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Modalities of Invasive Arterial Pressure Monitoring in Critically Ill Patients

A Prospective Observational Study

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Abstract: Few studies assessed modalities of invasive arterial pressure monitoring (IAPM). We evaluated effects on measured values of various combinations of transducer level, catheter access site, and patient position.

Prospective observational study in consecutive adults admitted to a French intensive care unit in 2009 to 2011 and fulfilling our inclusion criteria. Four combinations (B–E) of transducer level, catheter access site, and patient position were compared with a reference combination (A) (A: patient supine with all catheters in the same plane and a single transducer level (M) for zero point reference (Z) aligned on the phlebostatic axis; B: 45° head-of-bed elevation with M and Z aligned on the phlebostatic axis; C: 45° head-of-bed elevation with M aligned on the catheter access site and Z on the phlebostatic axis; D: 45° head-of-bed elevation with M and Z aligned on the catheter access site; and E: 45° head-of-bed elevation with M aligned on the phlebostatic axis and Z on the catheter access site).

We included 103 patients, 68 men and 35 women, with a median age of 69 years (interquartile range [IQR], 56–78); at inclusion, 91 (88.3%) received mechanical ventilation, 45 (43.7%) catecholamines, and 66 (64.1%) sedation. The IAPM access site was femoral in 49 (47.6%) and radial in 54 (52.4%) patients, with 62 of 103 (60.2%) catheters on the right side. Measured absolute mean arterial pressure values were significantly higher with 3 study combinations (C–E) than with the reference combination (A). After adjustment, the differences versus A (median, 83 [IQR, 74–92] mm Hg) remained significant for D (median, 91 [IQR, 85–100] mm Hg, $P < 0.001$) and E (median, 88 [IQR, 77–99] mm Hg, $P < 0.001$). The difference versus A was not significant for B (median, 85 [IQR, 76–94] mm Hg, $P = 0.21$) or C (median, 90 [IQR, 84–100] mm Hg, $P = 0.006$).

Several modalities used for zeroing and/or transducer leveling during IAPM may result in statistically and clinically significant overestimation of measured mean arterial pressure values. For patients in the 45° head-of-bed elevation position, aligning the Z on the phlebostatic axis provides values that are not significantly different from those obtained using the reference supine modality.

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Abbreviations: IAPM = invasive arterial pressure monitoring, ICU = intensive care unit, IQR = interquartile range, MAP = mean arterial pressure, M = transducer level, pA = phlebostatic axis, Z = zero reference point.

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INTRODUCTION

A common reason for arterial catheterization in the intensive care unit (ICU) is invasive arterial pressure monitoring (IAPM) in hemodynamically unstable patients.[1] Although IAPM is now widely used in ICUs,[2] the optimal modalities remain unclear. Little evidence exists about how patient position, transducer level, and catheter access site may affect the measured values.[3–7] Few guidelines are available.[1,8] A major factor when considering the optimization of IAPM modalities is the vascular bed of interest. Rather than the peripheral vascular bed, the coronary and cerebral arteries are the main targets of efforts to maintain an adequate blood supply.[9,10] In an experimental study of a pig model, transducer level and animal position significantly influenced the measurement results, with outlying values occurring in the nonsupine position except when the transducers were at the aortic root[11]; however, the animal positions used in this study differed markedly from the 45° head-of-bed elevation position generally used in ICU patients in the absence of contraindications.

To our knowledge, no study has assessed the potential clinical impact of various combinations of transducer level, catheter access site, and patient position on IAPM results. We designed a pragmatic study whose objective was to assess the effects of these combinations in ICU patients. We sought to determine which combination produced measurement values similar to those obtained under physiologic conditions.

MATERIALS AND METHODS

Our local ethics committee (*Comité de Protection des Personnes, Paris – Ile de France XI*) approved this prospective observational study (#09003) and waived the need for written informed consent. Oral consent was obtained routinely before study enrolment.

Patients

Adults admitted to the Versailles Hospital ICU between February 2009 and February 2011 were included prospectively if they were >18 years of age, undergoing continuous IAPM via a radial or femoral catheter, hemodynamically stable with no change >10 mm Hg in mean arterial pressure (MAP) over the 15 last minutes, and in sinus rhythm during all MAP measurements. Patients discharged from the ICU within the first 24 hours and/or enrolled in another study were not eligible for study inclusion. Patients with cardiac arrhythmias or who demonstrated hemodynamic instability responsible for frequent changes in MAP were not retained for study inclusion. Vasoactive and/or inotropic drug treatment did not prevent study inclusion.

The Versailles Hospital is a university-affiliated institution located in the Paris metropolis, France. It has 711 beds for medical and surgical patients, including 18 beds in a closed medical-surgical ICU. Most ICU patients are admitted through the emergency department or prehospital emergency medical system (SAMU); only 25% are referred from the wards.

IAPM was used in patients with cardiovascular instability (malignant hypertension or hypotension),[12] shock (septic, hypovolemic, cardiogenic, or neurogenic),[1] head injury,[10] multiorgan failure,[1] or a need for frequent arterial blood gas measurements.[13]

The decision to use IAPM and the catheter access site were at the discretion of the intensivists, who followed current guidelines. A 20-gauge radial artery set or 18-gauge femoral artery set (Prodimed, Le Plessis-Bouchard, France) was connected via an identical length of tubing to a pressure transducer (TruWave, Edwards Lifesciences, Irvine, CA) and attached to a movable transducer platform (TruWave). The pressure transducer device was connected to a monitor (DASH 4000, GE Healthcare, PA). The ICU nurse in charge of the patient checked the connections initially then every 4 hours and before all study measurements.

Definitions

The phlebostatic axis (Figure 1) was defined as the intersection of a vertical line (A) drawn from the fourth intercostal space at the right edge of the sternum with a horizontal line (B) drawn through the midpoint of a line going from the anterior to the posterior aspects of the chest.[14]

MAP Measurement

Patients were maintained supine for at least 5 minutes. Then, MAP was measured in various combinations of patient position, transducer level, and zero reference point (Z). After each combination, at least 5 minutes were allowed to elapse before changes were made to establish the next combination (Figure 2).

MAP was first measured in the reference combination defined as supine position, with all catheters in the same plane and a single transducer level for zeroing aligned on the phlebostatic axis (combination A). In all 4 experimental combinations, the patient was in the 45° head-of-bed elevation position. In combination B, the transducer level and Z were aligned on the phlebostatic axis for zeroing followed by MAP measurement. In combination C, the Z was aligned on the phlebostatic axis and the transducer level on the catheter access site for MAP measurement. In combination D, the transducer level and Z were aligned on the catheter access site for zeroing then MAP measurement. Finally, in combination E, the transducer level was aligned on the phlebostatic axis and the Z on the catheter access site. A template was created to standardize and ensure the reproducibility of the 45° head-of-bed elevation position.

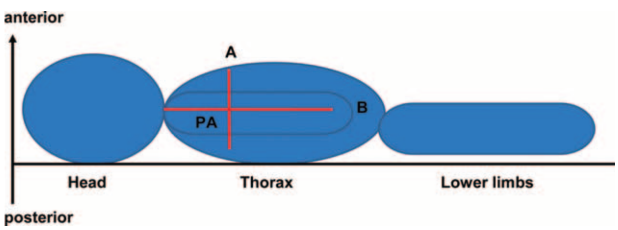
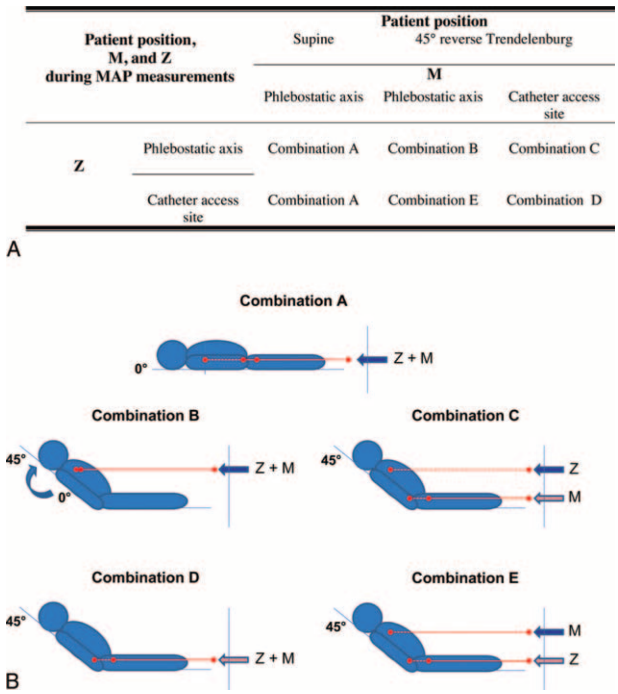


FIGURE 1. The phlebostatic axis. The phlebostatic axis (PA) is defined by the intersection of a vertical line (A) drawn from the fourth intercostal space at the right edge of the sternum with a horizontal line (B) drawn through the midpoint of a line going from the anterior to the posterior aspect of the chest.



Patient position, M, and Z during MAP measurements		Patient position: Supine	Patient position: 45° reverse Trendelenburg	
		M		
		Phlebostatic axis	Phlebostatic axis	Catheter access site
Z	Phlebostatic axis	Combination A	Combination B	Combination C
	Catheter access site	Combination A	Combination E	Combination D

FIGURE 2. Various combinations of patient position, transducer level (M), and zero reference point (Z) for invasive arterial pressure monitoring. Panel A describes the 5 combinations studied (A through E). Panel B shows diagrams of the 5 combinations studied (A–E). M is the transducer level for MAP measurement. Combination A: patient in the supine position with all catheters in same plane and a single transducer level for zeroing aligned on the phlebostatic axis. Combination B: patient in the 45° head-of-bed elevation position with M and Z aligned on the phlebostatic axis. Combination C: patient in the 45° head-of-bed elevation position with M aligned on the catheter access site and Z on the phlebostatic axis. Combination D: patient in the 45° head-of-bed elevation position with M and Z aligned on the catheter access site. Combination E: patient in the 45° head-of-bed elevation position with M aligned on the phlebostatic axis and Z on the catheter access site.

Data Collection

Demographic data (age, sex, height, weight, and body mass index) and MAP values were collected prospectively at the bedside on a standardized form. The reason for ICU admission was recorded as medical, scheduled surgical, or unscheduled surgical. At each MAP measurement, we recorded patient position, locations of the IAPM device and transducer, sedatives used (propofol, midazolam, sufentanil), Ramsay sedation score, type of respiratory support (invasive or noninvasive), and vasoactive drug use (epinephrine, norepinephrine, dobutamine).

Acute illness severity and organ dysfunction at ICU admission were assessed using the Simplified Acute Physiology Score II (SAPS-II).[15] Length of ICU stay, respiratory support, and outcome at ICU discharge were also collected.

Statistical Analysis

Quantitative parameters were described as median (interquartile range [IQR]) and qualitative parameters as number (%). Statistical analyses involved comparing the reference combination (A) to 4 other combinations (B–E). Combination A was taken as the reference because it involved a neutral patient position with alignment of all factors potentially capable of affecting measurement results. Paired Wilcoxon signed rank-sum tests were performed to assess differences between combinations B through E and combination A. The potential impact of technical and treatment characteristics on differences among the MAP values measured using the various combinations was tested using Wilcoxon signed rank-sum tests. Multiple linear regression models were built to adjust differences between the various MAP measurement combinations on several technical factors (catheter access site and side) and treatments (mechanical ventilation and vasoactive drug therapy), as suggested by prior studies.[16–23] Thus, we built 4 different multivariate models comparing the reference combination (A) to 4 other combinations (B through E), each adjusted on catheter access site, catheter access side, mechanical ventilation, and vasoactive drug therapy. Regression diagnostics were performed to validate the models thus obtained regarding residual normality and homoscedasticity. All tests were 2-tailed at the 0.05 significance level with a 2-sided hypothesis. Analyses were performed using the R statistical package version 3.1.2. (online at http://www.R-project.org).

RESULTS

During the 18-month study period, 946 patients were admitted to the ICU including 444 (46.9%) managed with arterial lines. Of these 444 patients, 65 were discharged from the ICU within 24 hours; 42 had cardiac arrhythmias; 76 had hemodynamic instability responsible for frequent changes in MAP; and 158 could not be enrolled in the study because the patient or family refused to participate, no research nurse was available, or the patient was enrolled in another study. Finally, 103 patients fulfilled our inclusion criteria and were included in the study. Table 1 lists their main characteristics.

MAP Values

Table 2 reports the MAP values obtained with the 5 combinations of patient position, transducer level, and Z. Measured MAP values were higher with the 4 study combinations (B–E) than with the reference combination (A). The differences with A were significant for C ($P = 0.006$), D ($P < 0.001$), and E ($P < 0.001$). The difference with A was not significant for B ($P = 0.21$) (Figure 3).

TABLE 1. Patient Characteristics (n = 103)

	n (%) or Median (IQR) All Patients n = 103
Male gender	68 (66.0)
Age (y)	69 (56–78)
SAPS II score at ICU admission	53 (40-67
Body mass index (kg/m^2)	26 (23–31.7)
Reason for ICU admission	
Medical emergency	79 (73.8)
Surgical emergency	19 (18.4)
Scheduled surgery	8 (7.8)
Mechanical ventilation	91 (88.3)
Noninvasive ventilation	5 (4.8)
Sedation	66 (64.1)
Vasoactive drugs	45 (43.7)
Catheter access, radial/femoral	54 (52.4)/49 (47.6)
Catheter on right side	62 (60.2)
Time on mechanical ventilation (d)	10 (5–21)
ICU length of stay (d)	18 (8–37)
ICU mortality	38 (36.9)

ICU = intensive care unit, IQR = interquartile range, SAPS II = Simplified Acute Physiology Score version II.

Evaluation of Potential Impact of Technical and Treatment Characteristics on Differences among Measurement Modalities

Table 3 reports the evaluation of heterogeneity in MAP values measured using the various modalities, according to catheter access site and side and to treatment with mechanical ventilation or vasoactive drugs. None of these 4 factors significantly influenced the differences in MAP values across the measurement modalities.

Multiple Linear Regression Analysis

Table 4 reports the multiple linear regression models. After adjustment on catheter access site and side and on the use of mechanical ventilation and vasoactive drugs, the MAP values measured with the A combination remained significantly different from those measured with the D and E combinations.

DISCUSSION

In this prospective study of 103 ICU patients, after adjustments on several technical and treatment characteristics, the only study combinations that did not differ significantly from the reference combination were the 45° head-of-bed elevation positions with the Z aligned on the phlebostatic axis.

IAPM is widely used in ICU patients; however, controversy surrounds the modalities of IAPM,[3–7] most notably the optimal transducer level and Z. Depending on the clinical goal, the best reference point may be the phlebostatic axis[14] or a point 5 cm below the angle of the sternum.[13] The most often recommended point for zeroing and MAP measurement during IAPM is the phlebostatic axis in the supine position[6,7,13]; however, to prevent ventilator-associated pneumonia, ICU patients are usually placed in the 45° head-of-bed elevation position.[24] We therefore used this position in our 4 study combinations, and we used a combination in which the patient was supine as the reference standard. Our population was comparable with those in earlier studies of ICU patients with multiorgan failure.[2,25]

TABLE 2. Mean Arterial Pressure Values Measured Using Various Combinations of Patient Position, Transducer Level, and Zero Reference Point

		Patient Position		
		Supine	45° Reverse Trendelenburg	
		M		
Patient Position, M, and Z During MAP Measurements		Phlebostatic Axis	Phlebostatic Axis	Catheter Access Site
Z	Phlebostatic axis	Combination A 83 (74–92) mm Hg	Combination B 85 (76–94) mm Hg	Combination C 90 (84–100) mm Hg
	Catheter access site	Combination A 83 (74–92) mm Hg	Combination E 88 (77–99) mm Hg	Combination D 91 (85–100) mm Hg

M = transducer level, MAP = mean arterial pressure, median (interquartile range), Z = zero reference point.

Very few studies have assessed the modalities of IAPM. The phlebostatic axis concept was developed in a 1945 study[14] assessing the influence of various hand and phlebostatic axis locations in 99 semi-seated patients. The results showed no differences in noninvasive venous pressure measurements related to variations in the degree of torso inclination. In the only other study of this point,[11] performed in pigs and reported in 2001, having the transducer at the catheter site rather that at the phlebostatic axis produced values that differed from the reference values (supine position).[11]

Various technical or clinical factors may theoretically influence IAPM. Among them, the catheter access site had an effect in some studies but not in others. In 2 studies of patients with sepsis and hypotension requiring vasopressor therapy, radial arterial pressure monitoring underestimated central arterial pressure measured using a femoral arterial catheter.[16,17] Conversely, a large prospective study in a similar patient population showed no difference in MAP values measured by radial and femoral arterial catheters.[18] The potential influence of catheter access side has been chiefly investigated in studies of noninvasive arterial blood pressure measurement in healthy adults. Again, the, results are inconsistent,[19–21] and according to current guidelines either arm can be used to measure blood pressure.[22] In recent years, the blood-flow variability related to the breathing cycle has probably received the most research attention as a factor possibly affecting IAPM. This variability predicts fluid responsiveness in sedated and mechanically ventilated critically ill patients.[23] In our study, catheter access site and side, mechanical ventilation, and/or vasopressor use were evaluated as potential sources of heterogeneity in the comparisons of the IAPM combinations. Nevertheless, the multivariable linear regression results ruled out heterogeneity for all combinations except B and C.

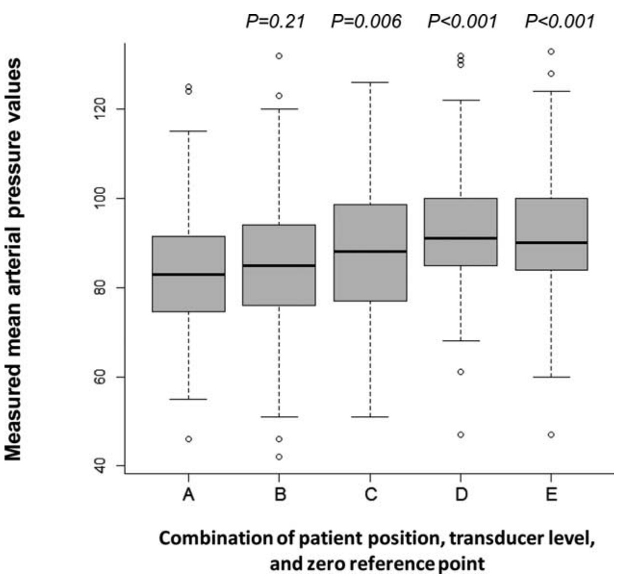


FIGURE 3. Boxplot of mean arterial pressure values obtained using the various combinations of patient position, transducer level, and zero reference point. Figure 3 shows 5 boxplots, 1 for each combination. The X axis shows the 5 combinations (A–E) and the Y axis the measured values of mean arterial pressure. The shaded box indicates the middle 50% of the data; the lower and upper ends of this box are therefore the 25th and 75th percentiles, respectively. The solid black horizontal line through each shaded box indicates the median of the distribution. The circles above the vertical solid black lines are individual outliers. *P* values are provided above each pair of combinations.

Our results are of relevance to clinical practice. Although we did not obtain pathophysiologic information, combinations with zeroing at the phlebostatic axis in patients with 45° head-of-bed elevation position was not significantly different from the reference supine position in terms of MAP values obtained during IAPM.

In the absence of contraindications, maintaining 45° head-of-bed elevation has important benefits in ICU patients including prevention of ventilator-associated pneumonia, neuroprotection with prevention of secondary brain damage, and improved breathing in patients with respiratory distress and orthopnea. We identified an IAPM modality in this position that provides MAP values comparable with those obtained in the supine position.

Our study has several limitations. Our patients were admitted to a single center, and the applicability of our results to the full spectrum of ICU patients requiring IAPM is therefore unclear. Unfortunately, we were unable to investigate all potentially eligible patients, as some of these died or were discharged alive from the ICU within 24 hours of admission. Moreover, our study population was heterogeneous. Catheter access side and site were not standardized, and the study was not confined to sedated and mechanically ventilated patients. Although nearly

TABLE 3. Evaluation of Heterogeneity in Mean Arterial Pressure Values Measured Using Various Combinations of Patient Position, Transducer Level, and Zero Reference Point, According to Technical and Clinical Characteristics

	Heterogeneity Evaluation According to Technical Characteristics						Heterogeneity Evaluation According to Treatment Characteristics					
	Catheter Access Site			Catheter Access Side			Mechanical Ventilation			Vasoactive Drugs		
Differences between combinations	**Radial n = 54 (52.4%)**	**Femoral n = 49 (47.6%)**	***P* value**	**Right n = 62 (60.2%)**	**Left n = 41 (39.8%)**	***P* Value**	**Yes n = 91 (88.4%)**	**No n = 12 (11.6%)**	***P* Value**	**Yes n = 45 (43.7%)**	**No n = 58 (56.3%)**	***P* value**
B vs A	1 (−5; 7) mm Hg	1 (−5; 9) mm Hg	0.76	1 (−6; 10) mm Hg	0 (−3; 7) mm Hg	0.99	1 (−5; 8) mm Hg	−0.5 (−4; 5) mm Hg	0.91	−2 (−5; 4) mm Hg	3 (−4; 11) mm Hg	0.17
C vs A	0.5 (−4; 7) mm Hg	7 (−3; 14) mm Hg	0.15	2 (−4; 8) mm Hg	3 (−1; 12) mm Hg	0.22	2 (−4; 11) mm Hg	3 (−2; 7) mm Hg	0.95	4 (−3; 7) mm Hg	4 (−4; 12) mm Hg	0.28
D vs A	8 (4; 14) mm Hg	9 (1; 17) mm Hg	0.54	8 (1; 15) mm Hg	10 (4; 15) mm Hg	0.45	8 (3; 15) mm Hg	9 (6; 15) mm Hg	0.70	8 (4; 12) mm Hg	10 (3; 18) mm Hg	0.19
E vs A	9 (2; 13) mm Hg	8 (−1; 14) mm Hg	0.46	8 (0; 14) mm Hg	8 (4; 13) mm Hg	0.49	8 (1; 13) mm Hg	9 (3; 15) mm Hg	0.68	7 (0; 11) mm Hg	9 (2; 17) mm Hg	0.20

TABLE 4. Multiple Linear Regression Analysis of Differences Between the Various Combinations Used for Mean Arterial Pressure Measurement, Adjusted on Technical Factors (Catheter Access Site and Side) and Treatment Characteristics (Mechanical Ventilation and Vasoactive Drug Therapy)

Variable	Parameter Estimates (95%CI)*	*P* value
Combination B vs A	−2.88 (−9.29 ; 3.53)	0.38
Combination C vs A	−4.42 (−11.05; 2.21)	0.19
Combination D vs A	−10.66 (−17.19; −4.12)	0.002
Combination E vs A	−8.51 (−15.01; −2.02)	0.02

CI = confidence interval.

*Parameter estimates are the regression coefficients obtained from each multiple linear regression model. The parameter estimates the increase in the dependant variable (combinations B through E with combination A) in the yes vs the no group for binary predictors (catheter access site, catheter access side, mechanical ventilation, and vasoactive drug use).

all patients received mechanical ventilation, only some of them were treated with sedatives and/or vasoactive agents.

CONCLUSION

In ICU patients in the 45° head-of-bed elevation position, several combinations of transducer position and Z used during IAPM may result in clinically significant overestimations in MAP values. The only 45° head-of-bed elevation combinations that were not significantly different from the reference modality in the supine position involved aligning the Z on the phlebostatic axis. Further studies are needed to determine the importance of our findings and to evaluate how they may improve the management of critically ill patients requiring continuous IAPM.

TAKE-HOME MESSAGE

The main finding from our study, which is of considerable clinical relevance, is that after adjustments on several technical and treatment characteristics, the only study combinations that did not differ significantly from the reference combination were the 45° head-of-bed elevation positions with the Z aligned on the phlebostatic axis. This finding holds potential for improving the management of critically ill patients requiring continuous invasive arterial blood pressure monitoring.

140-CHARACTER TWEET

Modalities of invasive arterial pressure monitoring require the Z aligned on the phlebostatic axis for zeroing.

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