Radial Mean Arterial Pressure Reliably Reflects Femoral Mean Arterial Pressure in Uncomplicated Pediatric Cardiac Surgery

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Objective: **To see if radial mean arterial pressure reliably reflects femoral mean arterial pressure in uncomplicated pediatric cardiac surgery.**

Design: **An ethics committee-approved prospective interventional study.**

Setting: **Operating room of a tertiary care hospital.**

Participants: **Forty-five children aged 3 months to 4 years who underwent pediatric cardiac surgery with hypothermic cardiopulmonary bypass.**

Measurements and Main Results: **Simultaneous femoral and radial arterial pressures were recorded at 10-minute intervals intraoperatively. A pressure gradient >5 mmHg was considered to be clinically significant. The patients' mean age was 14 ± 11 months and and mean weight was 8.0 ± 3.0 kg. A total of 1,816 simultaneous measurements of arterial pressure from the radial and femoral arteries were recorded during the pre-cardiopulmonary bypass, cardiopulmonary bypass, and post-cardiopulmonary bypass periods, including 520 (29%) systolic arterial pressures, 520 (29%) diastolic arterial pressures, and 776 (43%) mean arterial pressures. The paired mean arterial pressure measurements across the 3 periods were significantly and strongly correlated, and this was true for systolic arterial pressures and diastolic arterial pressures as well ($r > 0.93$ and $p < 0.001$ for all). Bland-Altman plots demonstrated good agreement between femoral and radial mean arterial pressures during the pre-cardiopulmonary bypass, cardiopulmonary bypass, and post-cardiopulmonary bypass periods. A significant radial-to-femoral pressure gradient was observed in 150 (8%) of the total 1,816 measurements. These gradients occurred most frequently between pairs of systolic arterial pressure measurements (n = 113, 22% of all systolic arterial pressures), followed by mean arterial pressure measurements (n = 28, 4% of all mean arterial pressures) and diastolic arterial pressures measurements (n = 9, 2% of all diastolic arterial pressures). These significant gradients were not sustained (ie, were not recorded at 2 or more successive time points).**

Conclusions: **The results suggested that radial mean arterial pressure provided an accurate estimate of central mean arterial pressure in uncomplicated pediatric cardiac surgery. There was a significant gradient between radial and femoral mean arterial pressure measurements in only 4% of the mean arterial pressure measurements, and these significant gradients were not sustained.**

KEY WORDS: cardiac surgical procedure, cardiopulmonary bypass, femoral artery, radial artery, congenital heart defects, blood pressure

INVASIVE ARTERIAL PRESSURE MEASUREMENT via an arterial catheter is an essential component of hemodynamic monitoring during cardiac surgery and cardiopulmonary bypass (CPB). Accurate measurement of arterial pressure is a prerequisite for optimal hemodynamic management during this type of surgery. Normally, mean arterial pressure (MAP) is relatively constant throughout the arterial tree;[1] however, systolic arterial pressure (SAP) rises slightly as the measurement site moves from central to peripheral arteries. This SAP gradient is negligible under normal conditions.

Generally, the radial artery is the preferred site for arterial catheterization because its anatomic location is relatively consistent, catheter placement in this vessel is a relatively easy procedure, and the rate of complications is acceptable.[2,3] However, several studies have demonstrated that hypothermic CPB may have significant effects on the central-to-peripheral arterial pressure gradient phenomenon.[4–13] First, hypothermic CPB may reverse the normal peripheral-to-central SAP gradient. Second, hypothermic CPB may significantly alter the consistency of MAP throughout the arterial tree. These changes mean that measurement of arterial blood pressure from a peripheral site, such as the radial artery, may significantly underestimate the central arterial pressure. Mismeasurement of MAP could have significant clinical implications with respect to hemodynamic mismanagement of patients.

Although several investigators have examined the impacts of hypothermic CPB on the radial-to-femoral arterial pressure gradient in adults, there is very little known about this in pediatric patients. The aim of this study was to investigate alterations of the radial-to-femoral arterial pressure gradient in pediatric cardiac surgery with hypothermic CPB.

METHODS

The study was approved by the institution's Ethics Committee and was supported by the Baskent University Research Fund. Written informed consent was obtained from the parents of all participants. The authors studied 45 American Society of Anesthesiologists class 3 or 4 children aged 3 months to 4 years who were scheduled for surgical repair of congenital heart defects with hypothermic CPB. The exclusion criteria were age <3 months, coarctation of the aorta, aortic interruption, need for vasoactive drugs preoperatively, CPB duration <30 minutes, need for deep hypothermic circulatory arrest, need for vasopressors other than dopamine <10 μg/kg/min, and signs of ischemia in the extremities.

Each child completed a predetermined age-adjusted fasting period (4–6 hours) and was premedicated with oral midazolam, 0.5 mg/kg, and

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hydroxyzine, 1 mg/kg. Initial routine hemodynamic monitoring, including electrocardiography, sphygmomanometric blood pressure measurements, respiratory rate, and pulse oximetry, was applied. After mask induction with sevoflurane, 8% in oxygen, a peripheral venous catheter was inserted and midazolam, 0.1 mg/kg IV, vecuronium, 0.15 mg/kg IV, and fentanyl, 25 μg/kg IV, were administered and sevoflurane was discontinued. Incremental doses of fentanyl, 5 μg/kg IV, were administered to a total dose of 50 μg/kg IV prior to sternotomy. For anesthesia maintenance, a constant infusion of fentanyl, 20 μg/kg/h, was started after intubation, and this was continued throughout the procedure. Isoflurane 0.2% to 1.5%, also was administered to assure depth of anesthesia. Vecuronium, 0.05 mg/kg IV, was repeated during the initiation and rewarming periods of CPB. Central venous and urinary catheters, esophageal and rectal temperature probes, and a nasogastric tube were inserted.

For invasive arterial pressure measurements, the femoral and radial arteries were cannulated after anesthetic induction using the catheter-over-the-needle technique. The radial artery was cannulated with a 22-G 2.5-cm catheter (Becton-Dickinson Venflon®, Helsingborg, Sweden). In patients with a Blalock-Taussig shunt, the site contralateral to the shunt was cannulated. The femoral artery was cannulated with a 20-G 3.2-cm catheter (Becton-Dickinson Venflon®, Helsingborg, Sweden). In patients who recently had undergone cardiac catheterization via this vessel, the site contralateral to the recent catheterization was used. The arterial catheters were connected to 2 pressure transducers (Biometrix B.V. Breda, Netherlands) using standard pressure tubing, and these transducers were zeroed at the level of the mid-axillary line. To eliminate errors from damping and frequency change, the natural frequency and damping coefficient for each system was determined by the flush method.[12,14] The femoral and radial arterial pressures were displayed simultaneously throughout the operation (Siemens SC 7000, Danvers, USA).

During CPB, systemic anticoagulation was achieved with heparin, 3 mg/kg. The CPB perfusate was composed of lactated Ringer's solution, fresh frozen plasma, or whole blood to achieve a calculated hematocrit of 28% to 30%. Methylprednisolone, 10 mg/kg, furosemide, 1 mg/kg, heparin, potassium, and sodium bicarbonate were added to the prime solution as part of standard protocol. Once the target core temperature (28°C) was achieved, 10 mg/kg of sodium thiopental was added to the CPB circuit. This same dose was repeated during the rewarming period. A membrane oxygenator was used for CPB, and systemic hypothermia, cold hyperkalemic cardioplegia solution, and topical cooling with ice were used to maximize myocardial preservation.

Simultaneous femoral and radial MAP, SAP, and diastolic arterial pressure (DAP) were recorded at 10-minute intervals intraoperatively. The other recorded variables were heart rate, core temperature, and the durations of aortic cross-clamping, CPB, and the entire operation.

Statistical analyses were performed with MedCalc 12.2.1 statistics software (9030 Mariakerke, Belgium). For each arterial pressure category (MAP, SAP, and DAP), 3 types of analyses were carried out: (1) paired-sample *t* tests were performed using the radial and femoral pressure measurements at each 10-minute interval, (2) Pearson correlation analysis was done to assess the relationship between measured radial and femoral pressure measurements, and (3) Bland-Altman plots were constructed to assess the agreement between the arterial pressure measurements at the 2 sites. The latter was done with correction for multiple observations per individual, as described by Bland and Altman.[15]

Occurrence of significant pressure gradients also was analyzed. Based on our clinical experience, a radial-to-femoral arterial pressure gradient ≥5 mmHg was considered significant. Numbers of these events were totaled and compared across the operative periods (pre-CPB, CPB, and post-CPB) and pressure categories.

Results are presented as mean ± SD or percentage with 95% confidence intervals (CI), as appropriate. A p value <0.05 was considered statistically significant.

RESULTS

The patients were 22 girls (44%) and 23 boys (46%). Their mean age, weight, and body surface area were 14.1 ± 11.6 months (CI, 10.7–17.5 mo), 8.0 ± 3.0 kg (CI, 7.1–8.9 kg), and 0.37 ± 0.11 m^2 (CI, 0.34–0.40 m^2), respectively. The most common congenital heart defect was ventricular septal defect (n = 21), followed by tetralogy of Fallot (n = 10), transposition of the great arteries (n = 5), complete atrioventricular septal defect (n = 3), partial atrioventricular septal defect (n = 3), and pulmonary stenosis (n = 3). The respective durations of aortic cross-clamping, CPB, and the surgery overall were 54 ± 22 minutes (CI, 48–60 min), 76 ± 25 minutes (95% CI, 69–83 min), and 171 ± 40 minutes (95% CI, 159–183 min). Patients' mean heart rate and core body temperature values are shown in Fig 1. The mean baseline, minimum, and end-of-surgery hematocrits were 33.0% (95% CI, 31.1%-34.9%), 28.7% (95% CI, 28.0%-29.4%), and 34.1% (95% CI, 32.9%–35.2%), respectively.

A total of 1,816 simultaneous measurements of arterial pressure from the radial and femoral arteries were recorded intraoperatively, including 776 (43%) MAPs, 520 (29%) SAPs, and 520 (29%) DAPs. The numbers of measurements during pre-CPB, CPB, and post-CPB were 708 (39%), 526 (29%), and 582 (32%), respectively.

During the pre-CPB period, none of the differences between mean radial MAP and mean femoral MAP at any of the 10-minute intervals was significantly different from zero ($p > 0.05$ for all, Fig 1 and Table 1). Regarding SAP, the only significant difference was at 40 minutes pre-CPB, with mean radial SAP higher than mean femoral SAP ($p = 0.042$, Fig 1 and Table 1). Regarding DAP, the only significant difference was at 20 minutes pre-CPB, with mean radial DAP lower than mean femoral DAP ($p = 0.039$, Fig 1 and Table 1).

Throughout the CPB period (ie, at all 10-minute intervals), the mean values for radial MAP, SAP, and DAP were all significantly lower than their corresponding femoral values ($p < 0.01$ for all time points, Fig 1 and Table 1).

During the post-CPB period, mean radial MAP was significantly lower than mean femoral MAP only at 0 and 10 minutes ($p < 0.001$ for both) (Fig 1 and Table 1). Mean radial SAP was significantly lower than mean femoral SAP at post-CPB 0 and 10 minutes ($p < 0.001$ for both), and was significantly higher than mean femoral SAP at 30 and 40 minutes ($p < 0.001$ and $p = 0.026$, respectively) (Fig 1 and Table 1). Mean radial DAP was significantly lower than mean femoral DAP at post-CPB 0, 10, 20, and 30 minutes ($p < 0.05$ for all, Fig 1 and Table 1).

For MAP, the paired radial and femoral measurements across all 3 periods of the surgery (pre-CPB, CPB, post-CPB) were significantly and strongly correlated, and this was true for SAP and DAP as well ($r \geq 0.937$ and $p < 0.001$ for all, Table 2).

Bland-Altman plots for each pressure category (MAP, SAP, and DAP) demonstrated good overall agreement between the femoral and radial measurements throughout the operation (Fig 2A-C). Bland-Altman plots for each individual period (pre-CPB, CPB, and post-CPB) revealed good agreement between femoral and radial measurements for MAP (Fig 3A-C). Bland-Altman plots for the pre-CPB and post-CPB periods