplegia

Median sternotomy, pericardiotomy and heparinization were followed by standard venous and arterial cannulation: a 24-Fr arterial cannula for the ascending aorta and a 32/37-Fr two-stage cannula for the right atrial appendage. Venting was accomplished by using a left atrial vent via the right upper pulmonary vein in the CECC group. In the MECC group, a double vent was used: the first vent was placed via the pulmonary artery; distal to the pulmonary valve, the second vent was placed as a needle vent in the ascending aorta. The aortic vent was used only before aortotomy, whereas the pulmonary artery vent was used during the cross-clamp period. Both vents were directly connected to the venous bubble trap. Antegrade warm blood cardioplegia (Calafiore, a mixture of arterial blood, 10 ml KCl 14.9% and 2 ml MgSO₄ 50 Vol%) was administered through the aortic root after aortic cross-clamping, and subsequently into the coronary arteries following aortotomy, or primarily into the coronary arteries in the case of relevant aortic valve regurgitation. Surgical intervention was performed during mild hypothermia (oesophageal temperature, 33–34°C). Cardioplegia boluses were given in 20-min intervals. The aorta was closed in the usual manner. After rewarming, the patient was weaned off CPB, and heparin was neutralized.

Orthogonal polarization spectral imaging

This imaging technique has been described in detail previously [8, 9]. Briefly, sublingual microcirculation was observed using the Cytoscan™
System (Cytoscan™, Cytometrics Incorporated, Philadelphia, USA) comprising an optical probe connected to an external light source via a liquid light guide cable. Using a standard video recorder (S-VHS, AG 7350-E, Panasonic, Matsushita Electric Ind., Osaka, Japan) and a standard video screen, online imaging and also recording of obtained images for later off-line analysis were performed. On the video screen, a final 465-fold magnification was achieved. To visualize erythrocytes, light was passed through a spectral filter to isolate the wavelength of 548 nm (isosbestic point of haemoglobin, Hb). The polarized light was then emitted to the target by a beam splitter. The light, sent back from the target, was collected by the same lens. All images obtained of the illuminated region were captured using a charge-coupled device video camera.

Similar to epi-illumination intravital microscopy, OPS imaging allows the measurement of the vessel diameter, length of the perfused vessels per observation area and flow velocity of the red blood cells inside the vessel.

OPS images were obtained from the sublingual mucosa where the probe was put in direct contact with the tissue. Once blood vessels were identified, it was manually focussed and, by stabilizing the probe gently on the patient's teeth, it was possible to obtain good images with minimal movement artefacts. Care was taken to minimize the contact pressure necessary for the venules and capillaries to remain in focus. In this way, artificial impairment of the sublingual blood flow could be minimized. OPS images were recorded at 4 time points: after induction of anaesthesia before skin incision (T1, baseline), after start of CPB and aortic cross-clamping (T2), 10 min after release of the aortic cross-clamp (T3) and 30 min after termination of CPB (T4). At each time point, 4 to 5 sequences of 30 s were recorded. All visible microvessels in each sequence were analysed. For the quantitative off-line analysis, a computer-assisted microcirculation image analysis system was used (CapImage v7.4, Zeintl, Heidelberg, Germany). Off-line analysis included red blood cell velocity, vessel diameter as well as functional capillary density (FCD), which is the total length of red blood cell-perfused capillaries per observation area, given in cm/cm², and was performed by a blinded investigator.

Intraoperative monitoring

Arterial oxygen saturation (SaO₂), central venous oxygen saturation (SvO₂), arterial lactate as well as Hb and haematocrit (Hkt) were monitored and recorded at the 4 time points of microvascular measurements described above.

Study conditions and recording of clinical and laboratory parameters

Several study conditions were predefined for standardization. The operations were performed by 2 experienced surgeons. The random allocation of the perfusion method was not communicated to the surgeon before the operation. During perfusion, Hkt values were not allowed to decrease to less than 0.25; otherwise, packed red cells were transfused. When mean arterial pressure decreased to less than 45 mmHg, a bolus of 0.01 mg of norepinephrine was administered. Units of packed red cells transfused, vasopressor use and intraoperative clinical events were recorded. Furthermore, during the initial postoperative period, several clinical and laboratory parameters were recorded, including:

postoperative creatine kinase and troponin T levels, the need for postoperative transfusions, as well as any neurological or cardiovascular event and the length of intensive care unit (ICU) stay. The study parameters were entered into a computer database and processed in a blinded manner by a single investigator.

Statistical analysis

The primary outcome variable was the change in FCD. Continuous data are expressed as means ± standard error of mean. Changes in the FCD, vessel diameter, red blood cell velocity, Hkt and lactate over time were analysed by using repeated-measures ANOVA and pairwise multiple comparison procedure (Holm-Sidak method). Intergroup comparison for preoperative, perioperative and postoperative data was assessed using the Student’s t-test for continuous variables and the Fisher’s exact test for proportions. Statistical analysis was performed with the SPSS software package (version 12.0; SPSS, Inc., Chicago, IL, USA).

RESULTS

All patients completed the study. Patient demographic data as well as baseline intraoperative characteristics are summarized in Table 1. There were no significant differences between the study groups regarding age, gender distribution, presence of diabetes, nicotine abuse or peripheral vascular disease, cross-clamp time, total CPB time or the need for intraoperative norepinephrine use (Table 1). All patients except 1 were discharged from the hospital following an uneventful postoperative course in a stable cardiovascular condition. One patient from the CECC group died on the fifth postoperative day after a massive cerebrovascular insult of unknown reason.

Intraoperative lactate and haematocrit levels

The baseline lactate level did not differ between the groups (0.8 ± 0.2 mmol in the CECC group vs 0.9 ± 0.2 mmol in the
MECC group at T1, \( P = 0.83 \). The intraoperative changes in serum lactate levels did not differ significantly between the groups (Table 2). Regarding intraoperative Hkt values, a significant difference between the MECC and the CECC groups was detected at the time points T2 (27.6 ± 3.5 in the CECC group vs 35.3 ± 4.8 in the MECC group, \( P = 0.008 \)) and T3 (27.9 ± 3.9 in the CECC group vs 33.3 ± 4.6 in the MECC group, \( P = 0.012 \)), indicating a more marked haemodilution in the CECC group during CPB (Table 2). Moreover, patients operated on within the CECC group exhibited an elevated need for intraoperative transfusions compared with the MECC group (0.56 ± 0.24 red blood cell units in CECC vs 0.20 ± 0.13 red blood cell units in MECC, \( P = 0.11 \)).

**Microvascular alterations measured by orthogonal polarization spectral imaging**

In general, the OPS imaging technique proved feasible in terms of visualizing sublingual microcirculation during aortic valve surgery (Fig. 1). Independent from the type of extracorporeal circulation, a certain degree of impairment regarding the microvascular tissue perfusion during CPB was detectable.

### Table 2: Intraoperative laboratory data

<table>
<thead>
<tr>
<th>Laboratory data</th>
<th>T1</th>
<th></th>
<th>T2</th>
<th></th>
<th>T3</th>
<th></th>
<th>T4</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CECC</td>
<td>MECC</td>
<td>CECC</td>
<td>MECC</td>
<td>CECC</td>
<td>MECC</td>
<td>CECC</td>
<td>MECC</td>
</tr>
<tr>
<td>Lactate (mmol/l)</td>
<td>0.8 ± 0.1</td>
<td>0.8 ± 0.2</td>
<td>1.0 ± 0.1</td>
<td>1.0 ± 0.3</td>
<td>1.7 ± 0.2*</td>
<td>1.4 ± 0.3*</td>
<td>1.6 ± 0.2*</td>
<td>1.4 ± 0.3*</td>
</tr>
<tr>
<td>Haematocrit (%)</td>
<td>37.2 ± 1.5</td>
<td>38.4 ± 1.4</td>
<td>28.6 ± 1.3*</td>
<td>35.3 ± 1.6*</td>
<td>27.8 ± 1.2*</td>
<td>33.3 ± 1.5*</td>
<td>30.4 ± 1.1*</td>
<td>31.2 ± 1.5*</td>
</tr>
</tbody>
</table>

| CECC: conventional extracorporeal circulation; MECC: minimized extracorporeal circulation. |
| Data are presented as means ± SEM. |
| *\( P < 0.05 \) versus T1, †\( P < 0.05 \) versus CECC. |

**Figure 1:** Representative images of sublingual microcirculation obtained by orthogonal polarization spectral imaging at 4 time points during surgical aortic valve replacement. T1: at skin incision; T2: 10 min after aortic cross-clamping; T3: 10 min after release of the aortic cross-clamp; T4: 30 min after termination of cardiopulmonary bypass (manual off-line measurement of the sublingual functional capillary density is illustrated by lines drawn).
Functional capillary density

There was no significant difference in the baseline level of the FCD between the two groups (159.9 ± 15.2 cm/cm² in the CECC group vs 164.9 ± 14.0 cm/cm² in the MECC group, P = 0.10). After the start of extracorporeal circulation and aortic cross-clamping (T2), both groups showed a significant drop of the FCD when compared with the respective baseline values, but with a significantly higher FCD in patients operated with the MECC system (153.1 ± 15.0 cm²/cm² in the CECC group vs 160.8 ± 12.2 cm²/cm² in the MECC group, P < 0.05). At T3, in the late phase of the CPB, the FCD in both groups was still significantly impaired and below the baseline values (153.5 ± 14.6 cm²/cm² in the CECC group, P < 0.05 vs T1; 159.5 ± 12.4 cm²/cm² in the MECC group, P < 0.05 vs T1). Intergroup comparison did not reveal a significant difference of the FCD between the 2 groups at T3 (P = 0.071). After termination of the CPB, FCD recovered in both groups to baseline values (Fig. 2).

Vessel diameter and blood flow velocity

There was no significant difference detectable between the groups regarding the diameters of post-capillary venules in the sublingual microcirculation at baseline (29.6 ± 2.7 μm in the CECC group vs 28.9 ± 2.0 μm in the MECC group, P = 0.07). At T2 and T3, the MECC group showed a significant reduction in microvascular diameter (27.7 ± 1.8 μm at T2 and 27.8 ± 1.9 μm at T3; P < 0.001 vs T1) before returning to baseline levels at T4 (Fig. 3). The CECC group revealed a significant reduction in the microvascular diameter at T2 (28.0 ± 2.3 μm at T2; P < 0.001 vs T1), but no further significant changes in the microvascular vessel diameter over the time course of the operation (Fig. 3). Measurements of red blood cell velocity in post-capillary venules revealed no significant intraoperative changes during surgical AVR utilizing either CECC or MECC. However, the blood flow velocity tended to be higher in the MECC group at T2 and T3 (0.542 ± 0.04 mm/s in the CECC group at T2 vs 0.552 ± 0.05 mm/s in the MECC group at T2, P = 0.43; and 0.550 ± 0.04 mm/s in the CECC group at T3 vs 0.554 ± 0.06 mm/s in the MECC group at T3, P = 0.41) (Fig. 4).

Postoperative parameters

The postoperative course of creatine kinase, representing a global marker of hypoperfusion during cardiopulmonary bypass, and troponin T, indicating the amount of myocardial damage during CPB, did not differ significantly between the groups (Table 3). Furthermore, there were no significant differences detectable regarding the postoperative course of serum lactate levels and Hkt (Table 3). No significant difference between the groups was detected regarding the length of ICU stay (1.56 ± 0.88 days in the

Figure 2: FCD of the sublingual microcirculation measured by OPS imaging at four time points. T1: after skin incision; T2: 10 min after aortic cross-clamping; T3: 10 min after release of the aortic cross-clamp; T4: 30 min after termination of the CPB. The plots illustrate the variation in FCD during surgical AVR utilizing conventional extracorporeal circulation (CECC, n = 10 patients) and minimal extracorporeal circulation (MECC, n = 10 patients). *P < 0.05 versus T1, #P < 0.05 versus CECC. Data are presented as means ± SEM. CECC: conventional extracorporeal circulation; MECC: minimal extracorporeal circulation.

Figure 3: Post-capillary venular diameter (μm) of the sublingual microcirculation measured by OPS imaging at four time points. T1: after skin incision; T2: 10 min after aortic cross-clamping; T3: 10 min after release of the aortic cross-clamp; T4: 30 min after termination of the CPB. The plots illustrate the variation in the venular diameter during surgical AVR utilizing CECC (n = 10 patients) and MECC (n = 10 patients). *P < 0.05 versus CECC. Data are presented as means ± SEM. CECC: conventional extracorporeal circulation; MECC: minimal extracorporeal circulation.

Figure 4: Post-capillary venular blood flow velocity (mm/s) of the sublingual microcirculation measured by OPS imaging at four time points. T1: after skin incision; T2: 10 min after aortic cross-clamping; T3: 10 min after release of the aortic cross-clamp; T4: 30 min after termination of the CPB. The plots illustrate the variation in the venular blood flow velocity during surgical AVR utilizing CECC (n = 10 patients) and MECC (n = 10 patients). *P < 0.05 versus CECC. Data are presented as means ± SEM. CECC: conventional extracorporeal circulation; MECC: minimal extracorporeal circulation.
patients tended to require fewer postoperative transfusions and units/patient in the MECC group, the need for postoperative transfusions (0.75 ± 0.89 red blood cell
reduce adverse effects associated with conventional CPB [10, 11]. Systems have also recently been proposed for surgical AVR to
Facing a continuously ageing patient population and challenged
DISCUSSION
CECC group vs 1.40 ± 0.70 days in the MECC group, P = 0.83) or the need for postoperative transfusions (0.75 ± 0.89 red blood cell units/patient in the CECC group vs 0.50 ± 0.85 red blood cell units/patient in the MECC group, P = 0.56), although MECC patients tended to require fewer postoperative transfusions and less time on ICU.

CECC vs MECC

Table 3: Postoperative laboratory data

<table>
<thead>
<tr>
<th>Haemodynamic and laboratory data</th>
<th>Postoperative</th>
<th>6 h postoperative</th>
<th>12 h postoperative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CECC</td>
<td>MECC</td>
<td>CECC</td>
</tr>
<tr>
<td>Creatine kinase (U/L)</td>
<td>187 ± 52</td>
<td>198 ± 42</td>
<td>285 ± 79*</td>
</tr>
<tr>
<td>Troponin T (ng/ml)</td>
<td>0.23 ± 0.18</td>
<td>0.25 ± 0.15</td>
<td>0.27 ± 0.12</td>
</tr>
<tr>
<td>Lactate (mmol/l)</td>
<td>1.5 ± 0.6</td>
<td>1.4 ± 0.4</td>
<td>1.7 ± 0.6</td>
</tr>
<tr>
<td>Haematocrit (%)</td>
<td>28.9 ± 3.0</td>
<td>31.1 ± 4.0</td>
<td>29.9 ± 3.2</td>
</tr>
</tbody>
</table>

CECC: conventional extracorporeal circulation; MECC: minimized extracorporeal circulation.

Data are presented as means ± SEM.

*P < 0.05 versus postoperative.

and contact activation of the blood. The problems resulting from movement artefacts as well as contact pressure during OPS imaging have been already discussed extensively [1]. As concluded by Bauer et al., we assume that potential error would be random and, therefore, differences between patients should still be detectable.

According to our findings, both MECC and CECC cause alterations in microvascular tissue perfusion. This is indicated by the significant intraoperative drop in FCD during CPB in both study groups. FCD represents a key indicator of nutritive tissue perfusion and we have previously shown a beneficial effect of MECC on the recovery of FCD during CPB in CABG surgery [15]. However, in the current study, analysing open-heart surgery, we detected a differential outcome regarding the MECC effects on intraoperative microvascular tissue perfusion. In contrast to CABG, the use of MECC in AVR did not result in a significantly enhanced recovery of FCD during CPB.

The reason for this discrepancy between CABG and surgical AVR regarding the beneficial effects of MECC on FCD cannot be answered conclusively. It is conceivable, however, that the nature of AVR representing open-heart surgery interferes with the MECC concept in terms of avoiding any blood–air contact. Microbubbles, for example, are more likely to occur even in a closed circuit and might cause transient microvascular emboli impairing tissue perfusion.

Hypothermia represents another factor potentially influencing microvascular perfusion during CPB. However, patients analysed in the current study were operated utilizing moderate hypothermia, whereas only deep hypothermia has been shown to be associated with relevant changes in FCD so far [16]. By contrast we, as others, were able to demonstrate the capability of MECC to reduce haemodilution during the course of CPB in surgical AVR. The deleterious effects of haemodilution on both microvascular tissue oxygenation [17] and clinical outcome following cardiopulmonary bypass [18, 19] have been shown before. Furthermore, recent experimental results provide good evidence that low Hkt and blood viscosity conditions lead to a constricted circulation [20] with consecutively impaired FCD. Therefore, MECC systems are likely to offer clinical advantages, especially in patient cohorts exhibiting medium or high perioperative risk and, as demonstrated by the current study, these advantages can be obtained without compromising the level of procedural safety in elective surgical AVR. Given that our study was not primarily designed to detect differences in the perioperative outcome between the treatment groups, we cannot demonstrate a significant clinical advantage for MECC in surgical AVR;
however, there was a trend towards a shorter ICU stay and reduced postoperative transfusions in the MECC group. By contrast the perioperative course might be influenced by a higher odds ratio for diabetes within the MECC group.

Interestingly, our analysis revealed a tendency of beneficial preservation of microvascular blood flow velocity in the MECC group, although marked haemodilution, as occurring during conventional ECC, is assumed to contribute to an increase in microvascular blood flow velocity [21]. The finding might be explained at least partially by the previously reported difference in systemic perfusion pressure during CPB with higher mean arterial pressures in the MECC [15] group, because a positive correlation between sublingual blood flow velocity and mean arterial pressure has been already described by Wiessner et al. [22].

In conclusion, we were able to show that the microvascular blood flow velocity in MECC remained at a higher level compared with that for CECC patients undergoing surgical AVR. Furthermore, the use of MECC in surgical AVR resulted in significantly reduced haemodilution during CPB and a trend towards perioperative advantages without affecting procedural safety. In contrast to coronary artery bypass surgery, MECC did not accelerate the recovery of the FCD during CPB. The clinical advantages possibly resulting from attenuated haemodilution and beneficial microvascular blood flow velocity require further validation in larger patient cohorts.

Conflict of interest: none declared.

REFERENCES