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Non-invasive oscillometric versus invasive arterial blood pressure measurements in critically ill patients: A post hoc analysis of a prospective observational study

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ABSTRACT

Purpose: The aim was to compare non-invasive blood pressure measurements with invasive blood pressure measurements in critically ill patients.
Methods: Non-invasive blood pressure was measured via automated brachial cuff oscillometry, and simultaneously the radial arterial catheter-derived measurement was recorded as part of a prospective observational study. Measurements of systolic arterial pressure (SAP), diastolic arterial pressure (DAP), and mean arterial pressure (MAP) were compared using Bland-Altman and error grid analyses.
Results: Paired measurements of blood pressure were available for 736 patients. Observed mean difference (±SD, 95% limits of agreement) between oscillometrically and invasively measured blood pressure was 0.8 mmHg (± 15.7 mmHg, −30.2 to 31.7 mmHg) for SAP, −2.9 mmHg (±11.0 mmHg, −24.5 to 18.6 mmHg) for DAP, and −1.0 mmHg (±10.2 mmHg, −21.0 to 18.9 mmHg) for MAP. Error grid analysis showed that the proportions of measurements in risk zones A to E were 78.3%, 20.7%, 1.0%, 0%, and 0.1% for MAP.
Conclusion: Non-invasive blood pressure measurements using brachial cuff oscillometry showed large limits of agreement compared to invasive measurements in critically ill patients. Error grid analysis showed that measurement differences between oscillometry and the arterial catheter would potentially have triggered at least low-risk treatment decisions in one in five patients.

1. Introduction

Blood pressure is one of the most frequently measured vital signs and can be measured non-invasively or invasively [1]. Measurements of blood pressure are commonly used as triggers and targets to guide hemodynamic interventions, especially in critically ill patients treated in the intensive care unit (ICU) [2]. Circulatory shock is a common condition in critically ill patients, affecting about one-third of all admitted ICU patients [3]. Systemic arterial hypotension is typically present in circulatory shock with associated tachycardia and signs of altered tissue perfusion [4]. Guidelines on hemodynamic monitoring and circulatory shock advocate initially targeting a mean arterial pressure (MAP) above 65 mmHg [2]. Therefore, clinicians need to have quick, reliable, and accurate measurements of blood pressure available at the bedside.

Invasive arterial blood pressure monitoring using an arterial catheter is considered the clinical reference method in critically ill patients. In situ arterial catheters also facilitate drawing blood for laboratory testing and blood gas analysis. Even though the guidelines recommend the placement of an arterial catheter for invasive monitoring in patients with suspected circulatory shock [2], non-invasive oscillometric blood pressure measurements using an upper-arm cuff are a widely used alternative [5]. This automated method allows for intermittent, quick, and convenient blood pressure measurements.

Several prospective studies showed an acceptable agreement of non-invasive oscillometric blood pressure measurements with invasive

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reference measurements in critically ill patients [6,7]. Some say that intermittent non-invasive oscillometric blood pressure measurements may even safely replace invasive measurements [8]. Other studies showed an unacceptable measurement performance of oscillometry in critically ill patients with circulatory shock, demonstrating a possible influence of the shock state and the use of vasoactive medication on the measurement performance [9,10].

This study aimed to compare blood pressure measurements obtained using upper-arm cuff oscillometry with arterial catheter-derived blood pressure measurements in a large prospective cohort of critically ill patients with and without receiving norepinephrine.

2. Material and methods

2.1. Design and setting

This study was part of the Simple Intensive Care Studies-I (SICS-I), a prospective single-center observational cohort study designed to evaluate the diagnostic and prognostic value of combinations of clinical and hemodynamic variables in critically ill patients [11]. We performed the study between 27 March 2015 and 22 July 2017. The local institutional review board approved the study (M15.168207).

2.2. Participants and study size

In SICS-I, all acutely admitted patients of 18 years and older with an expected ICU stay of at least 24 h were eligible for inclusion. Exclusion criteria were planned admission, inability to acquire research data due to interference with clinical care, and absence of informed consent. Patients without either invasive blood pressure or non-invasive blood pressure measurement were excluded from this analysis.

2.3. Objectives

The primary objective of this study was to evaluate the agreement between blood pressure measurements obtained with non-invasive oscillometry (test method) and arterial catheter-derived measurements (reference method) using Bland-Altman and error-grid analyses. The agreement between measurements was defined according to the Association for the Advancement of Medical Instrumentation (AAMI) standards for non-invasive arterial pressure measurement [12]. The AAMI definition of an acceptable agreement in adults between the test and reference method is a mean of the differences of ≤5 mmHg with a SD of ≤8 mmHg [12].

The secondary objective was to analyze the differences between the two methods separately in patients with and without receiving norepinephrine.

2.4. Variables

For the SICS-I study, clinical and hemodynamic variables were collected during a one-time clinical examination in the first 24 h of patient admission. Study procedures were only performed when there was no interference with clinical care. Complete data management was described in the design paper of the SICS-I [13]. Reference blood pressure was measured invasively using an indwelling arterial catheter placed in the radial artery. Non-invasive oscillometric blood pressure measurements were performed using an upper-arm cuff placed on the arm contralateral to the arm with the arterial catheter. The correct cuff size was estimated for each patient by the nurse, and the arterial catheter transducer was zeroed and leveled. Blood pressure data were recorded simultaneously from the display of the bedside monitor IntelliVue MP70 (Philips, Eindhoven, The Netherlands). The dose of norepinephrine infusion was documented at the time of the blood pressure measurements.

2.5. Statistical analysis

Data are presented as means with standard deviations (SD), medians with 25th and 75th percentile, or absolute numbers (with percentages). Student's *t*-test, Mann-Whitney *U* test, or the Chi-square tests were used as appropriate. Correlations between non-invasive and invasive blood pressure measurements are illustrated using scatter plots. The agreement was assessed using Bland-Altman plots, by plotting the mean of the two measurements against their difference and 95% limits of agreement (LOA) (= mean difference ± 1.96 × SD of the difference) [14].

Error grid analysis was used to assess the clinical relevance of differences between the two methods [15]. Error grid analysis assigns a specific risk level value to each pair of measured arterial pressures. Risk levels range from zones A to E with A representing no risk (i.e., no difference in clinical action between the reference and test method), B representing low-risk (i.e., test method values that deviate from the reference but would probably lead to benign or no treatment), C representing moderate risk (i.e., test method values that differ from the reference and would eventually lead to unnecessary treatment with potential moderate non-life-threatening consequences for the patient), D representing significant risk (i.e., test method values that deviate from the reference and would lead to unnecessary treatment with potential severe non-life-threatening consequences for the patient), and E representing dangerous risks (i.e., test method values deviate from the reference method and would lead to unnecessary treatment with potentially life-threatening consequences for the patient) [15]. The clinical relevance of the difference between two methods is reflected by the proportion of measurements in each risk level; i.e., higher proportions in the low-risk level indicate a lower clinical relevance of the difference. The risk levels were quantified for systolic arterial pressure (SAP) and mean arterial pressure (MAP) by consensus among 25 international experts in anesthesiology and intensive care medicine [15]. No consensus error grid for diastolic arterial pressure (DAP) was quantified by experts due to its limited use in anesthesiology and critical care as an isolated value. The proportions of measurements in the five risk levels were calculated and were visualized in a grid in which the consensus risk assessment is converted into a continuous risk level ranging from 0% to 100% [16]. The Chi-square test was used to compare the proportions of measurements in risk zone A versus risk zone B-E between patients with and without norepinephrine.

For statistical analysis, Microsoft Office Excel 2010 (Microsoft Corp, Redmond, WA, USA) and Stata version 15 (StataCorp, College Station, TX, USA) were used. Continuous error grids were constructed using a computer program written for MATLAB version 2018b (The MathWorks Inc., Natick, MA, USA) [16].

3. Results

Overall, 1075 patients were included in the SICS-I study [11]. Of these, 1052 patients (98%) had an invasive arterial pressure measurement, and 757 patients (70%) had a non-invasive arterial pressure measurement. Seven hundred thirty-six patients (68%) had paired blood pressure measurements, i.e., simultaneously measured using oscillometry and an arterial catheter (Fig. 1). Of 736 patients with a paired measurement, 352 patients (48%) received norepinephrine during the blood pressure measurements. Table 1 presents the characteristics of the 736 included patients, and the 339 excluded patients for this study based on the availability of paired blood pressure measurement.

Patients without a paired measurement of invasive and non-invasive blood pressure had a higher body mass index (BMI), were more often admitted for a cardiovascular reason, and were more critically ill as reflected by a higher APACHE-IV score at admission and increased 90-day mortality (Table 1).

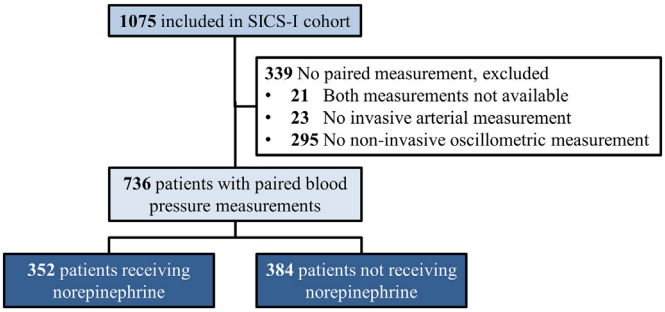

Fig. 1. Flowchart. Flowchart showing patient inclusion in this study.

The distribution and relation of arterial pressure data obtained non-invasively and invasively is illustrated in scatter plots (Supplementary Fig. 1 in Supplementary Material).

Bland-Altman analysis of all paired measurements revealed a mean difference (±SD, 95% limits of agreement) of 0.8 mmHg (± 15.7 mmHg, −30.2 to 31.7 mmHg) for SAP, −2.9 mmHg (±11.0 mmHg, −24.5 to 18.6 mmHg) for DAP, and −1.0 mmHg (± 10.2 mmHg, −21.0 to 18.9 mmHg) for MAP (Table 2; Fig. 2).

Bland-Altman analysis of paired measurements in patients receiving norepinephrine and patients not receiving norepinephrine showed similar results. In patients receiving norepinephrine, Bland-Altman analysis showed a mean difference (±SD, 95% LOA) of −1.1 mmHg (± 16.1 mmHg, −32.8 to 30.6 mmHg) for SAP, −1.9 mmHg (±10.0 mmHg, −21.5 to 17.7 mmHg) for DAP, and −1.0 mmHg (± 9.9 mmHg, −20.4 to 18.5 mmHg) for MAP (Table 2; Supplementary Fig. 2 in Supplementary Material).

In patients not receiving norepinephrine, Bland-Altman analysis showed a mean difference (±SD, 95% LOA) of 2.4 mmHg (± 15.2 mmHg, −27.5 to 32.4 mmHg) for SAP, −3.9 mmHg (± 11.8 mmHg, −27.0 to 19.3 mmHg) for DAP, and −1.1 mmHg (± 10.4 mmHg, −21.5 to 19.4 mmHg) for MAP (Table 2; Supplementary Fig. 3 in Supplementary Material).

In all patients with a paired measurement of blood pressure, error grid analysis showed that the proportions of measurements in risk zones A to E were 82.3%, 13.2%, 4.2%, 0.3%, and 0% for SAP and 78.3%, 20.7%, 1.0%, 0%, and 0.1% for MAP. Continuous error grids for SAP and MAP are shown in Fig. 3.

In patients receiving norepinephrine, error grid analysis showed that the proportions of measurements in risk zones A to E were 75.6%, 17.6%, 6.5%, 0.3%, and 0% for SAP and 74.7%, 23.6%, 1.7%, 0%, and 0% for MAP (Supplementary Fig. 4 in Supplementary Material).

In patients not receiving norepinephrine, error grid analysis showed that the proportions of measurements in risk zones A to E were 88.5%, 9.1%, 2.1%, 0.3%, and 0% for SAP and 81.5%, 18.0%, 0.3%, 0%, and 0.3% for MAP (Supplementary Fig. 5 in Supplementary Material).

Patients receiving norepinephrine had more paired measurements in risk zones B to E compared to patients not receiving norepinephrine ($p < .001$ for SAP, and $p = .03$ for MAP).

4. Discussion

In this study, non-invasive blood pressure measurements using upper-arm cuff oscillometry showed a low mean difference but large limits of agreement compared to direct invasive measurements in critically ill patients. Precision and accuracy of non-invasive SAP, DAP, and MAP measurements determined by Bland-Altman analysis failed the AAMI standards for non-invasive arterial pressure measurement [12].

Estimations of precision and accuracy obtained by Bland-Altman analysis provide information about the overall statistical agreement but do not offer the clinical relevance of differences between paired

Table 1
Patient characteristics.

Variable	Type	SICS-I cohort, *n = 1075*	Without paired measurement, *n = 339*	With paired measurement, *n = 736*	P
Age (years)		62 (15)	62 (14)	62 (15)	0.30
Male gender		674 (63%)	206 (61%)	468 (64%)	0.37
Body Mass Index (kg m^{-2})		26.9 (5.5)	27.4 (6.2)	26.7 (5.1)	**0.038**
Mechanical ventilation		632 (59%)	195 (58%)	437 (59%)	0.57
Sedation		430 (40%)	134 (40%)	296 (40%)	0.83
Heart rate (bpm)		87.7 (21.2)	86.8 (21.8)	88.1 (21.0)	0.35
Atrial fibrillation		78 (7%)	24 (7%)	54 (7%)	0.88
Norepinephrine use		529 (49%)	177 (52%)	352 (48%)	0.18
Norepinephrine dose (μg kg^{-1} min^{-1})		0.13 [0.06, 0.27]	0.12 [0.07, 0.21]	0.14 [0.06, 0.29]	0.38
Admission type	Medical	713 (66%)	212 (63%)	501 (68%)	0.16
	Acute surgery	316 (29%)	113 (33%)	203 (28%)	
	Planned surgery	46 (4%)	14 (4%)	32 (4%)	
Admission diagnosis by organ system	Cardiovascular	318 (30%)	118 (35%)	200 (27%)	**0.002**
	Gastrointestinal	167 (16%)	49 (14%)	118 (16%)	
	Genito-urinary	23 (2%)	11 (3%)	12 (2%)	
	Hematological	19 (2%)	8 (2%)	11 (1%)	
	Metabolic	22 (2%)	3 (1%)	19 (3%)	
	Musculoskeletal/skin	13 (1%)	5 (1%)	8 (1%)	
	Neurological	143 (13%)	31 (9%)	112 (15%)	
	Respiratory	229 (21%)	60 (18%)	169 (23%)	
	Transplant	58 (5%)	19 (6%)	39 (5%)	
	Trauma	82 (8%)	35 (10%)	47 (6%)	
Time to inclusion (hours)		15 [8, 20]	15 [8, 19]	15 [8, 20]	0.39
Circulatory shock	Total[a]	540 (50%)	183 (54%)	357 (49%)	0.095
	Cardiogenic	140 (13%)	52 (15%)	88 (12%)	
	Distributive	327 (30%)	107 (32%)	220 (30%)	
	Hypovolemic	120 (11%)	48 (14%)	72 (10%)	
	Obstructive	25 (2%)	12 (4%)	13 (2%)	
APACHE-IV score		76.1 (29.3)	79.1 (31.0)	74.7 (28.4)	**0.031**
SAPS-II		46.4 (16.8)	47.3 (16.8)	46.0 (16.8)	0.22
90-day mortality		297 (28%)	108 (32%)	189 (26%)	**0.035**

Significant differences of patient characteristics between patients with and without a paired measurement of blood pressure are shown in bold.
[a] Multiple types of circulatory shock may be diagnosed in a patient. SICS-I = Simple Intensive Care Studies-I, APACHE-IV = Acute Physiology and Chronic Health Evaluation-IV, SAPS-II = Simplified Acute Physiology Score-II.

Table 2
Arterial pressure values determined by non-invasive oscillometric cuff and arterial catheter.

Variable	Invasive arterial catheter (mmHg)	Non-invasive oscillometric cuff (mmHg)	Mean difference (CI)	SD of the Mean difference (mmHg)	Lower 95% Limit of Agreement (CI)	Upper 95% Limit of Agreement (CI)	Percentage error (CI)
All patients (n = 736)							
Systolic arterial pressure	118.8 ± 24.8	117.9 ± 25.2	0.8 mmHg (−0.4 to 1.9)	± 15.7	−30.2 mmHg (−32.1 to −28.2)	31.7 mmHg (29.7 to 33.6)	26.1% (24.5 to 27.8)
Diastolic arterial pressure	59.9 ± 11.4	62.8 ± 14.6	−2.9 mmHg (−3.7 to −2.1)	± 11.0	−24.5 mmHg (−25.9 to −23.1)	18.6 mmHg (17.2 to 20.0)	35.1% (32.9 to 37.4)
Mean arterial pressure	78.7 ± 14.3	79.7 ± 16.5	−1.0 mmHg (−1.7 to −0.3)	± 10.2	−21.0 mmHg (−22.2 to −19.7)	18.9 mmHg (17.7 to 20.2)	25.2% (23.6 to 26.8)
Patients on norepinephrine (n = 352)							
Systolic arterial pressure	107.8 ± 20.7	108.9 ± 21.3	−1.1 mmHg (−2.8 to 0.6)	± 16.1	−32.8 mmHg (−35.7 to −29.9)	30.6 mmHg (27.7 to 33.5)	29.3% (26.6 to 32.0)
Diastolic arterial pressure	56.5 ± 9.4	58.4 ± 11.9	−1.9 mmHg (−2.9 to −0.9)	± 10.0	−21.5 mmHg (−23.3 to −19.7)	17.7 mmHg (15.9 to 19.5)	34.1% (31.0 to 37.2)
Mean arterial pressure	72.7 ± 11.1	73.7 ± 12.9	−1.0 mmHg (−2.0 to 0.1)	± 9.9	−20.4 mmHg (−22.2 to −18.6)	18.5 mmHg (16.7 to 20.3)	26.6% (24.2 to 29.0)
Patients not on norepinephrine (n = 384)							
Systolic arterial pressure	128.6 ± 24.2	126.1 ± 25.8	2.4 mmHg (0.9 to 4.0)	± 15.2	−27.5 mmHg (−30.1 to −24.8)	32.4 mmHg (29.7 to 35.0)	23.5% (21.4 to 25.6)
Diastolic arterial pressure	63.0 ± 12.2	66.9 ± 15.7	−3.9 mmHg (−5.1 to −2.7)	± 11.8	−27.0 mmHg (−29.1 to −25.0)	19.3 mmHg (17.2 to 21.3)	35.6% (32.5 to 38.8)
Mean arterial pressure	84.2 ± 14.6	85.3 ± 17.5	−1.1 mmHg (−2.1 to 0.0)	± 10.4	−21.5 mmHg (−23.3 to −19.7)	19.4 mmHg (17.6 to 21.2)	24.1% (22.0 to 26.2)

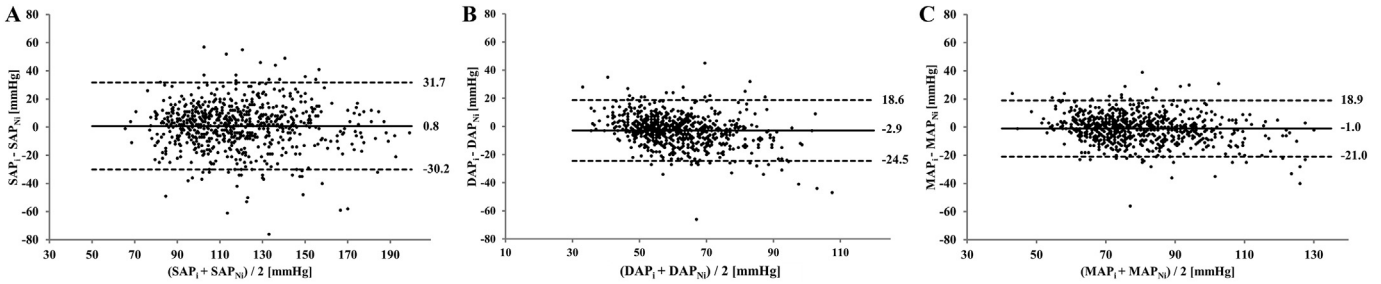

Fig. 2. Bland-Altman plots. A. Bland-Altman plot for systolic arterial pressure. Comparison between measurements of non-invasive oscillometric cuff (SAP_{Ni}) and invasive arterial catheter (SAP_i) is illustrated. B. Bland-Altman plot for diastolic arterial pressure. Comparison between measurements of non-invasive oscillometric cuff (DAP_{Ni}) and invasive arterial catheter (DAP_i) is illustrated. C. Bland-Altman plot for mean arterial pressure. Comparison between measurements of non-invasive oscillometric cuff (MAP_{Ni}) and invasive arterial catheter (MAP_i) is illustrated. In each plot, the continuous horizontal line represents the mean difference, and the upper and lower dashed lines represent the 95% limits of agreement.

measurements. Error grid analysis enables quantification and illustration of the clinical significance of observed differences between two blood pressure measurement methods [15]. This novel method is based on expert opinion and has yet to be externally validated using outcome data. In this study, error grid analysis showed that for all included patients, the majority of measurements were situated in the no-risk zone A, i.e., 82% for SAP and 78% for MAP. However, in approximately one in five patients, i.e., 18% for SAP and 22% for MAP, the paired measurements were positioned in risk zones B to E, which implies a potential risk of at least low-risk treatment decisions if treatment was based on the test method.

In patients receiving norepinephrine, there were more paired measurements, 24% for SAP and 25% for MAP, in the risk zones B to E compared to patients not receiving norepinephrine, which implies a higher potential risk of at least low-risk treatment differences. These results suggest that in approximately one in four patients receiving norepinephrine in this cohort, the measured difference could potentially have triggered at least low-risk treatment decisions if treatment was based on the test method. The distribution difference in the error grid risk zones for patients receiving norepinephrine may be explained by the reduced performance of the oscillometric blood pressure method with lower blood pressures [17].

Data used in this study were obtained as part of the SICS-I prospective observational cohort study, which evaluated clinical and hemodynamic variables obtained as a one-time clinical examination within the first 24 h of ICU admission to diagnose a low cardiac index [11] and to build a prognostic model for 90-day mortality [18]. Not all variables could be obtained in case of life-threatening disease, which could explain why patients without a paired measurement of blood pressure had a higher APACHE-IV score and increased mortality. Furthermore, the adequate size oscillometric cuff was not always directly available when study procedures were performed, which could explain why patients with a higher BMI had fewer paired measurements.

Our results on measurement agreement are in line with other studies comparing non-invasive oscillometric and invasive arterial blood pressure in critically ill patients. A poor statistical agreement was found in two retrospective observational studies of large ICU databases [17,19]. Similar to our study, MAP measurements were less inaccurate than SAP and DAP measurements.

Subgroup analysis according to the administration of norepinephrine showed similar results in both subgroups. Results we observed in patients treated with norepinephrine are comparable to results from previous studies. One study compared non-invasive oscillometric and invasive radial arterial blood pressure measurements in critically ill patients receiving norepinephrine [9]. A comparison between measurements of MAP showed a mean difference of 6.6 mmHg (95% CI 5.3 to 7.9) [9] in this study. In another study, non-invasive and invasive

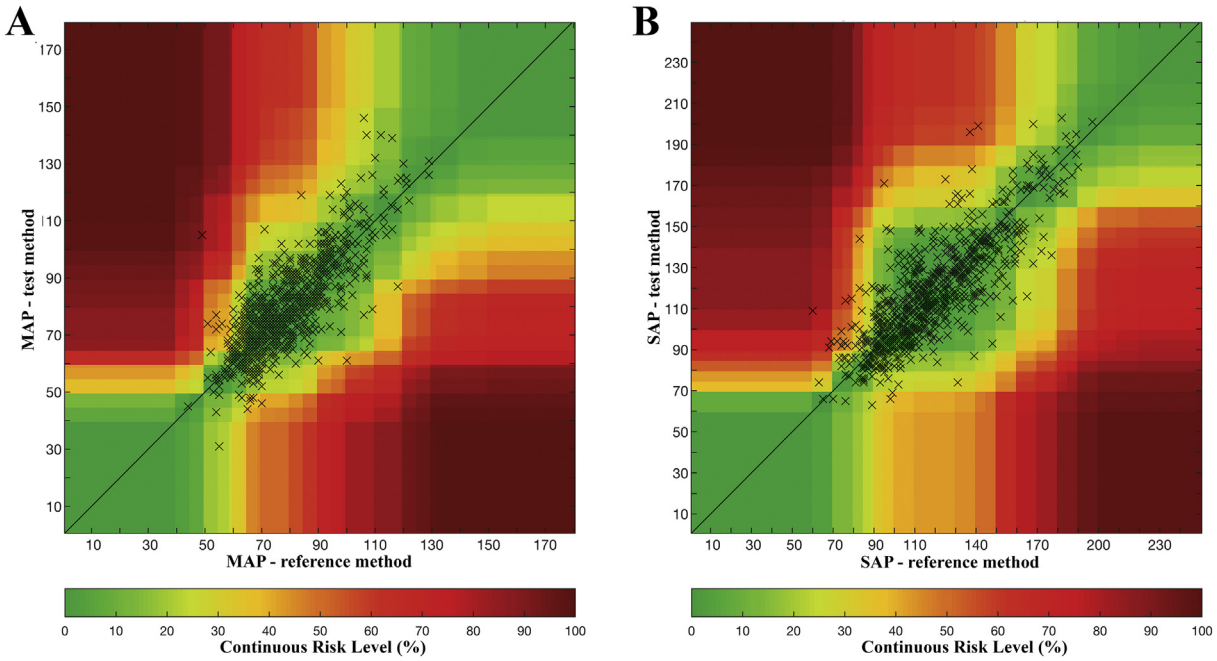

Fig. 3. Error-grid plots. A. Error-grid plot for mean arterial pressure. This figure illustrates the error grid for the test method (upper-arm cuff oscillometry) in comparison with the reference method (arterial catheter) for the 736 patients regarding mean arterial pressure. B. Error-grid plot for systolic arterial pressure. This figure illustrates the error grid for the test method (upper-arm cuff oscillometry) in comparison with the reference method (arterial catheter) for the 736 patients regarding systolic arterial pressure. In each plot, the background colors correspond to the risk level for each pair of measurements. The risk ranges from 0% to 100%, as shown below the plots. A risk level between 0% and 100% is assigned to each combination of measurement and true value (test device versus gold standard).

blood pressure measurements were prospectively compared in adult patients with septic shock in the ICU [10]. Similar to our study, non-invasive blood pressure monitoring showed poor statistical agreement with invasive measurements [10].

Currently, the invasive blood pressure measurement using an arterial catheter remains the clinical reference method in critically ill patients. Despite the widespread use of arterial catheters, there is no evidence suggesting that the outcomes of critically ill patients improve with continuous invasive compared to intermittent non-invasive blood pressure monitoring. Arterial catheters are associated with rare but serious complications such as infections, bleeding, thrombosis, and pseudoaneurysm formation [20], and placement of the catheters may be difficult and time-consuming in some patients. One retrospective cohort study showed an association between the use of arterial catheters and an increase in mortality in critically ill patients receiving vasopressors for shock [21]. Furthermore, invasive arterial pressure monitoring can be inaccurate because of underdamping and resonance phenomena [22]. Finally, a different blood pressure measurement may be obtained depending on the artery the catheter is placed in. Some evidence suggests that measurements obtained in the radial artery underestimates central blood pressure in septic shock patients receiving vasopressors and that femoral arterial pressure monitoring may be more appropriate in these patients [23].

Alternatively, frequent oscillometric cuff inflation is associated with patient discomfort and pressure bruises. Patient discomfort is increased if repeated percutaneous vascular punctures are needed for laboratory testing. Patient movement may also influence the performance of the oscillometric blood pressure method [24]. In addition, clinically relevant hypotensive episodes might be missed or detected late by intermittent measurements. Multiple manufacturers have developed appropriate devices, and each makes use of proprietary algorithms that have not always been reliably validated against invasive direct blood pressure measurements with an arterial catheter [25]. Although a structured method comparison study may better reveal the agreement between these two methods of blood pressure measurement, these data obtained as part of a prospective study may reflect clinical practice and therefore our results potentially have better generalizability. It is recommended to be cautious in clinical practice on the interchangeability of blood pressure measurement methods as the presented analyses do not provide information on individual measurement differences and preferences may vary for individual patients.

There are several limitations to this study. First, this study was a post hoc analysis of a single-center prospective observational study as this research question was not specified a priori [11]. Due to the study design there was no formal power calculation and the results are exploratory. These findings have to be used with caution and have to be validated in other cohorts. Second, not all patients included in the cohort had a paired measurement of blood pressure. Acquiring an oscillometric blood pressure measurement was not a primary aim of the SICS-I study, and the measurement was not always performed, most often if this would have led to interference with clinical care. Third, we only performed a single paired measurement during the first 24 h of patient admission. Fourth, we did not compare the non-invasive blood pressure measurements on both arms before performing a measurement.

5. Conclusions

Non-invasive blood pressure measurements using upper-arm cuff oscillometry showed a low mean difference but large limits of agreement compared to direct invasive measurements in critically ill patients. Error grid analysis showed that measurement differences between oscillometry and the arterial catheter would potentially have triggered at least low-risk treatment decisions in one in five critically ill patients, and in one in four patients on norepinephrine if treatment was based on oscillometry. It is recommended to be cautious in clinical practice on the interchangeability of blood pressure measurement methods as these analyses do not provide information on individual measurement differences and preferences may vary for individual patients.

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Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcrc.2020.02.013.

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