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Comparison of Arm and Calf Automatic, Noninvasive Blood Pressures In Pediatric Intensive Care Patients

Kathleen Schell, RN, PhD, RN[Associate Professor],
School of Nursing, University of Delaware, Newark, DE

Eileen Briening, RN, MSN, PNP-BC[Pediatric Nurse Practitioner],
Department of Anesthesiology and Critical Care, Nemours and Alfred I duPont Hospital for Children, Wilmington, DE

Ruth Lebet, RN, MSN, CCNS[Clinical Nurse Specialist],
PICU, Nemours and Alfred I duPont Hospital for Children, Wilmington, DE

Kelly Pruden, RN, MSN, CPNP, CCRN[Pediatric Nurse Practitioner],
Department of General Surgery and Trauma, Nemours and Alfred I duPont Hospital for Children, Wilmington, DE

Steven Rawheiser, RN, BSN[Staff Nurse], and
Pediatric Transport Team Nemours and Alfred I duPont Hospital for Children, Wilmington, DE

Barbara Jackson, RN, BSN[NACHRI Coordinator]
PICU, Nemours and Alfred I duPont Hospital for Children, Wilmington, DE

Kathleen Schell: kaschell@udel.edu; Eileen Briening: ebrienin@NEMOURS.ORG; Ruth Lebet: rlebet@NEMOURS.ORG; Kelly Pruden: kpruden@NEMOURS.ORG; Steven Rawheiser: srawheis@NEMOURS.ORG; Barbara Jackson: bjackson@NEMOURS.ORG

Background and Significance

In the pediatric intensive care unit (PICU), blood pressure (BP) measurement is a routine vital sign used to evaluate the hemodynamic stability of children and their responses to treatment (Axton, Bertrand, Smith, Dy, & Liehr, 1995; Menard & Park, 1995). Direct cannulation of arteries for continuous BP monitoring is often employed with unstable, critically ill children but this technique is sometimes difficult to accomplish and involves risks such as vessel trauma, bleeding, and infection. Automatic, noninvasive blood pressure (NIBP) monitoring is a common and acceptable practice in PICUs (Dobbins, 2002; National High Blood Pressure Education Program Working Group, 2004; Pickering et al., 2005). Although auscultatory BP measurement is considered the gold standard of NIBP assessment, the oscillometric technique has gained popularity due to its ease of use and decreased sensitivity to external noise (Pickering et al., 2005).

Oscillometric BP technique uses a cuff sensor or transducer to detect and send changes in amplitude of arterial wall pulsations to a microprocessor (GE Healthcare, n.d.; Guiliano, 2005; Pickering et al., 2005; Portman, Sorof & Ingelfinger, 2004). Initial cuff inflation

Corresponding Author: Kathleen A. Schell, RN, PhD, Associate Professor, School of Nursing, University of Delaware, Newark, DE 19716, kaschell@udel.edu, phone (302)831-8396, fax (302)831-2382.

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exceeds systolic arterial pressure. The pulsations or oscillations begin when the cuff is automatically released and the cuff pressure is then reduced in a step-like manner until it falls below the diastolic pressure. Maximum pulsations correspond to the mean arterial pressure (MAP) and values for systolic and diastolic BPs are calculated according to proprietary algorithms of each monitor's manufacturer (GE Healthcare, n.d.; Guiliano, 2005; Pickering et al., 2005; Portman, Sorof & Ingelfinger, 2004).

While brachial cuff pressures are standard and recommended in health care, calf and thigh BPs have also been used in pediatric nursing (Hockenberry, Wilson, Winkelstein, & Kline, 2003). Calf BPs are used in children when the upper arm is not accessible and/or when nurses do not want to awaken or agitate children, since disturbing them may make it difficult to obtain an accurate BP reading (Axton et al., 1995; Kunk & McCain, 1996). Inaccessibility may be the result of operative positioning, the presence of an intravenous catheter or shunt, trauma, and burns (Crapanzo, et al., 1996; Frauman, Lansing & Fennell, 1984). Comparison of calf and arm BP may also be used to detect aortic coarctation (Crossland, Furness, Abu-Harb, Sadagopan, & Wren, 2004; Lip, Beevers, Beevers & Dillon, 2001; Park & Lee, 1989; Pickering et al., 2005). Use of thigh pressures is another option, but accessing this site can be more disruptive and often less tolerable than calf BPs (Park & Lee, 1989).

For calf BPs, sometimes referred to as ankle BPs, the cuff is placed just above the malleolus. Although calf BP readings are generally accepted in pediatric clinical settings such as hemodialysis units, intensive care units and operating rooms (Frauman et al., 1984; Kunk & McCain, 1996; Short, 2000), there have been varied findings regarding their accuracy. Accurate readings are imperative to assist with assessment and treatment of critically ill children while in the PICU. For example, a fall in BP from age appropriate limits is a late sign of cardiovascular decompensation. Errors in measurement may delay or change treatment and ultimately patient outcomes (Arafat & Mattoo, 1999; Dickson & Hajjar, 2007; Menard & Park, 1995). According to Pickering et al. (2005), "Blood pressure determination continues to be one of the most important measurements in all of clinical medicine and is still one of the most inaccurately performed" (p. 144).

REVIEW OF THE LITERATURE

There is limited published research comparing arm and calf BPs in children. A search of CINAHL and MEDLINE databases between 1980 and 2008 resulted in identification of seven studies comparing arm and ankle/calf BPs using auscultation and/or oscillometric methods in pediatric populations. These studies focused primarily on neonates, infants and some toddlers (Axton et al., 1995; Crapanzano et al., 1996; Crossland et al., 2004; Kunk & McCain, 1996; Park & Lee, 1989). Although our research employed oscillometric methods, Frauman and colleagues' study, using BP by auscultation, was incorporated in the review because it was one of only two studies that included older children (Frauman et al., 1984; Short, 2000).

In the reviewed studies, mean differences in arm and calf BPs varied (Axton et al., 1995; Crapanzano et al., 1996; Crossland et al., 2004; Frauman et al., 1984; Kunk & McCain, 1996; Park & Lee, 1989; Short, 2000). For systolic BPs, differences ranged from -1.1 to 14.4 mm Hg. For diastolic BPs, differences ranged from -0.01 to 6.7 mm Hg. For MAPs, differences ranged from 0.9 to 9.7 mm Hg. Overall, standard deviations for these differences were broad (ranging from ± 5 to 17 mm Hg), suggesting that individual discrepancies were more clinically significant than indicated by group data. Statistical differences in diastolic BPs were only reported by Crapanzo et al. (1996) and Park & Lee (1989). Some researchers reported statistically significant differences in MAP (Crapanzo et al., 1996; Kunk & McCain, 1996; Park & Lee, 1989). In all studies, greatest clinical and statistical differences

were noted for systolic BP but whether arm or leg was higher was not consistent. Crossland et al. (2004) and Frauman et al. (1984) reported that calf BPs were higher than arm BPs in most subjects. Kunk and McCain (1996) confirmed this finding only in systolic BPs in preterm infants on day 7 but not on previous days. Park and Lee (1989) concluded the limb BPs were equivalent. Only Short (2000), who analyzed only MAPs, found that calf pressure was lower than arm pressure in children under 8 years old. Differences for older children were not statistically significant.

Variation in statistical analysis procedures complicates understanding of findings in BP measurement studies. Descriptive statistics and correlations provide some clinical insights but are inadequate in evaluation of interchangeability of calf and arm BPs. Inferential statistics such as multivariate analysis of variance and paired t-tests more accurately reflect significance of group BP differences. However, clinicians individualize treatment for their patients and should be cautious applying group statistic results to individuals. Bland Altman analyses are recommended to interpret significance of values for individual subjects (Bland & Altman, 1986). Of note, in paired t-test analysis, Axton and colleagues found no statistically significant difference in systolic or diastolic BPs. However, Bland Altman analyses by Axton et al. (1995) as well as others (Crossland et al., 2004; Short, 2000) revealed that 95% of the sample would have systolic arm-calf differences greater than ± 20 mm Hg and diastolic differences greater than ± 17 mm Hg. Furthermore, Frauman et al. (1984) recommended subtracting 15 mm Hg from the systolic BP but not to adjust the diastolic BP when using leg readings after comparing 375 pairs of brachial and dorsalis pedis auscultatory BP measurements in 4 male children undergoing chronic hemodialysis. Although repeated measures provided greater statistical power, use of four subjects of the same gender with chronic renal failure limited generalizability of the findings. Formulas to convert calf to arm equivalents do not address individual patients.

Comparison of BP measurement studies is also challenged by variation in data collection procedures (Houweling et al., 2006). Best practice for BP measurement is found in the American Heart Association's 2005 *Recommendations for Blood Pressure Measurement in Humans and Experimental Animals* (Pickering et al., 2005). Dinamap monitors were used for BP assessment in all but one of the reviewed studies but monitor models differed and calibration of the monitors was not always reported. In some studies, the same cuff was used for both limbs, regardless of limb circumference. Cuffs that are too small may falsely elevate BPs while cuffs that are too large may underestimate readings. Position of subjects did not always guarantee arm placement at heart level, thus hydrostatic pressure may affect BP differences. Time between measurements was not always described by the researchers. One minute is considered the minimum amount of time allowed between consecutive BPs on the same limb. Experts recommend at least two BPs from the same site to reduce variability and "white coat" effect. To reduce order effect, randomization of measurement order should be included when measuring BP in two or more sites. These procedures for cuff selection, positioning of subjects, time between measurements, order of measurements and number of measurements are critical to interpretation of findings (National High Blood Pressure Education Program Working Group, 2004; Pickering et al., 2005; Terra et al., 2004).

Variables influencing calf and arm BPs in children have been sporadically explored in this body of literature and include subject position, degree of agitation/activity, age, gender, ethnicity and anthropometrics, i.e. height, weight, body surface area. Inconsistent results and lack of thorough investigation prompted analysis of several of these variables in the current study. Influence of hypertension, repaired congenital heart disease, primary intensive care medical diagnoses and major categories of medications that may affect BP measurement

was also analyzed in the current study. The studies reviewed typically excluded these individuals or did no more than include this clinical information in the sample description.

Investigations of the effects of arm and body on BP measurements confirm that limb BP differences are greater when subjects' arms are not level with the heart (Netea, Lenders, Smits, & Thien, 2003). Only Frauman et al. (1984) addressed this variable and noted no clinically significant effect on arm-calf differences based on position (supine/sitting) but reported only descriptive statistics to support this claim. Several researchers did not describe arm position or, if body and arm position were noted, statistical analysis of their influence on BP differences was not performed.

Because movement and agitation are known to increase BP measurement in both adults and children (Menard & Park, 1995; National High Blood Pressure Education Program Working Group, 2004; Pickering et al., 2005; Stebor, 2005), the majority of investigations included BP measurement when subjects were quiet, resting and/or not agitated. Assessment methods for these states were not the same in any studies. Frauman et al. (1984) suggested that awake/asleep state in subjects undergoing hemodialysis did not affect arm-calf differences but did not analyze these data using inferential statistics. Park and Lee (1989) also explored this covariate and reported their effects as not statistically significant.

Crapanzo et al. (1996) and Short (2000) found that age was influential when comparing arm and calf BPs. Systolic, diastolic and mean arterial pressures (MAP) calf pressures were lower than the arm pressures until the age of 6 months when the values were most equivalent; then calf exceeded arm in later months (Crapanzo et al., 1996). Crapanzo and colleagues emphasized that there was wide variation among individuals. Short (2000) noted that calf pressures were lower than arm pressures in children less than 8 years old and attributed this finding to an immature vascular system and effects of regional anesthetics on sympathetic blockade.

Weak statistically significant correlations of arm-calf BP differences with height and weight were noted by some researchers (Crapanzo et al., 1996; Park & Lee, 1989) but not by others including Kunk and McCain (1996) and Short (2000) who found no correlation with birth weight nor body surface area, respectively. Park and Lee (1989) found that gender and ethnicity did not affect arm-calf differences but no other investigators explored the effects of these demographics on results.

In conclusion, data collection procedures, statistical analysis and results varied across studies using automatic, NIBP monitors to compare upper arm and lower leg BPs (Axton et al., 1995; Crapanzano et al., 1996; Crossland et al., 2004; Kunk & McCain, 1996; Park & Lee, 1989; Short, 2000). Kunk & McCain (1996) suggested that arm and calf BPs were clinically and statistically similar during the first five days of life and could be used interchangeably in children. However, others concluded that there were statistically and clinically significant differences between sites, warranting omission and/or cautious use of calf BPs (Axton et al., 1995; Crapanzano et al. 1996; Crossland et al., 2004; Frauman et al., 1984; Park & Lee, 1989; Short, 2000). Size and direction of these differences among BP parameters (systolic, diastolic and MAP) varied.

Further investigation is needed to clarify the accuracy of calf NIBPs. The current study will add to the body of knowledge on using different sites for NIBP cuff placement and address a gap in sampling of the pediatric population. It was the first study to compare simultaneous readings, eliminating physiologic and/or environmental changes that may occur during the minute/s between calf and arm readings. Clinical co-variates, some of which were not analyzed in previous studies and which potentially could affect BP differences, were also explored.

PURPOSE OF STUDY

The purpose of this study was to compare upper arm and calf automatic noninvasive BPs in children admitted to a PICU. A secondary aim was to explore the influence of demographics, height and weight, presence of agitation and pain, primary intensive care medical diagnoses, past cardiovascular medical history and current medications that could potentially effect BP on arm- calf BP differences.

METHODS

Study Population

Following approval by the institution's Clinical Research Review Committee, this descriptive comparison study was conducted with a convenience sample of children, ages 1 to 8 years, admitted to the PICU of a 180-bed teaching hospital in the Mid-Atlantic region of the United States. Informed consent was obtained from the parent/guardian for all enrolled subjects. Informed assent was obtained for children 7 and 8 years old, if appropriate. Between April 2006 and October 2007, children admitted to the PICU were eligible to participate if they: (a) were able to tolerate the head of the bed elevated 30 degrees and (b) their parents/guardians were English speaking or were non-English speaking and the hospital-approved AT & T healthcare translator or other translator was available. Potential subjects were excluded if they were: (a) individuals with dwarfism or congenital heart disease, (b) individuals with inaccessible upper and/or lower extremities due to casts, fractures, burns, etc., (c) status post posterior spinal fusion eight hours or less and/or until physician order permitted head of bed elevation, (d) status post osteotomies, (e) undergoing continuous renal replacement therapy, (f) on titrating drug drips, and/or were (g) unable to be quieted. Because children's BPs vary by age, subjects were divided into three groups: Group 1 included children 1 to < 2 yrs, Group 2 included children 2 to < 5 yrs and Group 3 included children 5 to 8 years.

Instruments and Measures

Pain and sedation scales—Prior to obtaining BP measurements, pain was objectively measured using one of four tools (see Table 1 for selection criteria for pain scales used). The FLACC Pain Assessment Tool (Merkel, Voepel-Lewis, Shayevitz, & Malviya, 1997), the COMFORT Scale (Ambuel, Hamlett, Marx & Blumer, 1992), Wong-Baker FACES Pain Rating Scale (Keck, Gerkensmeyer, Joyce, & Schade, 1996) and the Numeric Rating Scale (Jensen & Karoly, 1992) are instruments deemed valid and reliable in the literature.

The FLACC Pain Assessment Tool, commonly used in the PICU in which the study occurred, has established reliability and validity for objective pain measurement in children with cognitive impairment as well as pediatric postoperative patients (Merkel et al., 1997; Voepel-Lewis, Merkel, Tait, Trzinka, & Malviya, 2002). Reliability and validity of the COMFORT Scale has been established with postoperative infants to age three (van Dijk et al., 2000), ventilated preterm infants (Wielenga & de Leeuw, 2004), and children through adolescence in the Pediatric Intensive Care Unit (Ambuel et al., 1992). Reliability and validity of the FACES Pain Rating Scale developed by Wong and Baker (1988) has been established with verbal children over the age of four and with three year olds who are able to count and can demonstrate understanding of the tool (Keck et al., 1996). A review of the literature supports the validity and reliability of the Numeric Rating Scale (Jensen & Karoly, 1992; Paice & Cohen, 1997).

Because of their potential influence on BP measurements, agitation and movement were also assessed immediately prior to obtaining the BPs using the Richmond Agitation-Sedation

Scale (RASS) (Sessler et al., 2002). A literature review at the time of study design did not identify any pediatric-specific scales with well-established reliability and validity. After review of adult sedation/agitation assessment scales, the RASS was selected based on ease of use, well-established inter-rater reliability, and demonstrated scale validity (Ely et al., 2003; Sessler et al., 2002). Subsequent work has continued to demonstrate these characteristics (Pun et al., 2005; Rassin et al., 2007). The RASS is a 10-point scale ranging from -5 to +4 with 0 indicating absence of sedation or agitation, positive numbers indicating more agitation, and negative numbers indicating sedation.

Blood pressure monitor—BP was obtained using a Spacelabs Ultraview SL monitoring system (Spacelabs Healthcare, Issaquah, WA), which consists of hemodynamic parameter modules that can be inserted into stationary bedside and portable monitor housings. All monitoring functions are controlled through the modules. During data collection, each set of arm and calf BP measurements was obtained simultaneously using two identical parameter modules, one inserted into the subject's stationary bedside housing and the other inserted in to a portable monitor housing brought to the subject's bedside. Modules and housings are inspected and tested annually by Biomedical Support Services to ensure accurate functioning. The accuracy of these monitors for arm BPs meets or exceeds SP10-1992 Association for the Advancement of Medical Instrumentation (AAMI) standards (mean error ± 4.5 mmHg standard deviation ± 7.3 mmHg) for arm measurements (White et al., 1993). Spacelabs Healthcare did not report data regarding accuracy of calf BPs.

Training of data collectors—Data were collected by five pediatric intensive care nurses who attended a data training session that addressed location of arm and calf sites, measurement of limb circumference, and use of the Richmond Agitation/Sedation Score (RASS). These nurses also attended a BP monitor in-service offered by the Spacelab representative when the monitors were adopted in the PICU in January 2006. The nurses were experienced in the use of the various pain scales as part of standard protocol in the PICU.

Procedure

Subjects were placed in a supine position with the head of bed elevated 30 degrees as determined by a hand held protractor or the degree indicator incorporated into the bed frame. Subjects remained in this position for at least 5 minutes prior to data collection. Cuff sizes were selected based on limb circumferences measured to the nearest 0.5 centimeter. Spacelabs cuff sizes were as follows: neonate (6–11 cm.), infant (8–11 cm.), child (12–19 cm.), small adult (17–26 cm.), and adult (24–32 cm.). Per manufacturer's recommendations, if circumference overlapped two categories of cuff size, the larger cuff was selected. Using a paper tape measure, arm circumference was obtained at the point half way between the elbow and the shoulder. Calf circumference was measured at the point mid-way between the ankle and the knee. The BP cuffs were applied to the arm and calf on the same side. Subjects' extremities were positioned at the side of their bodies, resting on the bed, for all measurements

The child's pain score and level of sedation were assessed immediately prior to obtaining the BP measurement. As previously described, pain level was assessed using one of four scales (see Table 1) based on the child's developmental level and ability to interact. Because of the variety of scales used, the influence of pain on BP differences by cuff site was not statistically analyzed. Sedation level was assessed using the Richmond Agitation/Sedation Score (RASS). For regression analysis, subjects with RASS scores between and/or equal to 0 and -5 were considered "not restless or agitated" and subjects with RASS scores between and/or equal to 1 and 4 were considered "restless and agitated."

NIBPs were measured simultaneously in the upper and lower extremity using the Ultraview SL monitor system (Spacelabs Healthcare, Issaquah, WA). Systolic, diastolic and mean BP values for the arm and calf as well as a simultaneous heart rate were documented. Data collectors notified the child's nurse or physician if an abnormal arm reading was obtained.

Demographic data including gender, age and race were obtained through review of the medical record. Clinical information such as height and weight, primary intensive care medical diagnoses, past medical history of hypertension or unrepaired congenital heart disease, and administration of sedative, pain, paralytic, anti-seizure or antihypertensive medications was also extracted. Categorization of medical diagnoses and medications was initiated by the Principal Investigators and agreed upon by members of the research team.

Data Analysis

Statistical analyses were performed using the SPSS Statistical Package (version 15.0, SPSS, Chicago, Illinois, USA). Paired t-tests were used to detect differences between the group measurements. Multiple regression analyses were performed to determine how much variance in the arm-calf differences was explained by co-variables such as demographics, medical diagnoses, limb circumference, agitation level, and selected medications. Multiple regression may reveal specific variables that predict greater discrepancies between arm and calf BPs. These predictors are particularly relevant in situations where calf BPs are the only option. A p value of < 0.05 , set prior to data analysis, was used for significance. MedCalc for Windows, version 7.4.2.0 (MedCalc Software, Mariakerke, Belgium, 2004) was used to conduct Bland-Altman agreement analyses (Bland & Altman, 1986) to determine the extent of agreement between arm and calf BPs for individual children.

RESULTS

A convenience sample of 224 children participated in the study. The mean age of the sample was 3.89 years (range 12 months to 8 years, SD = 2.22 years). The majority were males (51%, $n = 110$) and white or Caucasian (61%, $n = 136$). See Table 2 for other demographic details. Mean body mass index (BMI) was 17.93 kg/m^2 (range 6.5 – 56.8, SD 8.5). Mean arm circumference was 16.88 centimeters (range 10.5 to 31.0 cm, SD 3.22) and mean calf circumference was 19.42 centimeters (range 2.0 to 30.0 cm, SD 3.46). The child-sized cuff was most commonly selected for the arm and the small adult-sized cuff was the most commonly selected for the calf.

Six subjects had a medical history of hypertension and nine subjects had previously repaired congenital heart disease. The most common categories of medical diagnoses were pulmonary and neurological disorders. Examples of the category "Other" included drug ingestion, near drowning, anaphylaxis, electrolyte imbalances and scarlet fever. See Table 3 for a summary of medical diagnoses and medication categories. The mean RASS was -0.04 with a range of -5 to 3 (SD 1.49). Children were most likely to be receiving sedative or anti-seizure medications.

Calf BPs were higher than arm BPs in 73% of the sample for systolic BP, 58% of the sample for MAP and 52.7% of the sample for diastolic BP. Table 4 shows details of the average systolic, diastolic and mean BPs with standard deviations and average differences between arm and calf BPs for the sample and by age group. For SBP, 26.3% of the sample had differences ≥ 10 mm Hg but < 20 mm Hg; 21.4% had differences ≥ 20 mm Hg. Overall, systolic BPs were ≥ 10 mm Hg for 49.6% ($n=111$) of the sample. For MAP, 23.2% of the sample had differences ≥ 10 mm Hg but < 20 mm Hg; 12.1% had differences ≥ 20 mm Hg. Overall, MAPs were ≥ 10 mm Hg for 35.3% ($n=79$) of the sample. For diastolic BP, 12.1% of the sample had differences ≥ 10 mm Hg but < 20 mm Hg; 9.8% had differences

≥ 20 mm Hg. Overall, diastolic BPs ≥ 10 mm Hg for 21.8% ($n=49$) of the sample. See Table 5 for further details of size of differences for systolic BP, diastolic BP and MAP by age group.

Results of paired t tests indicated that differences were statistically significant for systolic BP ($t = -8.76, p = 0.000$) and MAP ($t = -3.44, p = 0.001$) for the entire sample. Systolic differences remained statistically significant for each age group, but MAP differences were only statistically significant in age group 2 (2 yrs to < 5 yrs). Diastolic differences remained clinically and statistically insignificant. See Table 6 for details of paired t -test analysis of the entire sample and each age group.

Measures of central tendency and group descriptive data can be misleading when critically reviewing results of BP studies. To promote best practice, clinicians should base treatment choices on individual patient data, not group data. Therefore, Bland Altman analyses were used to determine agreement between arm and calf oscillometric BPs for individual subjects. Perfect agreement occurs when all data points lie on the line of equality of the x-axis. The bias (mean difference between arm and calf pressures) for systolic BP was 8.0 mm Hg with the limits of agreement -18.9 and 34.9 mm Hg. Limits of agreement indicate that 95% of the sample falls between these values (see Figure 1). The limits of agreement for diastolic BP were -22.7 and 25.0 mm Hg with a bias of 1.1 mm Hg (see Figure 2). For MAPs, the bias was 2.8 mm Hg and the limits of agreement were -12.1 and 26.7 mm Hg (see Figure 3).

Multiple regression analyses were performed to determine how much variance in the criterion variables, arm-calf systolic BP, diastolic BP, and MAP differences, were explained by a model that included the following predictors: age, sex, race (black/African American or not), BMI, arm circumference, calf circumference, agitation, seizure and sedative medications, neurological diagnosis and pulmonary diagnosis. It should be noted that only the most common medications and medical diagnoses were selected for analysis in this model because of the sample size and number of dependent variables. Using the enter method, a significant model emerged for systolic BP differences ($F_{11, 180} = 3.44, p < 0.000$; Adjusted R square = 0.123) and MAP differences ($F_{11, 179} = 2.369, p < 0.009$; Adjusted R square = 0.127). A neurological diagnosis ($\beta = 0.272, p = 0.049$) and arm circumference ($\beta = 0.221, p = 0.007$) partially predicted SBP differences in the sample. Arm circumference ($\beta = 0.302, p = 0.031$) and receiving anti-seizure medications ($\beta = 0.177, p = 0.026$) partially predicted MAP differences. Age, sex, race, BMI, calf circumference and presence of agitation did not influence arm-calf BP differences.

Discussion

Study findings were congruent with Crossland et al. (2004) and Frauman et al. (1984) who found that lower limb BPs were higher than arm BPs. Physiologically, amplification of the systolic pressure is considered the cause of the discrepancy between upper and lower limb BPs (Park, Robotham, & German, 1983). Similar to other investigations (Axton et al., 1995; Crapanzano et al., 1996; Crossland et al., 2004; Frauman et al., 1984; Kunk & McCain, 1996; Park & Lee, 1989; Short, 2000), the current study also confirmed that systolic BPs exhibit the greatest differences, both statistically and clinically, between calf and arm BPs. The descending size of differences from systolic to MAP to diastolic is also consistent with the reviewed studies. Unlike those studies, however, the MAP differences were also statistically significant in our older sample, ages 5 to 8 years. It is possible that in the other studies, subjects had both arms and legs level with the heart while our subjects' calves, but not arms, were more likely to be level with the heart when the head of the bed was elevated 30 degrees. Hydrostatic pressure influences BP values when limbs are not at the same level (McGhee & Bridges, 2002). Therefore caution is necessary when reviewing the findings.

Use of the appropriately sized cuff for arm and calf strengthens the accuracy of our study findings.

Furthermore, our findings are congruent with Axton et al. (1995) and Crapanzano et al. (1996) in that group differences (DBP and MAP) were relatively small and sometimes clinically insignificant but individual subjects' arm-calf BP differences varied widely within study samples. Clinicians may consider the systolic differences (between 4 and 8 mm Hg) negligible in clinically stable children. However, when titrating intravenous drug infusions, administering medications that can increase/decrease BP, e.g. narcotics, diuretics, or instilling fluid boluses or blood in a more critically ill child, these differences are clinically significant. Appropriate care is based on individual patients' assessment data.

Subjects who were diagnosed with a neurological problem, receiving anti-seizure medications and with greater arm circumferences had larger differences in calf and arm BPs. Rationale for why children with neurological diagnoses had larger arm-calf differences is difficult to explain. In this study, the most common neurological diagnoses were seizures (n=8), tumors (n=7), trauma (n=5) and infections (n=4). Interestingly, receiving anti-seizure medication was also a statistically significant influence. Specific details of the type of anti-seizure medication were not collected during the study. Arm circumference partially predicted systolic and MAP arm-calf BP differences. No other study reviewed included this anthropometric co-variate in their analyses. It is possible that the greater the subcutaneous tissue, the more difficult for the BP monitor to detect changes in the oscillometric waveform but further investigation is needed.

Limitations

Convenience sampling may lead to bias and limits generalizability of the study. Ethnic diversity of the sample was limited. Study results can only be generalized to children with head of bed elevated 30° in a PICU who have their arms and legs positioned on the bed when their BPs are obtained. The acuity of each subjects' critical illness was not documented and it is possible that the "sickest of the sick" were not included in the study due to patient instability and/or parents' unwillingness to subject their ill child to any "extra" procedures. Because there was only one measurement of simultaneous arm and calf BPs, it is possible that mean BPs for subjects would differ with repeated measures. The challenges of recruiting critically ill children and, once enrolled, helping them to remain quiet for a set of simultaneous BPs led the team to develop a data collection procedure that was simple and relatively quick.

Accuracy of assessment of sedation levels in pediatric subjects using the Richmond Agitation-Sedation Scale may be limited because the instrument has only been validated in adult critical care patients. The researchers had no difficulty applying the scale descriptions to children and recommend that the scale be validated in the pediatric population.

Conclusions and Implications

Calf and arm oscillometric BPs are not interchangeable for many children, ages 1 through 8 years, admitted to PICU. Clinical BP differences were greatest in children between ages 2 yrs to < 5 yrs. Calf BPs are not recommended for this population. If the calf is unavoidable due to medical reasons, trending of BP from this site should remain consistent during the child's stay.

Consistency in non-invasive measurement technique, i.e. oscillometry versus auscultation, is essential to promote BP accuracy in any setting. Clinicians should strive to maintain limbs at heart level to assure the most accurate readings. Selection of the appropriate cuff size based on limb circumference is mandatory. Documentation of BP site in the medical record is

necessary and the same site should be used consistently. If possible, baseline measurements of arm and calf BP upon admission will be helpful in identifying discrepancies for individual patients (Axton et al., 1995). Periodic re-education of nurses and other healthcare workers obtaining BP measurements is strongly recommended (Dickson & Hajjar, 2007; Pickering et al., 2005).

Future research should include a study using repeated measures of arm and calf BP to promote validity of findings in this particular age group. Replication of this study with a greater number of children of varying ethnicities is recommended. Leveling both arm and leg to heart level during readings will minimize potential differences from hydrostatic pressure. Further exploration of co-variables such as patient acuity and mechanical ventilation will provide further insight into which children may have greater arm-calf differences. With this knowledge, nurses will be better prepared to identify if and when obtaining calf BPs are appropriate.

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References

- Ambuel B, Hamlett KW, Marx CM, Blumer JL. Assessing distress in pediatric intensive care environments: The COMFORT scale. *Journal of Pediatric Psychology* 1992;17(1):95–109. [PubMed: 1545324]
- Arafat M, Mattoo TK. Measurement of blood pressure in children: Recommendations and perceptions on cuff selection. *Pediatrics* 1999;104:e30. [PubMed: 10469813]
- Axton SE, Bertrand S, Smith LF, Dy E, Liehr P. Comparison of brachial and calf blood pressures in infants. *Pediatric Nursing* 1995;21:323–326. [PubMed: 7644278]
- Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;1:307–310. [PubMed: 2868172]
- Crapanzano MS, Strong WB, Newman IR, Hixon RL, Casal D, Linder CW. Calf blood pressure: Clinical implications and correlations with arm blood pressure in infants and young children. *Pediatrics* 1996;97:220–224. [PubMed: 8584381]
- Crossland DS, Furness JC, Abu-Harb M, Sadagopan SN, Wren C. Variability of four limb blood pressure in normal neonates. *Arch Dis Child Fetal Neonatal Ed* 2004;89:F325–F327. [PubMed: 15210667]
- Dickson BK, Hajjar I. Blood pressure measurement education and evaluation program improves measurement accuracy in community-based nurses: A pilot study. *Journal of the American Academy of Nurse Practitioners* 2007;19:93–102. [PubMed: 17300535]
- Dobbins KR. Protocols for practice: Applying research at the bedside; Noninvasive blood pressure monitoring. *Critical Care Nurse* 2002;22:123–124. [PubMed: 11961934]
- Ely EW, Truman B, Shintani A, Thomason JWW, Wheeler AP, Gordon S, Francis J, Speroff T, Gautam S, Margolin R, Sessler CN, Dittus RS, Bernard GR. Monitoring sedation status over time in ICU patients: Reliability and validity of the Richmond Agitation-Sedation Scale (RASS). *JAMA: Journal of the American Medical Association* 2003;289:2983–91.
- Frauman AC, Lansing LM, Fennel RS. Indirect blood pressure measurement in children undergoing hemodialysis: A comparison of brachial and dorsalis pedis auscultatory sites. *AANT* 1984;11:19–21.
- G. E. Healthcare (n.d.). The DINAMAP[®] difference: A guide to our NIBP. Retrieved on January 7, 2009 from www.gehealthcare.com/us/en/patient_mon_sys/docs/DINAMAPDifference.pdf
- Giuliano, K. Noninvasive blood pressure monitoring. In: Burns, SM., editor. *AACN protocols for practice: Noninvasive monitoring*. 2. Sudbury, MA: Jones & Bartlett; 2005. p. 83-97.

- Hockenberry, MJ.; Wilson, D.; Winkelstein, ML.; Kline, NE. Wong's nursing care of infants and children. 7. St. Louis, MO: Mosby; 2003. Chapter 7: Physical and developmental assessment of the child – blood pressure; p. 182-186.
- Houweling ST, Kleefstra N, Lutgers HL, Groenier KH, Jong BM, Bilo HJG. Pitfalls in blood pressure measurement in daily practice. *Family Practice* 2006;23:20–27. [PubMed: 16332947]
- Jensen, MP.; Karoly, P. Self-report scales and procedures for assessing pain in adults. In: Turk, DC.; Melzack, R., editors. *Handbook of pain assessment*. New York: The Guilford Press; 1992. p. 135-151.
- Keck JF, Gerkensmeyer JE, Joyce BA, Schade J. Reliability and validity of the FACES and Word Descriptor scales to measure pain in verbal children. *Journal of Pediatric Nursing* 1996;11(6):368–374. [PubMed: 8991337]
- Kunk R, McCain GC. Comparison of upper arm and calf oscillometric blood pressure measurement in preterm infants. *Journal of Perinatology* 1996;16:89–92. [PubMed: 8732553]
- Lip GYH, Beever M, Beevers DG, Dillon MJ. The measurement of blood pressure and detection of hypertension in children and adolescents. *Journal of Human Hypertension* 2001;15:419–423. [PubMed: 11439318]
- McGhee BH, Bridges MEJ. Monitoring arterial blood pressure: What you may not know. *Critical Care Nurse* 2002;22(2):60–79. [PubMed: 11961944]
- Menard SW, Park MK. Blood pressure measurement in children: A brief review. *Seminars in Perioperative Nursing* 1995;4:92–95. [PubMed: 7780424]
- Merkel SI, Voepel-Lewis T, Shayevitz JR, Malviya S. Practice applications of research. The FLACC: a behavioral scale for scoring postoperative pain in young children. *Pediatric Nursing* 1997;23(3):293–7. [PubMed: 9220806]
- National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents. The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. *Pediatrics* 2004;114:555–576. [PubMed: 15286277]
- Netea RT, Lenders J, Smits P, Thien T. Influence of body and arm position on blood pressure readings: An overview. *J Hypertens* 2003;21:237–241. [PubMed: 12569245]
- Paice JA, Cohen FL. Validity of a verbally administered numeric rating scale to measure cancer pain intensity. *Cancer Nursing* 1997;20:88–93. [PubMed: 9145556]
- Park MK, Lee D. Normative arm and calf blood pressure values in the newborn. *Pediatrics* 1989;83:240–243. [PubMed: 2913554]
- Park MK, Robotham JL, German VF. Systolic pressure amplification in pedal arteries in children. *Critical Care Medicine* 1983;11(4):286–289. [PubMed: 6831899]
- Pickering TG, Hall JE, Appel LJ, Falkner BE, Graves J, Hill MN, Jones DW, Kurtz T, Sheps SG, Roccella EJ. Recommendations for blood pressure measurement in humans and experimental animals: Part 1: Blood pressure measurement in humans: A statement for professionals from the subcommittee of professional and public education of the American Heart Association Council on High Blood Pressure Research. *Hypertension* 2005;45:142–161. [PubMed: 15611362]
- Portman, RJ.; Sorof, JM.; Ingelfinger, JR., editors. *Pediatric hypertension*. Totowa, NJ: Humana Press; 2004.
- Pun BT, Gordon SM, Peterson JF, Shintani AK, Jackson JC, Foss J, Harding SD, Bernard GR, Dittus RS, Ely EW. Large-scale implementation of sedation and delirium monitoring in the intensive care unit: A report from two medical centers. *Critical Care Medicine* 2005;33:1199–205. [PubMed: 15942331]
- Rassin M, Sruey R, Kahalon A, Naveh R, Nicar I, Silner D. Between the fixed and the changing: Examining and comparing reliability and validity of 3 sedation-agitation measuring scales. *DCCN - Dimensions of Critical Care Nursing* 2007;26(2):76–82.
- Sessler CN, Gosnell MS, Grap MJ, Brophy GM, P'Neal PV, Keane KA, Tesoro EP, Elswick RK. The Richmond Agitation-Sedation Scale: Validity and reliability in adult intensive care unit patients. *American Journal of Respiratory Critical Care Medicine* 2002;166:1338–1344.
- Short JA. Noninvasive blood pressure measurement in the upper and lower limbs of anaesthetized children. *Paediatric Anaesthesia* 2000;10:591–593. [PubMed: 11119191]

- Stebor AD. Basic principles of noninvasive blood pressure measurement in infants. *Advances in Neonatal Care* 2005;5:252–261. [PubMed: 16202967]
- Terra SG, Blum RA, Wei GC, Lew RA, Digenio IR, Kazierad DJ. Evaluation of methods for improving precision of blood pressure measurements in Phase I clinical trials. *J Clin Pharmacol* 2004;44:457–463. [PubMed: 15102865]
- Van Dijk M, de Boer JB, Koot HM, Tibboel D, Passchier J, Duivenvoorden HJ. The reliability and validity of the COMFORT scale as a postoperative pain instrument in 0 to 3 year old infants. *Pain* 2000;84(2–3):367–77. [PubMed: 10666543]
- Voepel-Lewis T, Merkel S, Tait AR, Trzcinka A, Malviya S. The reliability and validity of the face, legs, activity, cry, consolability observational tool as a measure of pain in children with cognitive impairment. *Anesthesia & Analgesia* 2002;95:1224–9. [PubMed: 12401598]
- White WB, Berson AS, Robbins C, Jamieson MJ, Prisant LM, Roccella E, Sheps SG. National standard for measurement of resting and ambulatory blood pressures with automated sphygmomanometers. *Hypertension* 1993;21(4):504–9. [PubMed: 8458649]
- Wielenga JM, de Leeuw R. COMFORT scale: A reliable and valid method to measure the amount of stress of ventilated preterm infants. *Neonatal Network* 2004;23(2):39–44. [PubMed: 15077859]
- Wong D, Baker C. Pain in children: Comparison of assessment scales. *Pediatric Nursing* 1988;14:9–17. [PubMed: 3344163]

Figure 1.
Bland-Altman Plot Systolic Blood Pressure

Figure 2.
Bland-Altman Plot Diastolic Blood Pressures

Figure 3.
Bland-Altman Plot MAP

Table 1**Pain Assessment Tools**

Assessment Tool	Patient Population Application
FLACC Pain Assessment Tool (Merkel et al., 1997)	Infants and non-verbal children with or without cognitive delay. Exclude intubated, mechanically ventilated patients.
COMFORT Scale (Ambuel et al., 1992)	All intubated, mechanically ventilated patients
FACES Pain Rating Scale (Wong, 1988)	Verbal children > 4 years, old, 3-year-olds who are able to count and can demonstrate understanding of the tool.
Numeric Rating Scale (Jensen & Karoly, 1992)	Verbal children who are able to count to 10 and can demonstrate understanding of the tool.

Table 2

Demographic Characteristics of the Sample

Variable	Number (%)
Age	
0–1 Years	60 (27)
2–4 years	72 (32)
5–8 years	92 (41)
Gender	
Male	110 (49)
Female	106 (47)
Missing	8 (4)
Race	
American Indian or Alaskan Native	0 (0)
Asian	6 (3)
Black or African American	64 (29)
Hawaiian Native or other Pacific Islander	0 (0)
White or Caucasian	136 (61)
Other	12 (5)
Refused	1 (0.04)
Missing	5 (2)

Table 3**Medical Diagnosis & Current Medications by Category**

Medical Diagnosis	Number (%)
Neurological	52 (24)
Pulmonary	74 (34)
Esophageal/nasal/tracheal	13 (6)
Cardiovascular	3 (1)
Gastrointestinal	22 (10)
Endocrine	9 (4)
Genital/urinary or/Renal	9 (4)
Other	33 (15)
Orthopedic	1 (1)
Current Medications	
Sedative/Pain	80 (37)
Paralytic	3 (1)
Anti-Seizure	30 (14)
Antihypertensive	4 (2)

Table 4

Descriptive Statistics of Blood Pressure and Heart Rate of Entire Sample and by Age Group

Variable	Mean (SD)			
	Sample* (n=224)	Group 1* (n=58)	Group 2* (n= 69)	Group 3* (n=91)
Systolic BP (mmHg)				
Arm	104.06 (11.72)	100.81 (12.55)	100.78 (10.29)	108.62 (10.74)
Calf	112.11 (15.26)	110.22 (17.95)	111.58 (13.52)	113.73(14.63)
Difference	– 8.05 (13.58)	–9.41 (15.83)	– 10.79 (12.94)	–5.11 (11.98)
Diastolic BP (mmHg)				
Arm	64.74 (12.13)	63.16 (13.88)	63.41 (12.09)	66.78 (10.72)
Calf	65.95 (14.70)	64.45 (15.21)	65.99 (15.99)	66.70 (13.38)
Difference	–1.13 (12.18)	–1.29 (13.39)	–2.58 (14.61)	0.08 (8.88)
MAP (mmHg)				
Arm	77.97 (11.46)	76.33 (13.11)	76.19(10.62)	80.38 (10.59)
Calf	80.79 (13.88)	79.59 (15.21)	80.88 (14.21)	81.49 (12.79)
Difference	–2.83 (12.28)	–3.26 (13.02)	– 4.69 (14.39)	–1.11 (9.65)
Heart rate (beats/min)	123.88 (24.27)	135.03 (21.52)	122.90 (25.64)	117.43 (22.54)

* **Sample:** 1 to 8 yrs **Group 1:** 1 to < 2 yrs **Group 2:** 2 to < 5 yrs **Group 3:** 5 to 8 yrs

Table 5

Size of Systolic, Diastolic and MAP Arm-Calf Differences and Subject Percentage by Age Group

	Arm-Calf Differences	
	≥10 to 19.9 mm Hg	≥ 20 mm Hg
Groups 1 (N=60)		
Systolic Differences	26.7% (n = 16)	33.3%(n = 20)
MAP Differences	33.3% (n = 6)	11.7%(n = 7)
Diastolic Differences	31.7% (n = 19)	15.0% (n = 9)
Group 2 (N=72)		
Systolic Differences	31.9% (n = 23)	27.7% (n = 20)
MAP Differences	22.2% (n = 16)	18.1% (n = 13)
Diastolic Differences	33.3% (n = 24)	15.3%(n = 11)
Group 3 (N=92)		
Systolic Differences	34.8% (n = 32)	14.3% (n = 13)
MAP Differences	16.3% (n = 15)	6.5% (n = 6)
Diastolic Differences	19.6% (n = 18)	3.3% (n = 3)
Sample (N=224)		
Systolic Differences	26.3% (n = 63)	21.4% (n = 48)
MAP Differences	23.2% (n = 52)	12.1% (n = 27)
Diastolic Differences	12.1% (n = 27)	9.8%(n = 22)

Table 6

Paired T-Tests for Entire Sample and by Age Group

	Variable					
	Systolic BP		Diastolic BP		MAP	
	n	t	p	t	p	t
Entire Sample (1 yr to 8yrs)	224	-8.76	0.000*	-1.38	0.167	-3.44
						0.001*
Group 1 (1 yr to < 2 yrs)	58	-4.53	0.000*	-0.735	0.465	-1.91
						0.062
Group 2 (2 yrs to < 5 yrs)	69	-6.93	0.000*	-1.47	0.147	-2.71
						0.008*
Group 3 (5 yrs to 8 yrs)	91	-4.07	0.000*	-0.830	0.934	-1.09
						0.278

* Significant at the 0.05 level