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Original Contribution

Inconsistency between simultaneous blood pressure measurements in the arm, forearm, and leg in anesthetized children

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Abstract
Study Objective: To determine the accuracy and precision of simultaneous noninvasive blood pressure (NIBP) measurement in the arm, forearm, and ankle in anesthetized children.
Design: Prospective, randomized study.
Setting: University medical center.
Patients: 101 ASA physical status 1 and 2 children (aged 1-8 yrs) scheduled for elective surgery with general anesthesia.
Measurements: Simultaneous NIBP measurements were recorded at the arm, forearm, and ankle at 5-minute intervals.
Main Results: The systolic blood pressure difference between the arm-forearm or the arm-ankle was within the ± 10% range in 63% and 29% of measurements, and within the ± 20% range in 85% and 67% of measurements, respectively. The diastolic blood pressure difference between the arm-forearm or the arm-ankle was within the ± 10% range in 42% and 44% and within the ± 20% range in 67% and 74% of measurements, respectively. In patients in whom the initial three NIBP measurements were within the ± 20% range between the forearm and arm, 86% of the subsequent measurements were also within that limit.
Conclusions: Forearm and ankle NIBP measurements are unreliable and inconsistent with NIBP measured in the arm of anesthetized children. These alternative BP measurement sites are not reliable in accuracy (comparison with reference "gold" standard) and precision (reproducibility).

1. Introduction

The measurement of arterial blood pressure (BP) is mandatory during general anesthesia. Measurement is usually performed by an indirect, noninvasive oscillotonometric

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method using a BP cuff positioned on the arm. However, in some circumstances placement of the cuff on the arm is either not ideal or not feasible. This is particularly relevant in surgery where only one upper limb is accessible. If the arm is unavailable because of intravenous (IV) access or surgical site interference, the cuff may be placed on the forearm or lower limb/ankle instead.

It is crucial that clinicians know how alternative BP measurement sites perform in both accuracy (comparison with reference "gold" standard) and precision (reproducibility). Previous studies in adults have shown that a higher BP may be measured in the leg than in the arm [1,2]. In contrast, one study found that BP measured from the leg in children was significantly lower than when measured from the arm [3]. Previous studies that have examined alternative sites for BP measurement used a different patient population or physiological conditions [2,4,5], did not compare the alternative sites simultaneously [3], did not use an appropriate statistical approach for data analysis [4,5], or did not assess reproducibility and trending. The aim of the present study was to assess the accuracy, precision, and trending of simultaneously performed BP measurements in the arm, forearm, and leg/ankle in anesthetized children aged 1-8 years.

2. Materials and methods

2.1. Participants

Following Sheba Medical Center Institutional Research Ethics Committee approval and exemption from informed consent for participation, 101 consecutive pediatric patients, 1-8 years of age, undergoing general anesthesia for elective surgery (inguinal hernia repair or peripheral urological procedures), were enrolled in the study. Children with known significant heart, lung, or vascular disease; obesity; or skin lesions over the area that would interfere with measurements were excluded from the study.

2.2. Protocol

Following inhalation induction of general anesthesia with sevoflurane, placement of an IV catheter and placement of a Laryngeal Mask Airway, BP measurements were simultaneously performed in the arm, forearm, and leg at 5-minute intervals throughout anesthesia and surgery. All measurements were performed with patients placed supine.

2.3. Measurements

Blood pressure was measured using a standard anesthesia monitor (S/5 anesthesia monitor; GE Healthcare, Waukesha, WI, USA) calibrated according to the manufacturer's instructions. Three monitors were used to achieve simultaneous measurements and were randomly assigned between the arm, forearm, and leg using a table of random numbers. The ankle rather than the calf was chosen for BP measurements. Increased perception of pain when using the calf compared with the ankle has been observed [2], a factor that may have resulted in an unwanted effect on our study. We believe that in children the ankle diameter correlates better with the arm and forearm than with the calf, allowing us to use the same cuff size at each site.

Only three cuff sizes were used (small, standard, and large pediatric cuffs) and were fitted so that the bladder of the BP cuff fit at least 40% of the circumference of the measured limb [1]. The same size cuff was used in all three locations for each child so as to avoid measurement bias associated with different cuff sizes between locations. The middle of the BP cuff bladder was placed over the artery being measured: for the arm it was in the standard position [6,7]; for the forearm, it was over the mid-aspect of the anterior forearm, where one would anticipate the radial artery; and for the leg, it was over the most distal position of the lower limb, just posterior to the medial malleolus, so as to measure BP from the posterior tibial artery.

2.4. Statistical methods

Systolic blood pressure (SBP) and diastolic blood pressure (DBP) measurements were recorded from the anesthesia monitor, then entered into an Excel database (Microsoft, Redmond, WA, USA) and prepared for statistical analysis.

With a sample size of over 100 patients, the study had 80% power to detect differences of a 5% level of significance, adjusted for multiple comparisons between the three sites. This sample size also enabled calculation of 95% limits of agreement with associated confidence limits of ± 0.4 SD of measurement differences.

Measurement of BPs from the forearm and ankle were compared with arm measurements using paired t-test, and limits of agreement (mean ± 2SD) were calculated. Bland-Altman figures present results as means against differences for each pair of measurements. A typical Bland-Altman plot presents the mean value of each two observations (x-axis) versus their difference (y-axis), while the solid horizontal line in a plot represents the paired difference mean, and the dotted lines indicate the limits of agreement.

For further analysis, a BP difference of less than 20% between the forearms or leg and arm was arbitrarily considered clinically acceptable. A BP difference of > 20% was considered clinically unacceptable. We also attempted to determine if initial BP differences could predict subsequent measurements in specific subgroups of patients. Data from patients with 7 or more measurements were analyzed. For patients whose differences in SBP or DBP were within ± 10% or ± 20% in the first three simultaneous measurements, subsequent measurements compared with the initial three values. The proportion of subsequent measurements falling within the ± 10% or ± 20% ranges was then