



Contents lists available at ScienceDirect

Journal of Clinical Neuroscience

journal homepage: www.elsevier.com/locate/jocn

Clinical commentary

Differences in blood pressure by measurement technique in neurocritically ill patients: A technological assessment ☆

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ARTICLE INFO

Article history:

Received 19 June 2017

Accepted 23 October 2017

Available online xxxxx

Keywords:

Noninvasive blood pressure

Invasive blood pressure

Cerebral perfusion pressure

Blood pressure

Leveling

Transducer

Phlebostatic axis

External auditory meatus

ABSTRACT

Blood pressure data may vary by measurement technique. We performed a technological assessment of differences in blood pressure measurement between non-invasive blood pressure (NIBP) and invasive arterial blood pressure (ABP) in neurocritically ill patients. After IRB approval, a prospective observational study was performed to study differences in systolic blood pressure (SBP), mean arterial pressure (MAP), and cerebral perfusion pressure (CPP) values measured by NIBP arm, ABP at level of the phlebostatic axis (ABP heart) and ABP at level of the external auditory meatus (ABP brain) at 30 and 45-degree head of bed elevation (HOB) using repeated measure analysis of covariance and correlation coefficients. Overall, 168 patients were studied with median age of 57 ± 15 years, were mostly female (57%), with body mass index ≤ 30 (66%). Twenty-three percent ($n = 39$) had indwelling intracranial pressure monitors, and 19.7% ($n = 33$) received vasoactive agents. ABP heart overestimated ABP brain for SBP (11.5 ± 2.7 mmHg, $p < .001$), MAP (mean difference 13.3 ± 0.5 mmHg, $p < .001$) and CPP (13.4 ± 3.2 mmHg, $p < .001$). ABP heart overestimated NIBP arm for SBP (8 ± 1.5 mmHg, $p < .001$), MAP (mean difference 8.6 ± 0.8 mmHg, $p < .001$), and CPP (mean difference 9.8 ± 3.2 mmHg, $p < .001$). Regardless of HOB elevation, ABP heart overestimates MAP compared to ABP brain and NIBP arm. Using ABP heart data overestimates CPP and may be responsible for not achieving SBP, MAP or CPP targets aimed at the brain.

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1. Introduction

In critical care, hemodynamic monitoring and interventions are typically aimed at maintaining systolic blood pressure (SBP), mean arterial pressure (MAP) and cerebral perfusion pressure (CPP) within a desired range. Blood pressure data can be obtained either from non-invasive blood pressure measurements obtained from the upper arm (NIBP arm) or from invasive indwelling arterial catheters. While NIBP arm measurements are used in outpatient care, pre-hospital care, and on inpatient wards [1], placement of invasive arterial catheters occurs in neurocritical care units more often than in general ICUs [2]. While both NIBP arm and invasive

blood pressure data are available to clinicians for use, it is not clear which technique is preferred. Additionally, NIBP arm and ABP differences and their impact on clinical decisions have been reported in the intraoperative setting [3], but not in the neurologically ill.

Over the last fifteen years, clinical trials and guidelines related to the management of common neurocritical care emergencies such as acute ischemic stroke [4], spontaneous intracerebral hemorrhage [5,6], aneurysmal subarachnoid hemorrhage [7], and traumatic brain injury [8], fail to explicitly provide information specific to blood pressure monitoring techniques and how this affects study findings. Concerns regarding the accuracy of ABP at the level of the phlebostatic axis to estimate cerebral perfusion pressure [9] have resulted in recommendations only from the Councils of the Neuroanesthesiology Society of Great Britain and Ireland (NASGBI) and the Society of British Neurological Surgeons (SBNS) to position the transducer at the level of the tragus [10,11].

In addition, SBP targets [4,5,12] are frequently recommended in clinical scenarios where cerebral perfusion is at risk and where CPP, which considers MAP, appears to be the more appropriate

☆ This study was conducted at University of Kansas Hospital, Kansas City, KS, United States.

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target. The other consideration in estimating cerebral perfusion is the location of the invasive arterial catheter transducer. An international survey of neurointensivists reported wide variability in reported choice of calculation of CPP, where majority calculated CPP at level of the heart (59%) rather than the level of the brain (41%) [13], and there is inconsistency in adherence to recommendations of measurement of CPP at the level of the external auditory meatus, a practice followed in less than 10% of intensive care units [14]. Previous attempt at demonstrating differences in cerebral perfusion pressure at various HOB elevations, demonstrate widening gap between systemic arterial blood pressure measured at the level of the heart and the brain, is limited to small sample size study [15]. Agreement between blood pressures measured by ABP and NIBP with relationship to age, sex, body mass index, and mean arterial pressure ranges have not been studied, and comprehensive attempt to quantify these previously-described differences [15] are lacking. To bridge the gap in differences in measurement between blood pressure measurement techniques in neurocritically ill patients, we aimed to examine differences between NIBP arm and ABP leveled at heart and brain, to test the hypothesis that ABP at the phlebostatic axis overestimates ABP at the level of the external auditory meatus. This study was conducted as an assessment of blood pressure techniques.

2. Methods

2.1. Study design

We conducted an observational study in a 20-bed dedicated neurocritical care unit at a major academic level 1 trauma and comprehensive stroke center.

2.2. Study population

This was a convenience sample of patients over 18 years admitted to a dedicated neurocritical care unit with both an indwelling arterial catheter and non-invasive blood pressure in the arm (NIBP arm). Patients without indwelling arterial catheters were excluded. Institutional review board approval and informed consent were obtained from the patient or legal next of kin.

2.3. Data collection

Demographic data including age, body mass index (BMI), the presence of vasoactive medications, and the presence of intracranial pressure (ICP) monitoring. These variables did not change during testing.

2.4. Outcomes

Primary outcomes were differences in SBP, MAP, and CPP calculated by NIBP arm and ABP, with ABP at the level of the phlebostatic axis (ABP heart), followed by ABP at the level of the external auditory meatus (ABP brain). We also examined differences in blood pressure measurements with each technique between age groups of less than or greater than 65 years, BMI less than or greater than 30, gender, and vasopressor use (presence or absence of a vasoactive infusion at the time of blood pressure measurement).

2.5. Study protocol

2.5.1. Invasive blood pressure

All patients had pre-existing radial arterial catheters (20 gauge, 4.45 cm catheter, REF-RA-04020, radial artery catheterization set,

Arrow International, Inc. Reading, PA, USA) which were connected via 180 cm extension tubing to a transducer (REF: PX272, pressure-monitoring kit with Truwave disposable pressure transducer, Edwards Lifesciences LLC, Irvine, CA, USA). Before blood pressure measurements, we ensured a normal flush test, adequate dampening, and brisk aspiration.

2.5.2. Non-invasive blood pressure

Noninvasive blood pressure (NIBP) cuff, of appropriate size, was placed on the upper arm opposite to the invasive arterial catheter. The specific cuff was selected for size based on width equal to 40% of the arm circumference and used per manufacturer's guidelines (disposable soft adult blood pressure cuff with bayonet connector, Cardinal Health, Waukegan, IL, USA). Patients with pre-existing intracranial pressure monitoring device (external ventricular drain) were managed per standard institutional and manufacturer's recommendations.

2.5.3. Blood pressure measurements

Each patient had the first set of measurements with NIBP in the upper arm and an arterial line in the opposite radial artery leveled at the heart using a Carpenters level. Initial measurements were made with transducer leveled at heart. Upon completion of all measurements, the transducer was relocated to the level of the external auditory meatus, and measurements repeated. Any change of head-of-bed elevation was followed by five minutes of time to allow for blood pressures to stabilize, and similar protocol followed at 30-degree and 45-degree head-of-bed elevations. Blood pressure measurements were carried out by AL and DW. Blood pressures obtained by NIBP were synchronized with those obtained by ABP, and only simultaneous measurements were selected for final analysis. At the time of the conduct of the study, the standard of transducer placement was at the level of the phlebostatic axis.

2.6. Statistical analysis

Categorical variables were summarized by frequencies and percentages, and the continuous variables were summarized by mean and standard deviation.

The power analysis was carried out prior to initiation of the study to determine the appropriate sample size to detect the mean difference in blood pressure as low as 5 mmHg. A sample size of 168 achieves over 90% power to detect a mean of the paired differences of 5 mmHg with an estimated standard deviation of difference of 20 mmHg at a significance level of 0.05.

Repeated measure analysis of covariance (ANCOVA) was carried out on the blood pressure outcomes measured by three methods to assess the differences among the three methods adjusting for covariates age, sex, BMI and vasopressors. To complete the pairwise comparisons across the techniques, we used contrast test within the ANCOVA modeling framework. Multiple testing adjustments were carried out using Tukey's method [16]. Correlation coefficients were calculated for relationship between NIBP arm, ABP heart and ABP brain, and was graded as; very weak: r 0–0.19, weak: r 0.20–0.39, moderate: r 0.40–0.59, strong: r 0.60–0.79, and very strong: r 0.80–1.00 [17]. In a secondary analysis we studied correlations between groups of patients ages 65 and older compared to lower than 65 years, mean arterial pressure below 75 mmHg compared to those greater than 75 mmHg [3], and between males and females, and body mass index of lower than 30 compared to greater to or equal to 30.

The analyses were separately carried out for 30 degrees of bed elevation and 45 degrees of bed elevation. In addition, analyses were carried out for cerebral perfusion pressure (CPP) for the subset of data where CPP information was available. The results are

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