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Correlation between invasive and noninvasive blood pressure measurements in severely burned children

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Abstract

Introduction: Accurate blood pressure monitoring is essential for burn management, with the intra-arterial line method being the gold standard. Here we evaluated agreement between cuff and intra-arterial line methods.

Methods: Data from burned children admitted from 1997 to 2016 were retrospectively reviewed. Simultaneously collected intra-arterial and cuff measurements were crossmatched and linear regression performed to assess agreement for systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP).

Results: We identified 9,969 matches for SBP, DBP, and MAP in 872 patients (579 male) aged 8 ± 5 years with burns covering $52 \pm 20\%$ of the total body surface area and a hospitalization lasting 33 ± 31 days. Intra-arterial lines had a complication rate of 1%. The mean bias (95% CI) between methods was 1.3 (0.5, 2.1) mm Hg for SBP, -6.4 (-7.0 , 5.7) mmHg for DBP, and -5.8 (-6.4 , -5.3)

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Conflicts of interest: None

Analysis of a smaller dataset was presented at the Shock Society meeting in 2011. This project was presented at the American Burn Association annual meeting in 2017.

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mmHg for MAP. The standard deviation of the bias (95% limit of agreement) was 12.1 (–22.5, 25.1) mmHg for SBP, 9.9 (–25.8, 13.0) mmHg for DBP, and 8.7 (–22.8, 11.1) mmHg for MAP.

Conclusions: Cuff measurements vary widely from those of intra-arterial lines, which have a low complication rate. Intra-arterial lines are advisable when tight control of the hemodynamic response is essential.

Keywords

Arterial line; cuff pressure; monitoring; critical care; intensive care unit

1. Introduction

In pediatric burn management, vital signs including blood pressure are commonly used in the clinical decision making process. For this reason, the accuracy of diagnostic methods used to obtain these parameters is extremely important [1]. Blood pressure measurements must be accurate to avoid any under or overtreatment [2, 3]. The two most commonly used methods to measure blood pressure involve the use of invasive intra-arterial lines or a noninvasive blood pressure cuff. Of these, the arterial line method is considered the gold standard [2]. Burn injuries in children occur more commonly in low and middle income countries [4, 5]. This increased incidence of burn, coupled with a lack of resources and technologies in these countries, makes initial management of burn patients challenging [6]. Knowledge of the correlation between the invasive gold standard method and noninvasive techniques can improve the clinician's ability to assess the patient. To date, no one has examined the correlation between invasive and noninvasive blood pressure measuring, knowledge of which could drive practice in areas with limited resources. The aim of this study was to evaluate the correlation between measurements obtained with arterial lines and blood pressure cuffs as well as to assess the complications associated with arterial lines in a pediatric burn population.

2. Materials and Methods

2.1. Patients

The Institutional Review Board of the University of Texas Medical Branch (Galveston, Texas; IRB 15–0074) approved a retrospective review of the medical records of all pediatric burn patients who consented to research projects at the Shriners Hospitals for Children®—Galveston between 1997 and 2017. Informed consent was obtained from parents or legal guardians, and child assent was obtained as applicable. Inclusion criteria for this study were randomization to an institutional research protocol and burns covering more than 30% of the total body surface area. A total of 1,508 patients had both arterial line and blood pressure cuff measurements for systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP). Of these, 636 were excluded from the study because concurrently collected SBP, DBP, and MAP measurements using both methods were unavailable. All matching measurements from the remaining 872 children were analyzed, and demographic data were collected. In addition, we analyzed adverse event data collected

from 2012 to 2017 to identify complications due to arterial lines (infections, thrombosis, and embolism, and pseudoaneurysm).

All children underwent the usual acute standard of care treatment during hospitalization. This included early excision and grafting, early and appropriate nutrition, measures to mitigate the hypermetabolic response, fluid resuscitation, treatment of hyperglycemia, and an improved ventilation strategy [7].

2.2. Assessment of blood pressure and complications

All arterial line and cuff blood pressure measurements were collected during acute hospitalization using several generations of Philips IntelliVue® blood pressure monitors. All arterial lines were placed in the radial artery or femoral artery and replaced according to clinical judgment. The cuffs were always positioned on the side opposite from the arterial line. SBP, DBP, and MAP were simultaneously measured using each method. Moreover, intra-arterial line and cuff measurements were collected at approximately the same time, with cuff measurements being separated from the arterial line measurements by a maximum interval of 30 seconds, the time necessary for the cuff to measure the pressure. SBP and MAP values below 50 mmHg or over 350 mmHg, and DBP values below 40 mmHg or above 180 mmHg were excluded. In addition, data set matches between arterial line MAP and cuff MAP with differences greater than 40 mmHg were excluded, as they likely reflected a misreading via either method.

Complications associated with each method were also reviewed. Thrombosis and embolism were declared in cases of an absent peripheral pulse in the extremity of interest, with confirmation by diagnostic imaging. Infections were diagnosed in accordance with Centers for Disease Control and Prevention guidelines; primary bloodstream infections with positive catheter tip cultures for a pathogen not present on any wound were attributed to the arterial line [9]. Pseudoaneurysms were confirmed by diagnostic imaging.

2.3. Statistical analysis

Continuous data are presented as mean $\pm$ SD, and categorical data are reported as frequencies and proportions. To calculate agreement between noninvasive blood pressure (NIBP) and intra-arterial pressure (IAP) measurements, we used the methods proposed by Bland and Altman [10]. Mean difference in scores (bias) and 95% limits of agreement (bias $\pm$ 1.96*SD) were computed. Difference scores between NIBP and IAP were tested for normality, and for normally distributed difference scores, 95% CI for the bias were computed (precision of bias; bias $\pm$ t*SEM). Percentage error was calculated as (limits of agreement) divided by mean of IAP. To assess the interdevice reliability of NIBP, we performed intraclass correlations (ICCs). Relationships between NIBP and IAP recordings were assessed by ICC two-way mixed model of absolute agreement without interaction, treating mode of assessment (i.e., NIBP vs IAP) as a fixed variable and subjects as a random variable. All analyses were conducted using SPSS (version 23.0; IBM SPSS, Inc., Chicago, IL, USA) and Prism (version 5; GraphPad software, Inc., El Camino Real, CA, USA) statistical software. Two-sided statistical significance was considered for alpha at the 0.05 level.

3. Results

3.1. Patient characteristics

Patient demographics are summarized in Table 1. Patients were 8 ± 5 years old and had burns covering $52 \pm 20\%$ of the total body surface area. The predominant type of burn injury was flame injury (617/872; 71%), followed by scald injury (140/872; 16%), electrical injury (94/872; 11%), and other injury types (21/872; 2%).

3.2. Comparison of NIBP and IAP estimates

A total of 9,969 concurrently measured NIBP and IAP sample pairs were obtained from all patients. On average, the mean bias ($\pm 95\%$ CI or precision of bias) between NIBP and IAP was 1.3 mmHg (0.5 to 2.1 mmHg) for SBP, -6.4 mmHg (-7.0 to 5.7 mmHg) for DBP, and -5.8 mmHg (-6.4 to -5.3 mmHg) for MAP (Fig. 1, Table 2). The standard deviation of the bias ($\pm 95\%$ limits of agreement), both reflecting precision, were 12.1 mmHg (-22.5 to 25.1 mmHg) for SBP, 9.9 mmHg (-25.8 to 13.0 mmHg) for DBP, and 8.7 mmHg (-22.8 to 11.1 mmHg) for MAP. The limits of agreement were wide for SBP, DBP, and MAP measurements, and values did not meet the American Association for the Advancement of Medical Instrumentation criteria for accuracy and precision (bias < 5 mmHg or SD < 8 mmHg) [11]. The percentage error between concurrently measured NIBP and IAP was 41.2% for SBP, 56.7% for DBP, and 40.1% for MAP. The ICC for SBP and MAP was between 0.75 and 0.9 (ICC = 0.84 for SBP and 0.81 for MAP, $P < 0.001$ for both), indicating good reliability. The ICC for DBP was 0.73, reflecting moderate reliability.

3.2.3 Complications

In the 587 patients included in the safety analysis, the overall rate of complications associated with arterial lines was less than 1% (5/587). No complications were associated with cuff use. Arterial lines were associated with 2 cases of confirmed infection and 3 cases of thrombosis. Arterial line infections were caused by *Enterobacter cloacae* and *Aeromonas hydrophila*. No patient developed a pseudoaneurysm. Of the 3 patients with thrombosis, 2 were successfully treated with high doses of intravenous heparin. In the third patient, a thrombectomy was unsuccessful, and a below-the-knee amputation was performed. However, because of local infection, a foot amputation had already been planned prior to thrombosis in this patient.

4. Discussion

Accuracy and precision in blood pressure monitoring is crucial for strict control of the hypermetabolic stress response to burn injury. Our data show that a significant discrepancy exists between intra-arterial and cuff blood pressure values in severely burned pediatric patients, where NIBP monitoring appears to underestimate diastolic and mean blood pressure compared to IAP monitoring. Furthermore, we show that arterial lines have a low complication rate in severely burn patients. These findings suggest that IAP monitoring should be utilized instead of a noninvasive cuff-based method when tight control of the hemodynamic response is essential.

As noted previously, low and middle income countries have limited resources for the treatment of burn victims [12, 13], making cuff measurement devices the most feasible way to obtain blood pressure values [14]. Burn disaster management centers also use readily available and inexpensive noninvasive methods owing to the unpredictable nature of mass casualties and limited resources available in these situations. Furthermore, in high income countries, use of arterial lines is avoided in critically ill children because of complications associated with arterial catheterization such as thrombosis, embolism, and infection [15]. However, this study shows that arterial lines have an extremely low percentage of complications, and given the reliability they offer, they are preferred for blood pressure assessment in the ICU setting when feasible. Scheer et al. have previously reported in literature that the occurrence of pseudoaneurysm due to arterial lines is between 0.09 and 0.3%, but they only analyzed adults [16]. Our study showed that this rate in our cohort is 0% and to our knowledge is the first study showing this data.

Our findings are in line with those of a previous study in 30 critically ill young children. This small study showed that DBP and MAP were underestimated by a similar degree and that standard deviation of the bias and limits of agreement for SBP, DBP, and MAP were as wide as those reported here [17]. Our study was adequately powered to validate the conclusions of this small study [17] and to extend the findings to include severely burned children.

When resources do not allow for IAP measurement and NIBP monitoring is used, staff should avoid cuffs of inappropriate size because these can significantly influence readings [18]. The measurements should always be obtained from a non-burned area because edema can also influence the readings [19]. In addition, noninvasive measurements should be avoided in obese patients because the thick subcutaneous fat can weaken the arterial signal, thereby decreasing the cuff reading [20].

The major limitation of this study is the retrospective design. This could have influenced the results, as no precise data were available on whether any invasive procedures or events, such as displacement of the arterial line or the cuff, occurred during the concurrent measurements. In addition, we were not able to determine if the arterial line or cuffs were placed on non-burned, burned or healed skin during the measurement. We were also unable to measure the position of the arterial line or cuff for each patient during the matching readings. Except for the patients analyzed for complications due to arterial line and cuff use, we were not able to determine the number of necessary arterial line changes. Lastly, the extended time over which the study data were captured could have introduced additional bias because of changes in the management of blood pressure measurements due to the use of different generations of monitors or changes in intensive care practices.

In conclusion, this study of concurrent intra-arterial line and cuff measurements shows that a wide discrepancy exists between these blood pressure monitoring approaches in burned children. Given the low complication rate associated with arterial line use and the reduced accuracy of NIBP monitoring reported here, substitution of the IAP method with a noninvasive cuff-based method is not advised when tight control of the hemodynamic response is essential.

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Abbreviations:

IAP	intra-arterial pressure
ICC	intraclass correlations
DBP	diastolic blood pressure
MAP	mean arterial pressure
NIBP	noninvasive blood pressure
SBP	systolic blood pressure

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Highlights:

- Arterial line and blood pressure cuff measurements have high variability between one other.
- Blood pressure cuff values overestimate hypotension and hypertension
- Arterial lines have a very low complication rate (1%)

Figure 1.

Bland–Altman plots showing agreement between the noninvasive blood pressure (NIBP) and intra-arterial pressure (IAP) methods. Mean differences between the two methods are plotted against the mean values for these methods for systolic BP (A), diastolic BP (B) and mean arterial pressure (C). The solid horizontal line represents the mean difference (bias), and the dashed horizontal lines represent the upper and lower limits of agreement (2 standard deviations).

Table 1.Patient Characteristics.[/]

Characteristic	Value
Sex, n	
Female	293 (34%)
Male	579 (66%)
Ethnicity, n (%)	
Hispanic	688 (79%)
Caucasian	173 (20%)
Other	11 (1%)
Age, years	8 ± 5
TBSA 3 rd -degree burns, %	39 ± 25
Hospitalization, days	33 ± 31

TBSA, total body surface area.

[/]Data expressed as mean ± SD unless noted otherwise.

Table 2.

Comparison estimates between noninvasive blood pressure (NIBP) and intra-arterial pressure (IAP) measurements.¹

	NIBP (mmHg)	IAP (mmHg)	(NIBP - IAP) (mmHg) (95% CI)	Limits of agreement (mmHg)	Percentage error ²	ICC ³	P value
SBP	117 ± 15	115 ± 18	1.3 (0.5, 2.1)	-23 – 25	41%	0.84	< 0.001
DBP	62 ± 12	68 ± 12	-6.4 (-7.0, -5.7)	-26 – 13	57%	0.73	< 0.001
MAP	79 ± 12	85 ± 13	-5.8 (-6.4, -5.3)	-23 – 11	40%	0.81	< 0.001

SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean blood

pressure; CI, coefficient interval; ICC, interclass correlation coefficient.

¹Data expressed as mean ± SD unless noted otherwise.

²Percentage error as (limits of agreement) divided by mean of IAP.

³Two-way mixed model of absolute agreement without interaction, with measurement method as fixed variable and subjects as a random variable; P value associated with

ICC.