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COMPARISON OF FOREARM AND UPPER ARM BLOOD PRESSURES

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ABSTRACT

Objective. In the prehospital setting it is not always feasible to obtain blood pressure (BP) readings from the upper arm. This study was performed to compare BPs obtained from subjects' forearms and upper arms in order to assess the utility of forearm BP as a surrogate for standard BP. **Methods.** The authors performed a prospective, cross-sectional, convenience study in a sample of ambulatory university ED patients, where each subject had sequential determinations of left upper arm and forearm BPs with an automated monitor at ED triage. The order of measurement was determined by the day of the week. Demographic and clinical data were also recorded. The main outcome measure was the correlation between upper arm and forearm systolic and diastolic BPs. Pearson's correlation coefficient and Student's t-test were used to analyze the data. **Results.** 151 patients were enrolled. The mean age was 35.3 ± 15.7 years; 40% were female and 78% were white. The mean forearm and upper arm systolic BPs were 129.8 ± 20.7 mm Hg and 126.2 ± 17.6 mm Hg (p = 0.002). The mean forearm and upper arm diastolic BPs were 80.7 ± 14.5 mm Hg and 76.8 ± 13.4 mm Hg (p < 0.001). The correlations between forearm and upper arm systolic and diastolic BPs were 0.75 (p < 0.001) and 0.72 (p < 0.001). The differences between forearm and upper arm systolic and diastolic BPs were within 20 mm Hg in 86% and 94% of patients, respectively. **Conclusion.** Forearm BP is a fairly good predictor of standard upper arm BP in most patients. Forearm BP may be used when measurement of upper arm BP is not feasible. **Key words:** blood pressure; emergency department; forearm; out-of-hospital; EMS.

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Early identification of abnormal blood pressure (BP) is of paramount importance to EMS providers because field treatment and triage might vary based on this result. The American College of Surgeons trauma triage criteria use BP as one of the physiologic criteria for transport to a trauma center.[1] To this end, BP has been shown to be one of the criteria most highly predictive of trauma mortality and morbidity, whether measured in terms of admission/discharge decision, length of stay, need for ICU care, injury severity score, or need for operative intervention.[2,3] Likewise, in patients who activate the EMS system for nontraumatic complaints, the BP can help stratify the risk these patients incur.[4] Early identification and aggressive management of clinical shock are necessary to avoid significant morbidity and mortality. In less urgent situations, it is well known that hypertension is an important risk factor for vascular disease and that reduction in BP reduces long-term cardiovascular morbidity.[5–8]

The American Heart Association (AHA) recommends indirect BP determination by the auscultatory method.[9] In this method, an inflatable BP cuff is placed over the brachial artery on the upper arm. The method of BP ascertainment is critical to EMS providers who cannot routinely perform BP assessment in the manner recommended by the AHA. While occasional patients may have BPs obtained in the sitting position, most have BPs obtained while lying supine. In some instances (vehicle entrapment, heavy clothing), the upper arm may not even be accessible, and the forearm is used for BP determination. Patients with very large upper arms may also require field BP determinations in the forearm. In this case, the radial artery is used as the site of monitoring. Forearm BP measurements have been discouraged because of claims that falsely elevated diastolic readings can occur.[9]

In an attempt to identify prior studies comparing upper arm and forearm BPs, a MEDLINE search for the years 1966–1998 was performed using the following MeSH headings: *blood pressure, measurement, diagnosis,* and *forearm.* However, we were unable to identify any prior such study that directly compared forearm and upper arm BPs. For this reason, we studied the relative differences between forearm and upper arm BPs. The objective of the current study was to evaluate the correlation between standard upper arm and forearm BPs in ambulatory ED patients in order to determine whether forearm BP could be used to predict upper arm BP.

METHODS

Study Design

We performed a prospective cross-sectional study to determine the correlation between upper arm and forearm BPs.

Population and Study Site

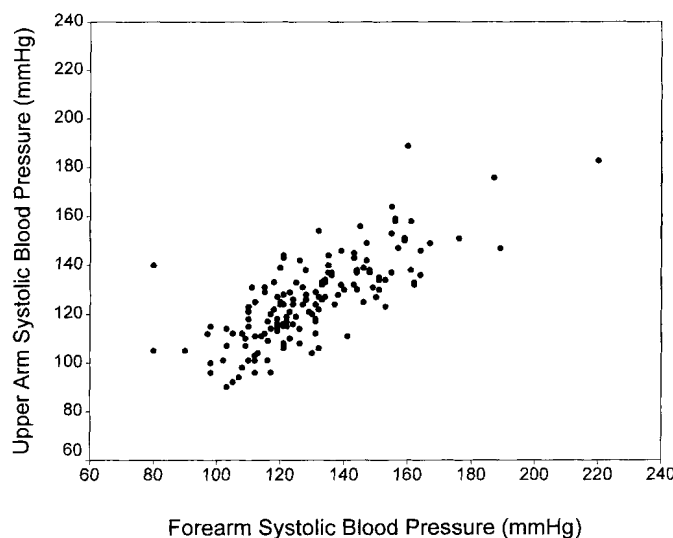This study was conducted between February and March

Figure 1. Relationship between upper and forearm systolic blood pressures.

1997 on a convenience sample of ambulatory patients who were seen by a single triage nurse (SRK) at a university-affiliated emergency department with an annual census of 50,000 patient visits. The study was approved by the institutional review board.

Ambulatory patients older than 5 years were included. Patients were excluded if they had a condition that precluded BP measurement (e.g., trauma, amputation) or if they arrived by ambulance, thereby bypassing our triage nurse.

Blood Pressure Measurement

All patients were seated, with the midpoint of the upper arm positioned at the level of the heart in accordance with the recommendations of the AHA.[10] Blood pressure measurements were obtained sequentially from all patients' left upper arms and forearms using noninvasive BP monitors (Omega 1400, In Vivo Laboratories Inc., Orlando, FL), which are based on the oscillometric technique. These monitors are calibrated semiannually with a standard mercury manometer and meet the standards proposed by the Association for the Advancement of Medical Instrumentation.[11] Appropriate sized BP cuffs were used in accordance with the recommendations of the AHA.[9] On even days of the month, BP measurements were obtained in the forearm first, followed by upper arm measurements. On odd days of the month, upper arm measurements preceded forearm recordings.

Data Collection

In addition to BP recordings, clinical and demographic data were recorded on the standard medical encounter record. Data collected included age, gender, race, chief complaint, medical history, cardiac risk factors, cuff size, arm and forearm circumferences, and use of med-

ications. Data were entered into Access 97 (Microsof Inc., Redmond, WA) and imported into SPSS 7.5 fc Windows (SPSS, Inc., Chicago, IL) for statistical analy sis.

Statistical Analysis

Upper arm–forearm BP differences were defined as th differences in both systolic and diastolic blood pres sures (SBP and DBP) between measurements. We als calculated the numbers of patients in whom the differ ence between upper arm and forearm measurement was less than 10 or less than 20 mm Hg. Continuou variables are reported as means and were compare using Student's t-test. The χ^2 test was used to compar categorical variables that are reported as percent fre quency of occurrence. Correlation between upper arr and forearm BPs in individual patients was deter mined using Pearson's test. Correlation between cor tinuous variables (such as age, SBP, DBP, arm circun ference) and the forearm upper arm BPs was als calculated. A two-tailed $p < 0.05$ was considered sig nificant for all tests.

Results

We enrolled 151 patients during the study period. Th mean age was 35.3 ± 15.7 years; 40% were female an 78% were white. At least one cardiac risk factor wa present in 63 (41.7%) patients [hypertension, 12 pa tients (7.9%); CAD, 2 patients (1.3%); smoking, 5 patients (34.4%); hypercholesterolemia, 9 patien (6.0%)]. In 110 patients (73%), the upper arm BP wa determined first, and in 41 patients (27%), measure ment of forearm BP preceded upper arm measure ment. The mean forearm and upper arm SBPs wer 129.8 ± 20.7 and 126.2 ± 17.6 mm Hg (p = 0.002). Th mean forearm and upper arm DBPs were 80.7 ± 14. and 76.8 ± 13.4 mm Hg (p < 0.001). The mean differ ence in SBPs was 3.6 (± 13.8) mm Hg (95% CI for th difference, 1.4–5.9 mm Hg). The mean difference i DBPs was 3.9 (± 10.5) mm Hg (95% CI for the differ ence, 2.2–2.6 mm Hg). Correlations between forearr and arm SBPs and DBPs were 0.75 (95% CI, 0.67–0.8I p < 0.001) and 0.72 (95% CI, 0.63–0.79; p < 0.001, Fig 1 and 2). The differences between forearm and uppe arm SBPs and DBPs were within 10 mm Hg in 58% an 70% of patients, respectively. The differences betwee forearm and upper arm SBPs and DBPs were within 2 mm Hg in 86% and 94% of patients, respectively. Th mean heart rate during upper arm BP measuremen was similar to that recorded during forearm measur ments (83.5 ± 15.6 beats/min vs 83.2 ± 14.5 beats/mii p = 0.56).

The difference between upper arm and forearm BF was unrelated to age, gender, race, SBP or DBP, pre ence of cardiovascular risk factors, or clinical diagnc sis.

Systolic hypertension (SBP >140 mm Hg) or diastolic hypertension (DPB >90 mm Hg) was present in 42 patients (28%). Hypotension (SBP <90 mm Hg) was identified at triage in only two patients, both on measurement of their forearm BPs only.

DISCUSSION

Accurate determination of BP is an essential element of patient evaluation both in the inhospital and out-of-hospital settings. Blood pressure is most accurately measured by inserting a catheter into the arterial system and connecting it to a calibrated pressure transducer for continuous measurement of the beat-by-beat arterial pressure. However, this technique is impractical in most situations. Thus, the indirect or occluding cuff method is used in most situations. Standard indirect BP measurements are obtained from the patient's bared arm that is unrestricted by clothing.[9] While this technique is possible in most patients in the emergency department, exposure of the bare arm may be difficult in several situations. For example, in the out-of-hospital setting the patient may be partially trapped in a building or motor vehicle with only the distal forearm exposed, or it may be undesirable to undress the patient to expose the upper arm in a cold environment. In the ED triage area patients lack privacy, again making exposure of the upper arm undesirable in some situations. Finally, in very obese patients an appropriate-sized BP cuff may not be available, making use of the forearm an attractive alternative to upper arm measurement. Currently there are no data on the accuracy of forearm BPs in predicting upper arm pressures.

In the current study we have demonstrated good correlation between upper arm and forearm BP measurements. While we found statistically significant differences between SBPs and DBPs measured at these different anatomic locations, it is unlikely that these differences (approximately 4 mm Hg) are clinically relevant. In most patients, these differences were less than 20 mm Hg. It is well known that there is considerable beat-to-beat variability in BPs even when measured directly.[12] Furthermore, there are considerable inter-arm differences in BPs even when measured simultaneoulsy.[13] Thus, the degree of BP variability found in our study is very similar to the inter-arm and beat-to-beat variability normally present for standard upper arm BP measurements.[13] Indeed, prior studies have noted differences of up to 60 mm Hg between arms[14] similar to the most extreme case in our study in which the SBP in the upper arm was 140 mm Hg, whereas the forearm reading was only 80 mm Hg (Fig. 1). These extreme cases may be the result of technical errors during measurement or the result of significant variation in the caliber and compliance of various portions of the artery.
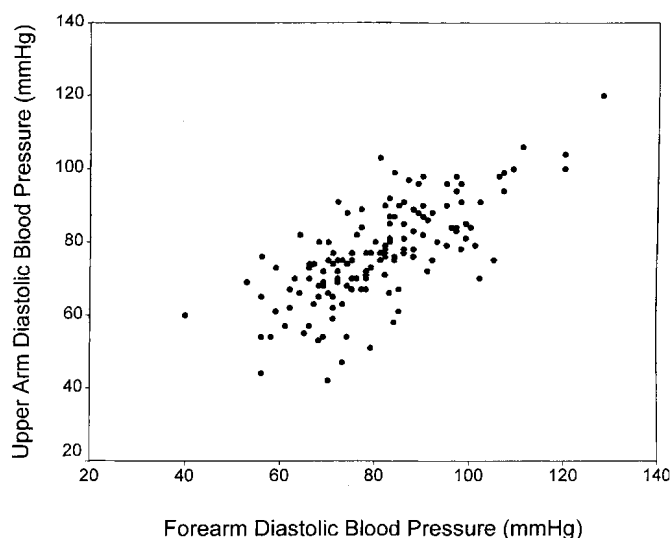

FIGURE 2. Relationship between upper and forearm diastolic blood pressures.

While our sample size was relatively small, there were no patients for whom hypotension would have been missed had only forearm BPs been determined. Conversely, there were no patients in whom exceedingly high BPs would have remained unrecognized had upper arm pressures not been obtained. Thus, while not a substitute for conventional measurements, forearm BP measurements seem reasonable when upper arm measurement is not feasible.

LIMITATIONS AND FUTURE DIRECTIONS

Our study has several limitations that merit further discussion. First, we did not measure direct intraarterial pressures from both the brachial and radial arteries. However, our study simulates the clinical scenario where BPs are measured indirectly. Second, we did not measure forearm and upper arm BPs simultaneously. It is possible that simultaneous measurements would have resulted in a reduction in the differences between upper arm and forearm pressures. However, simultaneous indirect BP measurements in the same arm are not technically possible. Third, we assessed the forearm–upper arm BP differential in ambulatory patients sitting in a triage station. It is possible that the relative differences in this position might not accurately reflect the relative differences obtained in supine patients. Fourth, the BP monitor was calibrated only once during the study period. While this follows the recommendations of the Association for the Advancement of Medical Instrumentation, it is possible that more frequent calibration may have altered our results. Fifth, the device used to measure BPs was designed for the upper arm. We did not use a device designed specifically for the forearm. This also may have had an effect on our results. Significantly more patients had BPs

measured in the upper arm first. Hashimoto et al. have noted a small yet statistically significant effect of order of measurement on SBPs yet not DBPs. They found that the mean first reading was 2.3 mm Hg higher than the mean second reading.[15] However, we do not feel that this small potential order effect has significantly contributed to our findings. Finally, we assessed these differences in the ED triage area, which does not precisely mimic the out-of-hospital environment. We chose to evaluate BPs in the controlled ED environment with one investigator to ensure standardization of measuring techniques. Future studies should address whether the results obtained in our study would be similar in the prehospital setting and in a larger group of hypotensive patients.

CONCLUSIONS

This study demonstrates that there is a fair degree of correlation between indirect sequential upper arm and forearm BP measurements, and most pressure differences are less than 10–20 mm Hg. Thus, forearm BP measurements can be used when upper arm measurements are not feasible.

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CLINICAL COMPARISON OF AUTOMATIC, NONINVASIVE MEASUREMENTS OF BLOOD PRESSURE IN THE FOREARM AND UPPER ARM

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- **BACKGROUND** *When the upper arm (area from shoulder to elbow) is inaccessible and/or a standard-sized blood pressure cuff does not fit, some healthcare workers use the forearm to measure blood pressure.*
- **OBJECTIVE** *To compare automatic noninvasive measurements of blood pressure in the upper arm and forearm.*
- **METHODS** *A descriptive, correlational comparison study was conducted in the emergency department of a 1071-bed teaching hospital. Subjects were 204 English-speaking patients 6 to 91 years old in medically stable condition who had entered the department on foot or by wheelchair and who had no exclusions to using their left upper extremity. A Welch Allyn Vital Signs 420 series monitor was used to measure blood pressure in the left upper arm and forearm with the subject seated and the upper arm or forearm at heart level.*
- **RESULTS** *Pearson r correlation coefficients between measurements in the upper arm and forearm were 0.88 for systolic blood pressure and 0.76 for diastolic blood pressure (P < .001 for both). Mean systolic pressures, but not mean diastolic pressures, in the upper arm and forearm differed significantly (t = 2.07, P = .04). A Bland-Altman analysis indicated that the distances between the mean values and the limits of agreement for the 2 sites ranged from 15 mm Hg (mean arterial pressure) to 18.4 mm Hg (systolic pressure).*
- **CONCLUSIONS** *Despite strict attention to correct cuff size and placement of the upper arm or forearm at heart level, measurements of blood pressure obtained noninvasively in the arm and forearm of seated patients in stable condition are not interchangeable. (American Journal of Critical Care. 2005;14:232-241)*

Measurement of blood pressure, an integral part of every patient's vital signs, was first introduced in 1896 by Riva Rocci.[1] It is commonly one of the first skills taught healthcare providers and one performed frequently by clinicians. Used to screen for hypertension, to estimate cardiovascular risk, and to diagnose, manage, and treat acute and chronic medical conditions, measurements of blood pressure can be obtained by 1 of 3 methods.

The first method, the gold standard, is direct intra-arterial measurement. However, because of impracticalities and potential risks (eg, infection and trauma), indirect, noninvasive methods are commonly used. One indirect, noninvasive technique is use of a sphygmomanometer and auscultation. The blood pressure cuff is inflated by hand to a level that obliterates the arterial pressure or pulse. The cuff is then gradually deflated, and the systolic pressure is noted when Korotkoff sounds appear; the disappearance of the sounds indicates the diastolic pressure. An alternative indirect noninvasive method is use of an automated device and oscillometric measurements. Oscillations, movement in the arterial walls due to cardiac contractions, begin at

the level of systolic blood pressure and reach their greatest amplitude at the level of the mean arterial pressure (MAP). The diastolic pressure is a derived value. The values are transmitted to a microprocessor, in conjunction with the cuff size, to determine the blood pressure.[1]

> *Use of blood pressure cuffs that are too large yields readings lower than actual values, whereas use of cuffs that are too small yields readings higher than actual values.*

The size and placement of the cuff are essential for accurate measurements. These features are specific to each manufacturer and are based on recommendations from the American Heart Association (AHA). Appropriate cuff size is key because cuffs that are too large yield readings lower than the actual values, and cuffs that are too small yield readings higher than the actual values.[1-3] Historically, the blood pressure cuff is placed on the upper arm (defined as the area from the shoulder to the elbow). However, the forearm (defined as the area from the elbow to the wrist) is increasingly becoming an alternative site because of the inaccessibility of the upper arm on some patients and the nonstandard, large-sized cuffs needed for the increasing numbers of morbidly obese patients.[2,4] Manufacturers of machines used in acute care to measure blood pressure noninvasively either do not recommend that the forearm be used or do not provide detailed, valid, and/or reliable directions for obtaining blood pressures in the forearm.[3,5] Cuffs designed specifically for measurements of blood pressure in the forearm are not available in most hospital settings. In the *Protocol for Practice: Noninvasive Blood Pressure Monitoring*[6] published by the American Association of Critical-Care Nurses, Dobbin indicates that the forearm and the ankle can be used for measuring blood pressure but does not detail the procedure for cuff size or technique and cites only studies that validated the accuracy of blood pressures measured in the ankle. Additionally, the authors[1] of the AHA recommendations for noninvasive measurement of blood pressure mention use of the forearm for measuring blood pressures in obese patients but indicate that this method has not been validated.

> *Although the forearm is used for automatic noninvasive measurements of blood pressure, the accuracy of this procedure has not been verified.*

Review of the Literature

An extensive electronic search of the database Cumulative Index to Nursing and Allied Health for research on the use of the forearm for measuring blood pressure noninvasively yielded 5 articles.[4,7-10] In an early study, Tachovsky[7] compared indirect measurements of blood pressure obtained via auscultation in the upper arm with measurements obtained in the forearm. A convenience sample of 100 healthy female nursing students were placed in a supine position, and 3 blood pressure readings were obtained from each site (right upper arm vs right forearm), with a 3-minute rest between measurements. In addition to the 1967 AHA recommendations for obtaining blood pressure, Tachovsky used the Ravin procedure to augment auscultated sounds in the forearm but not the upper arm. A standard cuff (13 cm) with Velcro closure and a pediatric stethoscope were used to obtain measurements from both sites.

The results revealed significant differences between measurements of systolic blood pressure obtained in the 2 sites; measurements obtained in the upper arm were significantly greater than those obtained in the forearm (mean difference 7.35 mm Hg, $P < .05$). Conversely, measurements of diastolic pressure obtained in the forearm were significantly greater than those obtained in the upper arm (mean difference 14.1 mm Hg, $P < .05$). The clinical significance of these differences was less clear, and Tachovsky cautioned against using measurements of blood pressure obtained in the forearm in situations in which an accurate measurement was imperative for making clinical decisions. Although this study[7] was one of the first on this topic, the current standard for measuring blood pressure often involves the use of automatic noninvasive instruments.

In 1996, Latman et al[8] published their evaluation of the performance of an automatic, noninvasive instrument, the B/P Clinic (CardioAnalysis Systems, Winchester, Tenn), specifically designed to use the forearm for measuring blood pressure. The auscultatory method in the upper arm and the B/P Clinic in the forearm were used to measure blood pressure in a convenience sample of 106 subjects. In addition, heart rate was measured by palpating the radial artery and by using the B/P Clinic during blood pressure measurement. Patients with forearm circumferences less than 20.3 cm or greater than 33.0 cm and/or with systolic blood pressures of 190 mm Hg or greater were excluded. All subjects were seated during the data collection, with the upper arm and forearm positioned at the level of the heart for each measurement. In addition, a subset of the sample (n=30) had 2 sequential measurements in the forearm obtained with the B/P Clinic to determine the reliability of the instrument.

Correlation coefficients for measurements of blood pressure and heart rate obtained with the B/P Clinic and with the auscultatory method and palpation were 0.82 for systolic pressure, 0.75 for diastolic pressure, and 0.95 for heart rate. Reliability coefficients for the sequential measurements with the automatic device were 0.85 for systolic pressure, 0.81 for diastolic pressure, and 0.96 for heart rate. Latman et al[8] concluded that the B/P Clinic was both accurate and precise and that the forearm could be used to measure blood pressure and heart rate.

This study[8] provided important information on the reliability and validity of the B/P Clinic as an instrument for measuring blood pressure in the forearm. Sequential measurements have been used as the standard for comparisons of blood pressures measured in the upper arm and the forearm; however, Latman et al chose to compare the automated measurements with measurements obtained by using the auscultatory method. In reality, blood pressures in the upper arm are routinely measured by using an automatic noninvasive instrument.

In a similar study, Latman and Latman[9] evaluated the accuracy and precision of an instrument used to measure blood pressure in the wrist that was developed for home blood pressure monitoring. The standard auscultatory method in the upper arm and the automatic noninvasive device in the wrist were used to measure blood pressure in a convenience sample of 150 subjects. In addition, heart rate was measured by palpating the radial artery and by using the noninvasive automatic device during blood pressure measurement. Patients with wrist circumferences less than 13.5 cm or greater than 19.5 cm and/or blood pressures of 280 mm Hg or greater and/or heart rates less than 40/min or greater than 200/min were excluded. All subjects were seated during the data collection, with the arm and wrist positioned at the level of the heart for each measurement. In addition, a subset of the sample (n=51) had 2 sequential measurements in the wrist obtained with the automatic device to determine the reliability of the device.

Correlation coefficients for measurements of blood pressure and heart rate obtained with the automatic device and with the auscultatory method and palpation were 0.75 for systolic pressure, 0.76 for diastolic pressure, and 0.89 for heart rate. Reliability coefficients for the sequential measurements obtained in the wrist with the automatic device were 0.83 for systolic pressure, 0.92 for diastolic pressure, and 0.95 for heart rate. However, with the wrist instrument, hypotensive blood pressures tended to be overestimated and hypertensive pressures were significantly underestimated. The researchers concluded that the wrist instrument was easy to use and could have potential for home blood pressure monitoring. The major limitation of the earlier study[8] also applies to this research.[9]

In a more recent study, Emerick[10] evaluated the use of the wrist for determining blood pressure in a convenience sample of 85 nonhospitalized adults. Each subject was placed in the supine position, and upper arm and wrist circumferences were measured to determine proper cuff size. An oscillometric noninvasive device was used to obtain 3 sequential, paired measurements of blood pressure in the upper arm and the wrist of the right upper extremity, for a total of 255 paired readings. For each subject, measurements were obtained with the extremity at the subject's side.

Mean differences between measurements obtained in the wrist and those obtained in the upper arm were 11.2 mm Hg (SD 7.56 mm Hg) for systolic blood pressure and 10.2 mm Hg (SD 5.60 mm Hg) for diastolic pressure. Emerick concluded that the mean differences exceeded an a priori standard (for accuracy) of a mean difference of less than 5 mm Hg set by the Association for the Advancement of Medical Instrumentation.[11] The author[10] further concluded that if the wrist were used to measure blood pressure, adjustments would be required. Emerick recommended that 10 mm Hg be subtracted from the systolic and diastolic pressure measurements obtained in the wrist or that the wrist be elevated approximately 15 cm when a reading is obtained.

Emerick's study[10] was the first in which standards were incorporated to determine if observed differences between 2 measurements of blood pressure obtained at different locations on the upper extremity would be acceptable in practice. Unfortunately, Emerick did not validate the recommendations for adjusting the measurements obtained in the wrist or repositioning the wrist as a means of compensating for the observed differences.

In 1999, Singer et al[4] reported the results of a study designed to determine if measurements of blood pressure in the forearm could be used to predict blood pressure in the upper arm. Measurements were obtained in a convenience sample of 151 subjects (mean age 35 years, SD 15.7 years) by a single triage nurse in a university-affiliated emergency department. Subjects were excluded if they were less than 5 years old, had arrived by ambulance, or had any condition that would preclude a blood pressure measurement (eg, amputation). An Omega 1400 automatic noninvasive blood pressure monitor (In Vivo Laboratories, Inc, Orlando, Fla) was used to obtain sequential measurements of blood pressure and heart rate in the left upper extremity (positioned at heart level) of the subjects while the subjects were seated. Cuff selection was based on recommendations from the AHA.

Mean systolic pressures were 129.8 mm Hg (SD 20.7) in the forearm and 126.2 mm Hg (SD 17.6) in the upper arm ($P = .002$). Mean diastolic pressures were 80.7 mm Hg (SD 14.5) in the forearm and 76.8 mm Hg (SD 13.4) in the upper arm ($P < .001$). Mean differences were 3.6 mm Hg for systolic pressures and 3.9 mm Hg for diastolic pressures. Correlations between the measurements obtained in the upper arm and the forearm were 0.75 for systolic pressures ($P < .001$) and 0.72 for diastolic pressures ($P < .001$). Heart rates recorded during the blood measurements in the upper arm and forearm did not differ significantly ($P = .56$). Measurements obtained in the 2 sites differed by 10 mm Hg or less in 58% of the patients for systolic pressure and in 70% for diastolic pressure and by 20 mm Hg or less in 86% of the patients for systolic pressure and in 94% for diastolic pressure. Differences in measurements obtained in the 2 sites were not related to demographic variables (age, sex, race, blood pressure, cardiac risk factors, and diagnosis). The researchers concluded that use of the forearm could be considered reasonable when the upper arm was not readily available.

The findings from this study[4] contributed important information to the issue of using the forearm to measure blood pressure. It is the only study in which an automatic noninvasive monitor was used to sequentially measure blood pressure in the upper arm and the forearm and then the correlation between the 2 values was determined. It is unclear how the forearm was positioned in relation to the level of the heart and whether cuff selections for measurements in the forearm were based on forearm circumferences. Finally, Singer et al commented, rightfully so, that the Omega 1400 monitor was not designed specifically for measuring blood pressure in the forearm. Together, these aspects of the study[4] may have introduced instrumentation and measurement errors.

In summary, the research on using the forearm to measure blood pressure is extremely limited. We have observed an increase in the use of the forearm as an alternative site for measuring blood pressure in a variety of clinical areas (the emergency department, medical-surgical units, labor and delivery units, and the operating room). Clearly the research to date does not provide the evidence needed to verify the accuracy of this practice. The purpose of our study was to compare automatic noninvasive measurements of blood pressures in the upper arm and forearm.

Methods

A descriptive correlational comparison study was conducted in the emergency departments of 2 acute care facilities (Wilmington Hospital and Christiana Hospital) of a 1071-bed teaching hospital system (Christiana Care Health System) located in Delaware. The study was approved by the institutional review board and was implemented in June of 2003.

Sample

A convenience sample of English-speaking patients 5 years or older whose medical condition was stable and who entered the triage or fast-track areas of the emergency department either on foot or in a wheelchair were recruited. Potential subjects were excluded if (1) they bypassed the triage or fast-track areas and/or their medical condition was unstable, (2) the noninvasive blood pressure cuffs available did not fit their upper arms or their forearms, (3) they could not expose the left upper extremity for measurement of blood pressure, and/or (4) they had conditions (eg, amputation, trauma to arm, previous mastectomy, arteriovenous fistula) that precluded measurement of blood pressure in the left upper extremity.

We determined that a sample of 189 patients would have 90% power to detect an effect size of 5 mm Hg (SD 15 mm Hg) at $\alpha = .05$. We considered a difference of 5 mm Hg or greater between upper arm and forearm blood pressures clinically significant.

Instruments

The Welch Allyn Spot Vital Signs 420 series noninvasive blood pressure monitor (Welch Allyn, Beaverton, Ore) was used for the study. The blood pressure accuracy of the monitor meets or exceeds SP10-1992 Association for the Advancement of Medical Instrumentation standards for noninvasive blood pressure accuracy (SE ±5 mm Hg, SD 8 mm Hg).[11] The accuracy of the measurements of blood pressure was validated by using the arm only.[3] Four new monitors provided by Welch Allyn were used exclusively for study purposes. The monitors were calibrated by the hospital system's clinical engineering department before the start of and at the conclusion of data collection, which occurred during a 2-week period.

A demographic/clinical data form was developed for this study. For each patient in the study, medical record number, age, sex, race, medical history, cardiac risk factors, medications, and emergency department medical diagnosis were collected retrospectively through electronic chart review. Retrospective chart review was more convenient because charts were not always accessible and complete during data collection periods. Clinical data collected included upper arm and forearm circumferences, upper arm and forearm cuff sizes, upper arm and forearm blood pressure measurements, upper arm and forearm heart rates, order of measurements, and time between measurements.

Procedure

Patients who met the inclusion criteria were approached after they had completed the emergency department registration process. They were given a brief, scripted description of the study to determine their interest in participating. If interested, triage patients were escorted from the waiting room to a private data collection station in the emergency department; fast-track patients were seen in the fast-track treatment areas. Data collectors provided patients a formal explanation of the study and obtained written informed consent. Permission from a legal guardian or parent was required for subjects between 5 and 18 years old. Assent was obtained from subjects ages 7 to 18 years.

Blood pressures were measured in accordance with the 1993 AHA standards.[1] Each subject was seated in a chair or assisted to a seated position (dangling) on a stretcher and was asked to expose the left upper extremity. Data collectors measured upper arm and forearm circumference and determined cuff size according to the manufacturer's recommendations (Table 1). The extremity was placed at heart level. For measurements in the forearm, the extremity was positioned on a bedside table raised to the level of the phlebostatic axis; for measurements in the upper arm, the extremity was placed in the subject's lap. Blood pressures were measured by using one of the Welch Allyn monitors. The order in which the measurements were obtained was alternated. For example, in the first subject, the blood pressure was measured first in the forearm and then, at least 1 minute but no more than 2 minutes later, in the upper arm. For the next subject, blood pressure was measured first in the upper arm and then in the forearm. Measurements were obtained in subsequent subjects in a similar manner. Subjects were asked to remain quiet during all measurements. During blood pressure measurement, pulse rate was also obtained from the monitor.

Error messages displayed by the monitor were handled according to Welch Allyn guidelines.[3] If the error code C06 ("Measurement was outside of device's measurement range") was displayed, the participant's data were eliminated from the study. However, follow-up measurements of blood pressure and heart rate were obtained by using a manual cuff with auscultation and palpating the radial artery to ensure the patient's safety. Abnormally high or low blood pressures, other unusual signs or symptoms, and changes in condition were communicated to the triage nurse or the fast-track practitioners.

Before data collection, 8 data collectors were trained in the use of the blood pressure monitor by a Welch Allyn representative. Interrater reliability was

Table 1 Selection of cuff size on the basis of circumference of upper arm or forearm*

| | Circumference, cm | |
Cuff size	Minimum	Maximum
Small child	12.4	16.8
Child	15.8	21.3
Small adult	20.0	27.0
Adult	25.3	34.3
Large adult	32.1	43.4
Extra large adult	40.7	55.0

*Based on recommendations of Welch-Allyn. If circumference overlapped 2 categories of cuff size, the larger cuff size was selected.

established for measurement of upper arm and forearm circumferences, selection of cuff size, and positioning of the forearm at heart level (mean $\alpha = .97$). Two researchers abstracted demographic and clinical data from the electronic charts of the first 10 subjects, and this trial information was validated by a third researcher so that 100% agreement was obtained. Intercoder reliability was established at 97% agreement for the 4 data coders before data entry into Microsoft Word files.

Data Analysis

Data were entered into Microsoft Word and imported into SAS version 8.2 (SAS Inc, Cary NC). Descriptive statistics were used to characterize the sample and to summarize the demographic and clinical data. Measures of central tendency aggregated data and reflected the group of subjects. The Pearson correlation coefficient was used to determine the relationship between measurements of blood pressure, MAP, and heart rate in the upper arm and the forearm. The difference between mean blood pressures in the upper arm and the forearm was tested by using paired t tests. The influence of the variables of age, sex, race, cardiac risk factors, current medications, and emergency department diagnosis on the differences was tested by using analysis of covariance. Significance was set at $P < .05$.

In order to obtain a clearer picture of the measurements for individual subjects, a Bland-Altman agreement analysis[12] was used to determine the extent of agreement between measurements of blood pressure in the upper arm and the forearm. The purpose of the agreement analysis, recommended for comparisons of clinical measurements, is to answer the question, Are forearm blood pressures interchangeable with upper arm blood pressures? This analysis was performed by

Table 2 Demographics of the sample (n=204)

Variable	Value
Age, mean (SD), years	36.5 (16.5)
Sex, No. of subjects	
Male	106
Female	98
Race, No. of subjects	
Black	94
Hispanic	14
White	94
Unknown	2

Table 3 Cardiac risk factors, medications, and emergency department diagnoses of the sample

Variable	No. of subjects (n=204)
Cardiac risk factors	
Coronary artery disease	3
Diabetes	12
Hypertension	30
Use of tobacco	22
High cholesterol level	9
Medications by category	
Cardiovascular	31
Pulmonary	31
Gastrointestinal	12
Antibiotics/antifungals/antivirals	14
Pain	47
Antihyperglycemic	10
Psychological/neurological	19
Other	27
Emergency department diagnosis by category	
Musculoskeletal	83
Cardiovascular	7
Pulmonary	26
Neurological/psychological	15
Gastrointestinal	15
Eyes, ears, nose, throat	41
Skin	34
Miscellaneous	21

using MedCalc for Windows, version 7.4.2.0 (Med-Calc Software, Mariakerke, Belgium).

Results

The demographics of the sample (n=204) are given in Table 2. Post hoc power was 80%. Approximately 52% of the subjects were male; subjects' ages ranged from 6 to 91 years (mean 36.5 years). Seventeen children (subjects between ages 5 and 18 years) were included in the study. Forty-six percent of the subjects were black, 46% were white, 7% were Hispanic, and 1% were reported as unknown race. The remaining demographics (Table 3) were coded according to frequency; some subjects had more than 1 category identified under cardiac risk factors, current medications, and emergency department diagnosis. The most common cardiac risk factor was hypertension (n=30). Medications related to pain relief (eg, acetaminophen, ibuprofen) were the drugs most often used by subjects. Of the 242 emergency department diagnoses, 34% were categorized as musculoskeletal (eg, muscle strain, back pain). Eyes-ears-nose-throat (eg, dental abscess, pharyngitis) and skin (eg, laceration, contusion) were the next most common diagnostic categories (17% and 14%, respectively).

The descriptive statistics for arm circumference, cuff size, blood pressure (systolic, diastolic, and MAP), and heart rate for both upper arm and forearm are given in Table 4. Although heights and weights were not obtained during this study, 8 subjects required use of the extra large cuff on the upper arm, suggesting that only a few (<1%) morbidly obese subjects were included in the convenience sample.

Pearson r correlation coefficients between measurements at the 2 sites were 0.88 for systolic blood pressure, 0.76 for diastolic pressure, 0.84 for MAP, and 0.94 for heart rate ($P < .001$). A paired t test revealed significant differences between mean systolic blood pressures at the 2 sites ($t=2.07$, $P=.04$). By paired t tests, differences in diastolic pressures, MAPs, and heart rates were not significant. However, measures of central tendency can be misleading because they reflect a group of subjects. Clinicians are typically more focused on accuracy of readings for individual patients; thus, data were further analyzed by using the Bland-Altman procedure.

The Bland-Altman procedure was used to determine agreement between the upper arm and the forearm for measurements of systolic blood pressure, diastolic blood pressure, and MAP. The bias (mean difference between upper arm and forearm measurements) for systolic pressures was -1.3 mm Hg (Figure 1). The computed upper and lower limits of agreement for systolic pressures were +17.1 mm Hg and -19.7 mm Hg, respectively. The limits of agreement for the diastolic pressures were +14.5 mm Hg and -16.5 mm Hg (Figure 2), and the bias was -1.0 mm Hg. For MAPs, the limits of agreement were +13.9 mm Hg and -16.0 mm Hg, and the bias was -1.1 mm Hg (Figure 3).

Five subjects had especially large differences between measurements of systolic and diastolic pressures in the upper arm and the forearm. For example, in 1 subject, blood pressure was 84/48 mm Hg in the upper arm and 122/80 mm Hg in the forearm. In this subgroup, the mean of the differences in systolic pressure was 33 mm Hg (range 19-39 mm Hg), and the

Table 4 Descriptive statistics of arm circumference, cuff size, blood pressure, and heart rate of sample
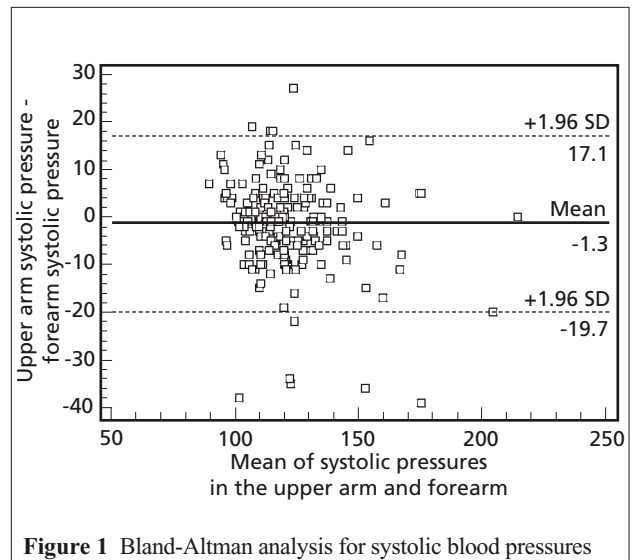
Variable	Mean	SD	Range
Circumference, cm			
Upper arm	31.8	5.34	19-47
Forearm	24.2	3.33	16-33
Cuff size*			
Upper arm	4.34	0.78	2-6
Forearm	3.29	0.66	2-5
Systolic blood pressure, mm Hg			
Upper arm	122.52	18.18	84-218
Forearm	123.83	20.05	87-218
Difference	1.31	9.40	ND
Diastolic blood pressure, mm Hg			
Upper arm	78.16	10.68	48-113
Forearm	79.03	11.84	42-122
Difference	0.87	7.83	ND
Mean arterial pressure, mm Hg			
Upper arm	92.94	12.52	60-141
Forearm	93.96	13.88	59-147
Difference	1.02	7.61	ND
Heart rate, beats/min			
Upper arm	76.47	14.44	49-129
Forearm	76.14	14.21	49-129

*Welch Allyn cuff size: 1, small child; 2, child; 3, small adult; 4, adult; 5, large adult; 6, extra-large adult.
Abbreviation: ND, not determined.

Figure 1 Bland-Altman analysis for systolic blood pressures

mean of the differences in diastolic pressure was 25 mm Hg (range 21-32 mm Hg), with the measurements in the forearm higher than the measurements in the upper arm. Demographics and clinical data varied within this subgroup, and no obvious pattern in cuff size or order of cuff placement was detected.

> *Differences between measurements of systolic, diastolic, and mean arterial blood pressures in the upper arm differed widely from measurements in the forearm, indicating that measurements obtained in the 2 sites are not interchangeable.*

Paired t tests revealed that as a group, smokers (n = 22) had significant differences between the upper arm and the forearm in measurements of systolic pressure (t = -2.42, P = .02) and MAP (t = -2.40, P = .03); measurements in the forearm were more than 3 mm Hg higher than those in the upper arm. Black subjects (n = 93) had significant differences between measure-
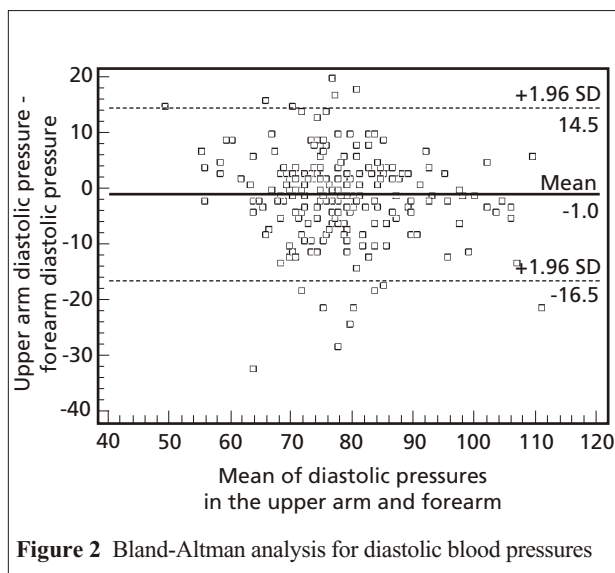
ments in the upper arm and the forearm of MAP (t = -2.98, P = .004), systolic pressure (t = -3.28, P = .002), and diastolic pressure (t = -2.26, P = .03); measurements in the forearm were 1.7 to 3.4 mm Hg higher than those in the upper arm. Paired t tests indicated no significant differences in the blood pressures of children (<18 years old), elderly subjects (>65 years old), males, females, small and large cuff sizes, cuff order, emergency department diagnoses, current medications, or cardiac risk factors other than smoking.

Discussion

Use of the forearm for measuring blood pressure has been incorporated into practice by clinicians despite the lack of research evidence supporting its use. In this replication study, we compared automatic noninvasive measurements of blood pressure in the forearm and the upper arm. Our results indicated a strong correlation between measurements obtained at the 2 sites. Nevertheless, experts advise that correlation does not measure the agreement of 2 variables; rather it simply indicates the strength of the relationship.[12,13] Paired t tests, used to analyze group data, revealed no significant differences between the 2 sites in measurements of diastolic blood pressure or MAP and a statistically significant difference between measurements of systolic blood pressures (mean systolic blood pressure 122.5 and 123.9 mm Hg for the upper arm and the forearm, respectively; with a mean difference of 1.31 mm Hg between measurements obtained at the 2 sites). However, the Bland-Altman procedure, a more relevant analysis when measurements of individual subjects are examined, revealed different results (see Appendix).

Figure 2 Bland-Altman analysis for diastolic blood pressures

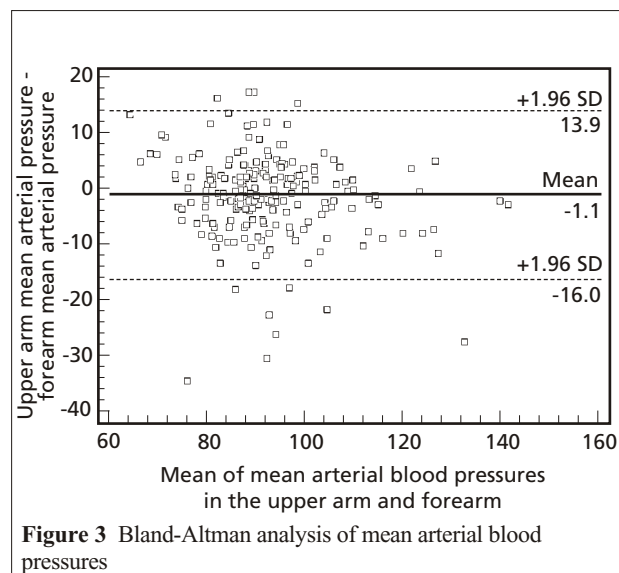**Figure 3** Bland-Altman analysis of mean arterial blood pressures

The Bland-Altman procedure was used to calculate the amount of agreement between measurements of systolic pressure, diastolic pressure, and MAP in the upper arm and the forearm. The distances between the mean values and the limits of agreement ranged from 15 mm Hg (MAP) to 18.4 mm Hg (systolic pressure). This finding means, for example, that in approximately 95% of subjects, measurements of systolic pressure in the forearm will be within 18.4 mm Hg above and 18.4 mm Hg below the subjects' mean measurements of systolic pressure in the upper arm and the forearm. Because differences of this magnitude could be clinically important, the analysis indicates that measurements of systolic pressure obtained by using the forearm are not interchangeable with measurements obtained by using the upper arm. In fact, the limits of agreement for measurements of systolic blood pressure, diastolic blood pressure, and MAP in the 2 sites all exceeded the difference of 5 mm Hg we specified as indicating a clinically significant difference. Thus, the degree of agreement for the measurements of all 3 blood pressures in the 2 sites is not clinically acceptable, and the forearm and upper arm measurements are not interchangeable.

A review of demographics for the 5 subjects who had dramatically significant differences between measurements in the upper arm and measurements in the forearm did not reveal any identifiable patterns. Possibly some unexplained or undisclosed vascular problems existed in this group.

In this study, we replicated the research of Singer et al[4] with modifications to minimize some of the limitations of their study. In our study, we used pre and post hoc power analyses to determine adequacy of sample size, thus reducing the risk of type II error.[14] Although it was unclear whether Singer et al[4] selected cuff sizes for measurements obtained in the forearm on the basis of the circumference of the forearm or the circumference of the upper arm, we included separate measurements of the circumferences of the 2 sites and subsequently selected cuff sizes on the basis of those measurements; that is, cuff sizes for the forearm were based on forearm circumference, and cuff sizes for the upper arm were based on upper arm circumference. Additionally, Singer et al[4] positioned the upper arm at heart level but did not indicate where the forearm was positioned with respect to heart level. In our study, we placed both the forearm and the upper arm at heart level, a step that necessitated a change in the position of the upper extremity, on the basis of the phlebostatic axis, for each measurement of blood in the forearm. Singer et al noted that a limitation of their study was that more subjects had blood pressure measured in the upper arm first. In our study, sequence of measurements in the forearm and upper arm was alternated for each subject. Finally, we used the Bland-Altman procedure to analyze the amount of agreement between measurements obtained at the 2 sites.

Our overall results differ from those of Singer et al,[4] specifically when the results of the Bland-Altman analysis are included. Although like Singer et al, we found a statistically, but not clinically, significant difference between mean measurements of systolic pressure in the forearm and the upper arm, the Bland-Altman analysis indicated that in individuals, measurements obtained from the 2 sites are not interchangeable. Singer et al found that mean differences were unrelated to demographics, presence of cardiovascular risk

factors, or clinical diagnoses. However, in our study, in smokers and blacks, mean measurements of systolic pressure in the forearm were higher than mean measurements in the upper arm.

Limitations and Recommendations

Our study has several limitations. A convenience sample allows minimal control for biases.[15] We used demographic and other relevant information such as patients' history of cardiovascular disease, medications, and emergency department diagnoses to help control these biases. Additionally, we obtained information on cardiac risk factors retrospectively through electronic chart review, and this information was not consistently recorded by emergency department practitioners during all history and physical examinations. Findings related to smokers should be considered cautiously because the number of smokers was small and was based on patients' self-reports.

Generalizability of the findings to supine hospitalized patients may be limited because the subjects were seated when blood pressure was measured. Generalizability of findings to patients who require extra large blood pressure cuffs is also limited because of the small number of these subjects in the study. Last, noninvasive blood pressure monitors found in hospitals are not specifically designed for measuring blood pressure in the forearm.

Future Research

According to the Bland-Altman analysis, differences between the 2 sites in measurements of systolic pressure, diastolic pressure, and MAP ranged between approximately 14 and 20 mm Hg. Use of a predictive design in future investigations of the relationship between measurements of blood pressure in the forearm and measurements in the upper arm would provide a more concrete method of determining the accuracy of measurements obtained in the forearm.

In our study, both the upper arm and the forearm were placed at heart level for measurements of blood pressure. In practice, the forearm is often resting in the patient's lap when the patient is seated. Future research is in progress to examine the effects of the position of the forearm on the accuracy of measurements of blood pressure and the effects of supine versus head-of-the-bed elevation on measurements of blood pressure obtained by using the forearm. In our study, the frequency of error codes displayed on the Welch Allyn monitor was increased when the extra large adult size cuff was used, suggesting that measurement of blood pressure in patients who are obese may be a problem. Influence of body mass index and race on differences between measurements obtained from the 2 sites (forearm and upper arm) should also be explored. Finally, future studies are indicated in children and in patients who are critically ill.

Conclusions and Clinical Implications

Our findings indicate that in seated, adult patients in stable clinical condition in the clinical setting, despite strict attention to correct cuff size and placement of the upper arm or forearm at heart level, noninvasive measurements of blood pressure obtained in the forearm are not interchangeable with measurements obtained in the upper arm. Realistically, situations in which the forearm is used to measure blood pressure will continue to arise in the clinical setting because of the inaccessibility of the upper arm and/or lack of proper-sized cuffs for the upper arm. Our findings underscore the importance of indicating which site was used to measure blood pressure, forearm or upper arm, when documenting blood pressure, and of using the same site for serial measurements to determine trends in blood pressure values. Additionally, proper selection of cuff size is imperative for accurate measurements.[16] Clinicians who manage patients must realize that measurements of blood pressure obtained in the forearm may differ from measurements obtained in the upper arm by up to 20 mm Hg.

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APPENDIX

The results reported in this article differ from those reported at the poster session of the May 2004 National Teaching Institute of the American Association of Critical-Care Nurses and subsequently published as an abstract in the *American Journal of Critical Care.* At that time, statistical analysis by paired *t* tests indicated that although measurements of blood pressure obtained by using the forearm differed statistically from measurements obtained by using the uper arm, this difference was not clinically significant for subjects as a group.

Upon editorial review of the study manuscript, it was suggested that the Bland-Altman procedure be included in the statistical analyses. This procedure revealed a wider variation in differences between measurements of systolic, diastolic, and mean arterial blood pressures obtained in the upper arm and measurements obtained in the forearm for individual subjects. Revisions to the discussion, conclusions, and clinical implications of the study were necessary and are reported in this article. We apologize for any confusion that these changes may have caused.