IJAO The International Journal of Artificial Organs

Original Research Article

The International Journal of Artificial Organs
1–9

DOI: 10.1177/0391398818784791
journals.sagepub.com/home/jao
SAGE

Pressure difference between radial and femoral artery pressure in minimally invasive cardiac surgery using retrograde perfusion

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Abstract

Objective: To investigate whether radial artery pressure is a reliable surrogate measure of central arterial pressure as approximated by femoral artery pressure in minimally invasive cardiac surgery with retrograde perfusion via femoral cannulation.

Method: Fifty-two consecutive patients undergoing minimally invasive cardiac surgery were prospectively included in this study. Cardiopulmonary bypass was established via a femoral artery cannulation and femoral vein. Radial and femoral arterial pressures were recorded continuously, and the pressure differential between them was calculated for both systolic and mean arterial pressures. The agreement between measurements from the two arteries was compared using Bland–Altman plots. An interval of 95% limits of agreement of less than 20 mm Hg was set as satisfactory agreement.

Results: Average age was 65 ± 14 years. With respect to systolic arterial pressure, 28 patients (54%) had a peak pressure differential between radial and femoral arteries $\geqslant$20 mm Hg. With respect to mean arterial pressure, only five patients (9%) had a peak pressure differential $\geqslant$20 mm Hg. The pressure differential changed with time. Pressure differential in systolic arterial pressure was 5 ± 8 mm Hg until aortic declamping, then increased to a peak of 23 ± 16 mm Hg when cardiopulmonary bypass was turned off. The femoral systolic arterial pressures were significantly greater than radial systolic arterial pressures from time of aortic declamping to 20 min after cardiopulmonary bypass. The Bland–Altman plots revealed large biases and poor agreement in this period.

Conclusion: Radial and femoral systolic artery pressure readings can differ significantly in minimally invasive cardiac surgery with retrograde perfusion. Intraoperative arterial pressure management based solely on radial systolic arterial pressure readings should be avoided.

Keywords
Minimally invasive cardiac surgery, monitoring, cardiopulmonary bypass, femoral cannulation, retrograde perfusion, radial artery

Date received: 27 February 2018; accepted: 3 June 2018

Introduction

It is imperative that blood pressure monitoring be accurate in any cardiac surgery. While the monitoring of radial artery pressure is generally accepted as a way to confirm that systemic blood pressure is adequate during cardiac surgery, it has been reported that the radial artery pressure can become lower than central artery pressure during cardiopulmonary bypass (CPB).[1,2] Notably, these data were obtained from

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patients who underwent conventional cardiac surgery, which we define as surgery with median sternotomy and antegrade systemic perfusion via central aortic cannulation. Minimally invasive cardiac surgery (MICS) in which systemic perfusion is achieved retrogradely via femoral cannulation is becoming increasingly common.[3,4] However, there are no reports that assess whether the phenomenon of low radial artery pressure reading relative to central artery pressure occurs during MICS with its retrograde perfusion. In our own experience of approximately 400 MICS cases with retrograde perfusion via femoral cannulation, we have the impression that using radial artery pressure for blood pressure monitoring has been less reliable and that it frequently leads to overuse of vasoconstrictors in MICS compared to conventional cardiac surgery. As such, the goal of this study was to assess the time course of the pressure differential (PD) between radial and femoral arterial pressure using perioperative simultaneous continuous pressure measurements, for both systolic (SAP) and mean (MAP) arterial pressures. Approximating central arterial pressure by femoral arterial pressure is well established.[4,5]

Methods

This study was approved by the institutional review board. All patients provided written consent preoperatively and received proper care according to the approved research plan. All patients underwent enhanced computed tomography (CT) prior to surgery. Patients who had atherosclerosis greater than mild were excluded as candidates for MICS to avoid possible embolism due to retrograde perfusion. Fifty-two consecutive patients undergoing MICS were prospectively included in this study. A right mini-thoracotomy of 5–7 cm was used for access in all cases. CPB was established via a femoral artery cannulation (PCKC-A, MERA, Tokyo, Japan) and femoral vein ± internal jugular cannulations (HLS Cannulae, Maquet, Rastatt, Germany). Retrograde arterial perfusion was used via the femoral cannulation in all cases. Perfusion was controlled between 2.2 and 2.6 L/m^2. Antegrade cardioplegia was delivered through an aortic root needle. The lowest blood temperature during CPB was 32°C. Radial SAP and MAP were monitored by a 5-cm long 20G catheter (Thurflo™ Terumo, Tokyo, Japan). Central perfusion pressure was approximated by femoral artery pressure according to methods published in previous reports.[4,5] Femoral SAP and MAP were monitored by a 15-cm long 3Fr. catheter (Super Sheath™, Medikit, Tokyo, Japan) inserted in the contralateral femoral artery. The arterial catheters were connected to pressure transducers using standard pressure tubes. To eliminate errors from damping and frequency change, the natural frequency and damping coefficient for each system were determined by the flush method. The radial and femoral arterial pressures were continuously monitored throughout the surgery. Radial SAP and MAP, as well as femoral SAP and MAP, were recorded at the 10 following times: 30 min before CPB, CPB on, applying aortic clamping, during arrest 30 min after application of aortic clamping, aortic declamping, beat on, CPB off, 10, 20, and 30 min after CPB off. The PDs between radial and femoral SAP and MAP were calculated. To try to identify factors that might lead to greater PD, patients were split into those with maximum PD > and < 20 mm Hg, and patient characteristics and intraoperative data were compared between the two groups. Norepinephrine administration was left to the discretion of the individual anesthesiologists, but tended to be given just prior to CPB off regardless of femoral or radial pressure values.

Statistical analysis

All data were collected prospectively. Continuous patient data are presented as mean ± standard deviation (SD) with 95% confidence interval (CI), and categorical data are presented as number (%). Analysis of variance was used to compare differences in radial and femoral arterial pressure over the entire time course. For post hoc tests, we used the Bonferroni method. $p < 0.05$ was considered significant. The independent samples t-test was used to compare continuous variables whereas categorical variables were analyzed using Fisher's exact test. The Bland–Altman method was used to assess agreement between femoral artery pressure and radial artery pressure measurements.[6]

The Bland–Altman method evaluates the concordance or discordance between two techniques of measuring the same quantity. It is visualized by plotting the difference between the two measurements against the average of those measurements. If there is no dependence of the difference on the average value, the mean and SD of the difference are calculated. The mean difference indicates the constant bias in the two techniques and can be used to adjust the measurement value obtained with one technique to match the other. However, if the width of two (more precisely 1.96) SD of the difference is larger than what one would consider to be clinically acceptable, then the two techniques should not be used interchangeably, because based on a normal distribution, 95% of the values are expected to fall within ±2SD. We refer to mean − 2SD to mean + 2SD as the 95% limits of agreement. We regarded an interval of 95% limits of agreement of <20 mm Hg as satisfactory.[7,8] The Bland–Altman plots were constructed for each of the 10 surgical timepoints. All analysis was performed using SPSS version 24 (IBM, Armonk, NY, USA).

Results

Patient demographics

Patient characteristics are shown in Table 1. Average age was 65 ± 14 years and male/female ratio was 29/23. Preoperative enhanced CT revealed all patients had little-to-no atherosclerosis in the entire aorta, iliac arteries, and

Table 1. Patient characteristics (n = 52)

Age (years)	65 ± 14
Female/male	23/29
Body surface area (m^2)	1.57 ± 0.19
Pulse wave velocity/right leg (cm/s)	1554 ± 353
Pulse wave velocity/left leg (cm/s)	1546 ± 356
Comorbidities	
Hypertension	26
Diabetes mellitus	11
Coronary artery disease	3
Chronic kidney disease	6
Chronic obstructive pulmonary disease	0
Peripheral vascular disease	0
Left ventricular ejection fraction	63 ± 10
EuroSCORE II	3.2 ± 4.1
Type of surgery	
Aortic valve replacement	23
Mitral valve surgery	21
Aortic + mitral valve surgery	5
Mitral + tricuspid valve surgery	3
Concomitant procedure	
Maze	5
Atrial septal defect closure	2

Table 2. Intraoperative data.

CPB time (min)	153 ± 31
Aortic cross clamp time (min)	118 ± 30
RBC transfusion	15 (28%)
FFP transfusion	11 (21%)
Fluid balance during CPB (mL)	–955 ± 1195
Urine output (mL)	1014 ± 796
Administration of norepinephrine	41 (79%)

CPB: cardiopulmonary bypass; RBC: red blood cell; FFP: fresh frozen plasma.

femoral arteries. In addition, preoperative pulse wave velocities (PWVs) assessing the arterial stiffness were measured in all patients, and it was confirmed that they were within normal limits in all patients. Operation types included 23 isolated aortic valve replacements, 21 isolated mitral valve surgeries ± maze procedure, and 8 double valve surgeries (mitral and aortic valves: 5 cases; mitral and tricuspid valves: 3 cases). Intraoperative data are shown in Table 2. Average CPB time and cross clamp time were 153 ± 31 min and 118 ± 30 min, respectively. As a vasoconstrictive medication, norepinephrine was administered by anesthesiologists in 41 patients (79%) during surgery. Average total amount of norepinephrine given during surgery was 541 ± 799 µg.

Prevalence of significant PD

With respect to SAP, 28 patients (54%) had a peak PD between radial and femoral readings of ⩾20 mm Hg. For MAP, five patients (9%) had a peak PD between radial and femoral readings of ⩾20 mm Hg. Sixteen patients (31%) had a peak PD between radial and femoral SAP of ⩾30 mm Hg, while no patients had a peak PD between radial and femoral MAP of ⩾30 mm Hg.

Time course of PD

Figure 1 compares femoral and radial pressures during surgery for the different surgical timepoints. On average, both

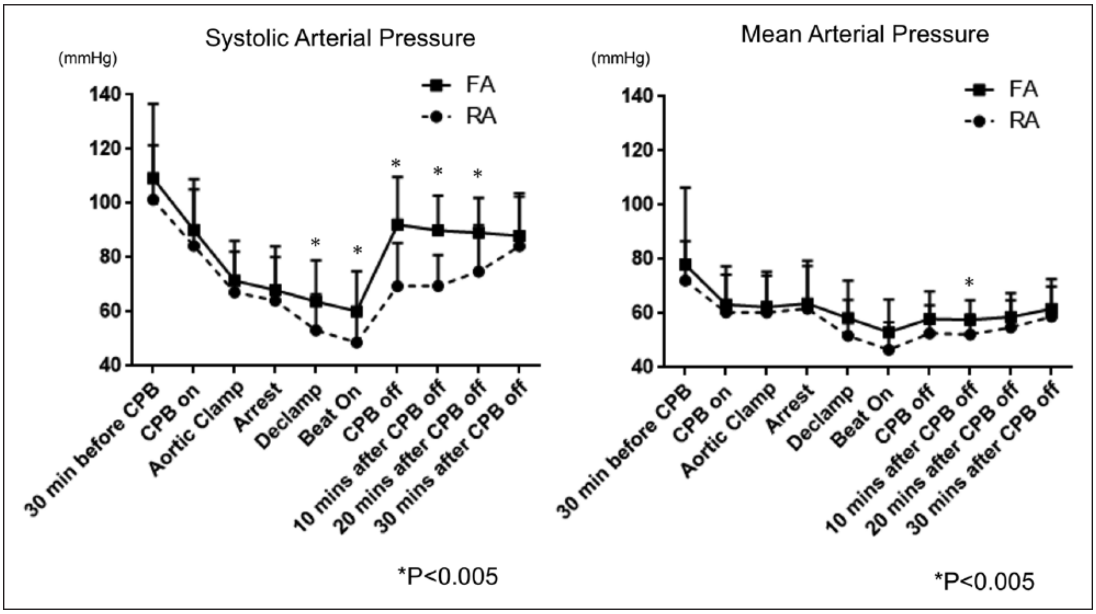

Figure 1. Intraoperative change of blood pressure. The bars express standard deviation.
FA: femoral artery (square); RA: radial artery (circle).
Asterisk indicates significant difference between femoral and radial pressure.

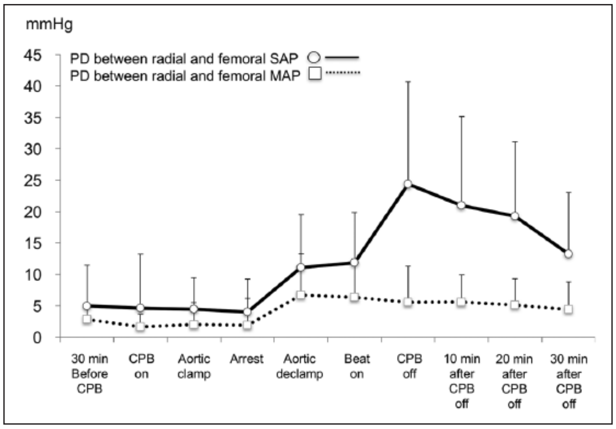

Figure 2. Intraoperative change of blood pressure differential. The bars express standard deviation.
PD: pressure differential; SAP: systolic arterial pressure (circle); MAP: mean arterial pressure (square); CPB: cardiopulmonary bypass.

femoral and radial SAPs gradually decreased from baseline (30 min before CPB) through aortic clamping and declamping and beat on in tandem, then sharply increased at CPB off and stayed level or increased over the next 30 min. Average femoral SAP values were consistently greater than radial SAP values at all timepoints. Statistically, femoral and radial SAPs were similar at baseline and stayed similar through cardiac arrest, but became divergent ($p<0.005$) at time of aortic declamping and stayed divergent through 20 min after CPB off, and only converged at 30 min after CPB off (left panel). Figure 2 plots the time course of PD itself. The PD of SAP hovers around 5 mm Hg through cardiac arrest, then increases over the next three timepoints to peak at CPB off with 23 ± 16 mm Hg, then gradually diminishes thereafter. We note that an average PD of 12 ± 10 mm Hg was still present at 20 min after CPB.

In contrast to SAP, the femoral MAP was significantly greater than radial MAP only at one timepoint, 10 min after CPB off (Figure 1, right panel). The PDs between radial and femoral MAP were smaller and more stable at all measurement points (Figure 2). Peak PD was observed earlier than for SAP at aortic declamping and was only 7 ± 6 mm Hg.

Concordance between radial and femoral artery pressure

The Bland–Altman plots of SAP (Table 3) showed large biases (average PD) from CPB off until 20 min after CPB off. Overall, there was poor agreement throughout the surgery, especially after CPB off. The interval of 95% limits of agreement was >50 mm Hg from CPB off to 30 min after CPB off. For example, at 30 min after CPB off, the limits of agreement were −19.7 to 39.2 mm Hg. This means that radial SAP could be as much as 40 mm Hg less than or 20 mm Hg higher than the femoral SAP. Meanwhile, the Bland–Altman plots in MAP (Table 3) showed that the bias (average PD) was less than 7 mm Hg, and 95% limits of agreement in MAP were satisfactory until declamping. After declamping, it increased, but remained lower than half of that of SAP (the interval of 95% limits of agreement: 23.8 mm Hg at the widest). As representative of timepoints, Figure 3 shows the Bland–Altman plots of SAP and MAP at CPB on, declamping, and CPB off.

Other indicators of adequacy of perfusion pressure during MICS surgery

During MICS surgery, other parameters are also monitored. In this study, cerebral regional oxygen saturation (rSO_2), venous oxygen saturation (vSO_2), and serum lactate were measured at three representative timepoints (CPB on, declamping, and CPB off) shown in Figure 3 (Table 4). Although PD of SAP peaked at CPB off and that of MAP at declamping, with the former being statistically significant a difference, the measures of systemic adequate circulation remained satisfactory at all times.

Risk factors for PD

Comparison of patients with maximum PD > 20 and <20 mm Hg showed that longer CPB time ($p=0.006$) and longer aortic cross clamp time ($p=0.002$) were associated with PD > 20 mm Hg (Table 5). The use of norepinephrine did not differ between the two PD groups ($p=0.40$).

Discussion

Our findings showed that large PD between radial and femoral SAP could be observed in MICS patients with retrograde perfusion. PD of SAP was minimal through cardiac arrest, but became significantly large by the time of declamping of the aorta and remained so through 20 min after CPB off. In addition, the Bland–Altman plots revealed large biases and poor agreement of femoral and radial SAP values at those surgical timepoints. In contrast, PD between radial and femoral MAP was small and clinically acceptable throughout the surgery. Longer CPB time and aortic cross clamp time were risk factors for PD > 20 mm Hg.

Although MICS have become increasingly prevalent,[3,4] there are no reports that assess to what extent PD occurs during MICS with retrograde perfusion via femoral cannulation. This is the first report to approach this issue. The frequency of PD in our study regarding MICS was greater than in previous reports regarding conventional cardiac surgery (34%–63%), although the definition of what threshold value to count as PD between femoral and radial artery pressure differed in those reports.[1,2,5,9,10] Moreover, the magnitude of PD in SAP was greater than that described in previous reports (average 13 (12–27) mm Hg).[1,2,5,9,10]

Table 3. The time course of pressure differential between femoral and radial arteries.

	30 min before CPB	CPB on	Aortic clamp	Arrest	Declamp	Beat on	CPB off	10 min after CPB off	20 min after CPB off	30 min after CPB off
Bias of SAP (mm Hg)	5.6	5.8	4.3	3.9	10.6	11.6	22.7	20.5	18.4	9.8
Limits of agreement (mm Hg)	–7.4 to 18.5	–14.2 to 25.9	–5.7 to 14.2	–6.5 to 14.3	–5.1 to 26.3	–5.8 to 28.9	–11.9 to 57.2	–8.7 to 49.7	–7.5 to 44.3	–19.7 to 39.2
Bias of MAP (mm Hg)	2.8	1.8	2.0	1.4	6.5	6.5	5.4	5.4	5.2	4.1
Limits of agreement (mm Hg)	–1.7 to 7.4	–2.6 to 6.2	–5.0 to 9.0	–3.0 to 5.7	–5.4 to 18.3	–5.4 to 18.4	–6.1 to 16.8	–3.2 to 13.9	–3.0 to 13.4	–2.5 to 10.7

PD: pressure differential; SAP: systolic arterial pressure; MAP: mean arterial pressure; CPB: cardiopulmonary bypass; limits of agreement: mean ± 2 standard deviation.

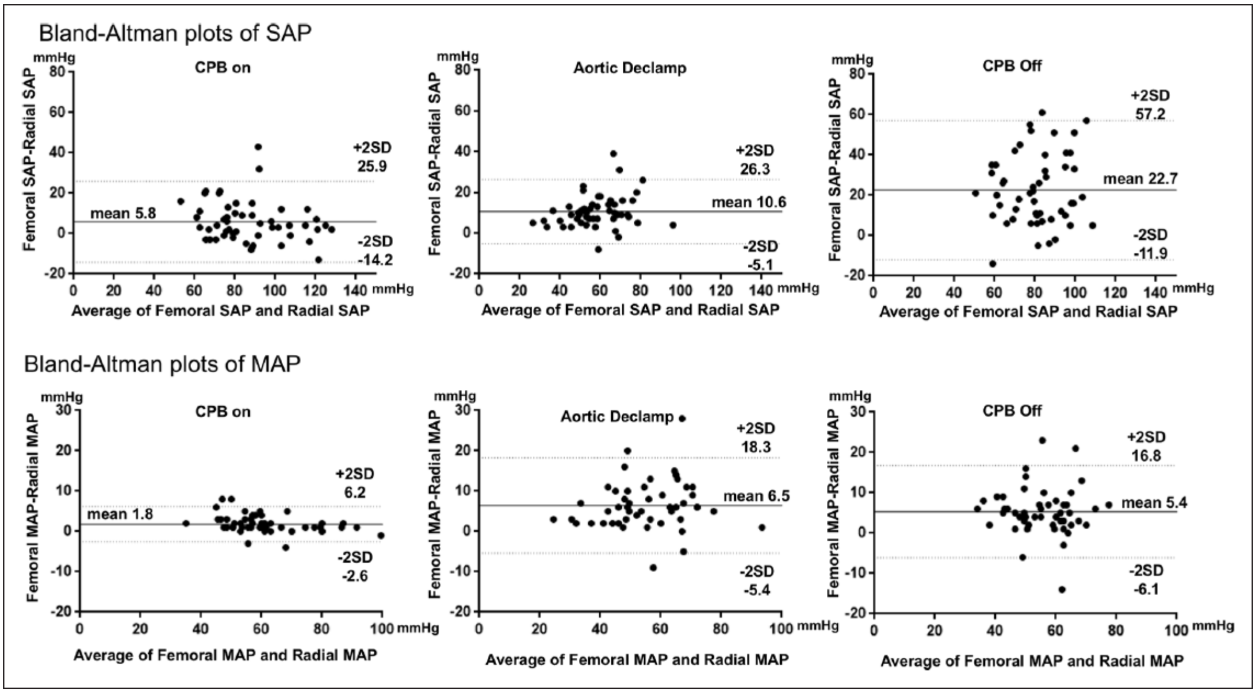

Figure 3. The Bland–Altman plots at CPB on, declamping, and CPB off.
SAP: systolic arterial pressure; MAP: mean arterial pressure.
Lines show mean and 95% limits of agreement.

Table 4. Other indicators of adequacy of perfusion pressure.

	CPB on	Declamp	CPB off
rSO_2 R (%)	56 ± 8	62 ± 15	61 ± 11
rSO_2 L (%)	57 ± 10	64 ± 14	61 ± 14
vSO_2 (%)	82 ± 7	78 ± 6	83 ± 8
Lactate (mmol/L)	1.4 ± 0.5	1.9 ± 0.9	3.5 ± 4.2

rSO2: regional cerebral oxygen saturation; R: right frontal region; L: left frontal region; vSO_2: venous oxygen saturation.

Compared to CPB with antegrade perfusion via central aortic cannulation, CPB with retrograde perfusion via femoral cannulation has several disadvantages, such as distal limb ischemia of the cannulation side and cooling/warming starting from groin site. In addition, MICS generally requires longer CPB and cross clamp time than conventional cardiac surgery as CPB time and aortic cross clamp time are found to be the risk factors for significant PD between femoral and radial SAP in this and other studies.[3,4,7,8,11] We speculate that these disadvantages are possible reasons for the differences of PD between MICS and conventional cardiac surgeries. Previous reports suggest that surgical manipulation causing unphysiological conditions can lead to the progression of PD, such as the interception of blood circulation, cooling/warming for circulatory arrest, and the use of CPB.[10,12–15]

Moreover, the mechanisms for the development of PD are not known. As norepinephrine was used in 79% of the patients in this study, its influence on PD should be considered, because it may have caused vasoconstriction of the radial artery resulting in overdamping of the pressure measurement in monitors. Norepinephrine usage did not differ between high and low maximum PD groups in this study, but since we did not have a protocol in place for norepinephrine administration, further study is necessary to clarify its role. Interestingly, several studies from the 1980s suggested that vasodilatory agents might intensify PD.[10,12] Maruyama et al.[16] reported that the use of vasodilating agents such as nitroglycerin and calcium channel blockers could promote PD. The authors of these studies suggested that a decrease in peripheral vascular resistance could cause a loss of arterial wave reflection and blunting of the arterial pressure wave resulting in underestimation of radial artery pressure. Kanazawa et al.[17] reported that a decrease in the arterial elasticity rather than vasodilation was responsible for the development of PD. Another view

Table 5. Comparison of demographic and intraoperative data between two groups according to pressure differential.

	PD (<20 mm Hg)	PD (= or >20 mm Hg)	p
Cases	24	28	
Preoperative data			
Age (years)	66 ± 13	65 ± 16	0.42
Female/Male	11/13	12/16	0.83
BSA (m^2)	1.59 ± 0.19	1.56 ± 0.20	0.27
Pulse wave velocity/right leg (cm/s)	1551 ± 391	1557 ± 327	0.48
Pulse wave velocity/left leg (cm/s)	1558 ± 428	1536 ± 299	0.42
Comorbidities			
Hypertension	16	10	0.05
Diabetes mellitus	8	3	0.09
Coronary artery disease	2	1	0.59
Chronic kidney disease	4	2	0.40
Chronic obstructive pulmonary disease	0	0	-
Peripheral vascular disease	0	0	-
Left ventricular ejection fraction	59.7 ± 12.7	65.0 ± 7.6	0.81
EuroSCORE II	3.4 ± 4.1	3.1 ± 4.2	0.84
Intraoperative data			
CPB time (min)	143 ± 28	162 ± 32	0.006
Aortic cross clamp time (min)	105 ± 24	129 ± 31	0.002
RBC transfusion (unit)	1.6 ± 3.0	2.1 ± 3.4	0.23
FFP transfusion (unit)	1.0 ± 2.3	1.5 ± 2.6	0.24
Fluid balance during CPB (mL)	–848 ± 1210	−1047 ± 1218	0.28
Urine output (mL)	1136 ± 817	917 ± 794	0.17
Administration of norepinephrine	18 (75%)	23 (82%)	0.40

CPB: cardiopulmonary bypass; RBC: red blood cell; FFP: fresh frozen plasma; PD: pressure differential; BSA: body surface area.

suggested by Pauca et al.[18] is that arterial venous shunting in the hand could cause development of PD.

The monitoring of SAP is generally conducted using the radial artery in MICS due to its accessibility and low complication rate. However, as illustrated in our Bland–Altman plots, physicians should be aware that radial artery monitoring is not always accurate and reliable. This study demonstrated a PD that widened as surgery progressed, from declamping of the aorta to 20 min after CPB off. Understanding PD is especially important, as it can assist surgeons and anesthesiologists in understanding hemodynamics during MICS and provide accurate intraoperative management of blood pressure, particularly, after declamping of the aorta. As shown in Table 4, the levels of rSO_2, vSO_2, serum lactate measured at three representative timepoints showed no clinical issues, suggesting that the existence of PD does not necessarily mean systemic circulatory damage or insufficient blood supply to important organs. Vasoconstrictors should not be administered based solely on observation of low radial SAP because they may cause significant impairment of blood flow to organs.

One of the solutions to obtain accurate blood pressure measurement during MICS is taking a femoral arterial pressure line routinely. It has been proved that femoral artery pressure can be measured to assess central pressure during open heart surgery, and the PDs between peripheral and femoral pressures are very similar to those between peripheral and central pressures according to previous studies.[5,18] A primary concern of this method involves the formation of an iatrogenic hematoma around the puncture site, which may progress after heparin administration. Haddad et al.[19] investigated this further and found a low complication rate. Only 3% of patients developed hematomas, all of which were small, and serious bleeding was a rare occurrence (0.13%). As such, they concluded that femoral arterial pressure lines can be used for routine monitoring in cardiac surgery. However, the use of the femoral arterial pressure line can result in bleeding in the retroperitoneal space if the line is inserted too proximally. Therefore, the femoral arterial pressure line is not used routinely in our institution. Second, it is possible to use an axillary arterial pressure line via long radial arterial catheter for central blood pressure measurement.[9,20] Although brachial arterial lines may provide a better estimate compared to radial arterial lines, the former may be ineffective in reflecting central pressure.[9,21] Finally and most importantly, intermittent non-invasive blood pressure (NIBP) monitoring can be used in addition to measurement of radial SAP. This method has been introduced as the current strategy for blood pressure monitoring in our hospital based on the results of this research. As an invasive method, only a radial arterial line is used for continuous blood pressure monitoring. At the timing of declamping, the aortic pressure is measured through the aortic root cannula with two lumens (one for de-airing and the other for the pressure monitoring). If significant PD between radial SAP and aortic root SAP is detected, femoral artery pressure is monitored via the branch line of femoral cannula inserted for CPB at the timing of CPB off, and it remains monitored through the time of protamine administration. Since the femoral cannula is removed after protamine is administered, we use NIBP measured at patients' upper arms after the protamine administration. This is because NIBP can reflect systolic aortic pressure reliably,[15,22] and radial SAP can help us understand the progressing trend of blood pressure after PD between the radial SAP and the aortic root SAP is recognized. Therefore, the combination of continuous radial SAP and NIBP measurement is sufficient to understand patients' hemodynamics after PD is noted.

As a limitation, this study was non-randomized and did not compare conventional cardiac surgery with antegrade perfusion. At our institution, the first-line approach for valve surgery has been MICS, and we believe this procedure is better for patients. Thus, randomized comparison between MICS and conventional approach would not be ethically feasible, especially for a study regarding mere blood pressure monitoring.

In conclusion, PD between radial and femoral artery pressure was clinically significant in MICS using retrograde perfusion. Intraoperative arterial pressure management based solely on radial SAP should be avoided.

Acknowledgements

Y.N. analyzed the data and wrote the manuscript. S.E. and F.S. participated in the study design and performed the statistical analysis. Y.N., Y.I., and C.S. participated in data collection. All authors read and approved the final manuscript.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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