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Invasive arterial blood pressure monitoring may aid in the medical management of hypertensive patients with acute aortic disease

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A B S T R A C T

Introduction: Blood pressure (BP) monitoring and management is essential in the treatment of acute aortic disease (AoD). Previous studies had shown differences between invasive arterial BP monitoring (ABPM) and non-invasive cuff BP monitoring (CBPM), but not whether ABPM would result in patients' change of clinical management. We hypothesized that ABPM would change BP management in AoD patients.
Methods: This was a prospective observational study of adult patients with AoD admitted to the Critical Care Resuscitation Unit from January 2019 to February 2021. Patients with AoD and both ABPM and CBPM measurements were included. Clinician's BP management goals were assessed in real time before and after arterial catheter placement according to current guidelines. We defined change of management as change of current antihypertensive infusion rate or adding a new agent. We used multivariable logistic and ordinal regressions to determine relevant predictors.
Results: We analyzed 117 patients, and 56 (47%) had type A dissection. ABPM was frequently ≥10 mmHg higher than CBPM values. Among 40 (34%) patients with changes in management, 58% (23/40) had [ABPM-CBPM] differences ≥20 mmHg. ABPM prompted increasing current antihypertensive infusion in 68% (27/40) of patients. Peripheral artery disease (OR 13, 95% CI 1.18–50+) was associated with changes in clinical management, and ordinal regression showed hypertension and serum lactate to be associated with differences between ABPM and CBPM.
Conclusions: ABPM was frequently higher than CBPM, resulting in 34% of changes of management, most commonly increasing anti-hypertensive infusion rates.

1. Introduction

Acute aortic disease is a spectrum of painful and life-threatening diseases that are associated with a high mortality rate. In the United States, the incidence of acute aortic disease is approximately 4.4 cases yearly per 100,000 [1]. Known risk factors include advanced age, male sex, history of arterial hypertension, history of smoking and history of certain congenital and inflammatory diseases [2]. The better-known pathology in this spectrum of diseases is aortic dissection, but other conditions include aortic aneurysm, intramural hematoma, and aortic ulcers.

Blood pressure (BP) monitoring and management is essential in the treatment of acute aortic disease. Initial treatments aim at decreasing the aortic wall stress by controlling the blood pressure and heart rate to prevent dissection extension or aneurysm expansion. The American Heart Association guidelines suggest that hypertensive patients with acute aortic disease should maintain a systolic blood pressure between 100 and 120 mm Hg (mmHg), heart rate <60 beats per minute and receive adequate pain control [3]. Non-invasive cuff blood pressure monitoring (CBPM) and invasive arterial blood pressure monitoring (ABPM) are the two main modalities for assessing blood pressure at bedside. Previous studies have demonstrated that CBPM measurements frequently vary based on cuff

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placement location and arm circumference [4,5]. Additionally, other studies have demonstrated that CBPM measurements underestimated systolic BP when compared to ABPM measurements in the acute phase of patients presenting with aortic dissection [6] or with hypertensive emergencies [7]. Despite these studies showing that differences exist between invasive and non-invasive blood pressure methods, they did not address whether these discrepancies resulted in a change in blood pressure management in patients with hypertensive emergencies.

A retrospective study by Raffman et al [8] showed that monitoring blood pressure with arterial catheters in patients who had hypertensive emergencies was associated with increased likelihood of change in management of patients' blood pressure, when compared to monitoring with cuff measurements alone. This retrospective study involved a heterogenous group of patients with acute aortic disease, ischemic stroke, and spontaneous intracerebral hemorrhage. Additionally, the authors' definition for change of management was hypothetical in nature due to the study's retrospective design. The authors defined a change in management as a difference of at least 10 mmHg between ABPM and CBPM measurements and hypothetically inferred that difference would cause a change in management. To address this gap, we aimed to identify how the initiation of invasive arterial blood pressure monitoring would change clinical management in real time. We hypothesized that the use of arterial blood pressure monitoring would result in changes in medical management in patients with acute aortic disease. We aimed to identify the prevalence of change in clinical management when arterial blood pressure monitoring was initiated as well as clinical predictors associated with this change.

2. Methods

2.1. Study setting

This Institutional-Review-Board (IRB)-approved prospective observational pilot study occurred at the Critical Care Resuscitation Unit (CCRU) at the University of Maryland Medical Center (UMMC), which is a regional quaternary medical center. The CCRU was established at the University of Maryland Medical Center (UMMC) in July 2013 with the goal to expedite transfer of patients from other hospitals within the state and region when these patients have critical illnesses or require therapeutic interventions that are not available at the first hospital, while awaiting an appropriate inpatient bed at UMMC [9]. Once patients undergo effective resuscitation, diagnostic or therapeutic interventions, they are subsequently moved to the next available inpatient bed at our medical center. For patients who potentially need urgent surgical evaluations, our hospital policy indicates that these patients are transferred first to the CCRU to be evaluated by our surgical subspecialties, which are available in the hospital at all hours of the day. Therefore, when patients who have acute aortic diseases present to other hospitals that do not have the appropriate expertise, they are frequently transferred to the CCRU for further evaluation and management by our subspecialty surgeons.

The CCRU follows the American Heart Association guidelines that suggest hypertensive patients with acute aortic disease should maintain systolic blood pressures <120 mmHg, although certain patients may need tighter or more liberal blood pressure targets, as decided by our surgical physicians after they evaluate patients and relevant imaging studies. The clinical policy of the CCRU requires that all patients who need frequent blood gas analysis or hemodynamic monitoring should have arterial blood pressure monitoring. Therefore, during the patient's initial resuscitation, CCRU clinicians perform most arterial catheter cannulations under sterile conditions. The CCRU nursing staff record blood pressure measurements at least every hour as clinically indicated. While awaiting arterial catheter placement, patients have non-invasive cuff blood pressure measurements at 3-min intervals. Once arterial blood pressure monitoring is available, the bed side nurse would check cuff pressure at regular intervals of every hour while recording the concurrent arterial blood pressure at the same time.

2.2. Patient selection

We included adult patients, who were admitted to the CCRU for management of acute aortic diseases between January 01, 2019, and February 28, 2021. Patients with a diagnosis of acute aortic disease and who had both ABPM and CBPM initiated in the CCRU were eligible. Patients who had arterial blood pressure monitoring prior to arrival at the CCRU were not eligible because we did not have information regarding change of clinical management when the arterial catheters were first inserted. We also included patients with symmetric (both ABPM and CBPM measurements were taken from the same body side) and asymmetric (ABPM and CBPM measurements were taken from opposite side, i.e., arterial catheter from right arm, while blood pressure cuff was on left arm) measurements, as blood pressure discrepancies between arms is a key diagnostic feature of acute aortic dissection [10]. We excluded patients with chronic aortic dissections because these disease states usually do not require urgent surgical interventions nor would require urgent blood pressure measurements. We excluded patients with hypotensive disease states, which was defined as systolic blood pressure <90 mmHg on arrival or patients who required vasopressors to maintain adequate pressure. These patients were excluded because they are managed with mean arterial pressure (MAP) goals rather than systolic blood pressure goals [4,11]. Therefore, patients who had type A dissection-induced hypotension were also excluded from our study.

2.3. Prospective data collection

We collected decisions regarding blood pressure management prospectively. When patients first arrived at the CCRU and prior to the insertion of arterial catheters, the CCRU clinicians would indicate which anti-hypertensive medications should be administered, according to the initial CBPM value. After the arterial catheters were inserted and ABPM became available, the CCRU clinicians would indicate the management of antihypertensive medication, according to the ABPM value. CCRU clinicians completed a standardized form outlining patient identifying information, diagnosis on presentation, systolic blood pressure goals and management plans following each blood pressure modality for all patients arriving to the CCRU during the dedicated study period and who would need arterial blood pressure monitoring. Forms for patients with the target diagnosis of this study were then organized for further data collection and analysis. CCRU nursing staff collected the prospective data according to protocol as part of patients' clinical care. An Advanced Practice Practitioner and the Principal Investigator checked patients' charts to adjudicate the missing data on the forms. For the serum lactate values and pain score, we planned to impute the missing values with the population's mean, although there were no missing values, as these values were part of the CCRU standard measurements.

A change in clinical management was defined as any difference in management between the two modalities, including increasing or decreasing anti-hypertensive infusion rate or adding a new antihypertensive agent. For example, a change in clinical management occurred if the CCRU clinician decided to maintain existing rates of anti-hypertensive infusions because the CBPM value indicated the blood pressure was at goal, but decided that increasing the infusion rate was necessary to achieve target blood pressure goals based on the ABPM measurement. On the other hand, if both the CBPM and ABPM measurements indicated that increasing of existing rates of anti-hypertensive infusions was necessary to achieve target blood pressures, then it was not considered a change of management, as both modalities of blood pressure monitoring agreed on increasing anti-hypertensive medications. Typically, the American Heart Association recommends reducing the systolic BP

(SBP) of patients with AoD to 120 mmHg or less, or as tolerable by the patients without further signs and symptoms of organ damage [4]. Thus, if patients' systolic blood pressure by CBPM monitoring was 122 mmHg, the CCRU clinician would indicate no change in existing antihypertensive medication, but if the systolic blood pressure by ABPM monitoring was 130 mmHg, then increasing current rates of antihypertensive medication is indicated or adding another agent if the existing rate already reached its maximal therapeutic dosage.

2.4. Retrospective data collection

We collected other clinical data retrospectively from patients' electronic medical records at our institution. Demographic data included age, gender, and past medical history. Clinical data at the time of arterial catheter placement, including pain score, heart rate, mechanical ventilation status, and serum lactate levels. Additionally, surgical intervention, intravenous antihypertensive infusions and pain management were recorded. We also reported data about arterial catheter complications, which was defined as any necrosis of hand, wrist or extremity, source of blood stream infection or local infection, bleeding, or aneurysm [14]. Investigators also collected other data which had previously been correlated with a difference in blood pressure values such as sites of blood pressure measurements [5] and body side (same arm versus opposite arm) [1].

The research team members, who were not blinded to the study hypothesis, were first trained by the principal investigator to extract data into a standardized Excel spreadsheet (Microsoft Corp, Washington, USA). Research team members were trained with sets of 10 patients until results from all research team members reached 90% agreement with an experienced investigator. To reduce further bias, investigators independently collected data in separate sections. For example, investigators who collected data about intravenous anti-hypertensive infusions would not collect pain scores, blood pressure values, and vice versa.

2.5. Outcome measures

The primary outcome was the prevalence of changes in clinical management based on the difference in blood pressure readings between invasive arterial blood pressure and non-invasive cuff blood pressure monitoring. The secondary outcomes included demographic and clinical predictors, at the time of arterial catheter placement, that may have been associated with changes in management or the magnitude of difference between the two blood pressure modalities.

2.6. Data analysis

We did not perform a sample size calculation because this is pilot study because we attempted to include as many patients during the study period as possible.

We used descriptive analyses (mean ± [Standard Deviation]) and median [Interquartile Range [IQR], or percentages to present continuous or categorical variables as appropriate. We used 95% confidence intervals to compare the differences between groups. Besides patients who had change in blood pressure management versus those without change of blood pressure management, we also compared the characteristics of patients who had ABPM and CBPM on opposite arms or body sides (asymmetric) versus those with both measurements on the same arm or same body side (symmetric). To test whether having asymmetric blood pressure measurement would affect clinical management or value differences between invasive and non-invasive blood pressure readings, we created a new independent variable, in which patients who had both blood pressure modalities on the same body side were coded as 0, while patients with asymmetric blood pressure measurements were coded as 1.

To identify significant independent variables that are associated with a change of blood pressure management, we identified independent variables a priori (Supplementary Data) and entered all variables into forward stepwise multivariable logistic regressions. We expressed the results of the logistic regressions as odds ratio (OR) with 95% Confidence Interval (95% CI). Collinearity among independent variables was assessed via the Variance Inflation Factor (VIF). We considered any independent variable with VIF ≥ 5 as having significant collinearity with other variables and would remove them from the logistic regression model.

We assessed the goodness-of-fit of our regressions using the Hosmer-Lemeshow test. Regression models with *p*-value for Hosmer-Lemeshow test >0.05 were considered as having good fit of the data. We used the Area Under the Receiver Operating Characteristic (AUROC) curve to assess our logistic regression models' discriminatory capability. AUROC values approaching 1.0 were considered as having really good discriminatory capability between two dichotomous outcomes. We also performed a multivariable ordinal logistic regression to identify predictors for the order of systolic blood pressure difference between invasive and non-invasive blood pressure ([ABPM-CBPM]) measurements. The order of [ABPM-CBPM] differences was ranked from 0 for [ABPM-CBPM] ≤ −1 mmHg, 1 for [ABPM-CBPM] difference between 0 and 9 mmHg, 2 for an [ABPM-CBPM] between 10 and 19, and 3 for [ABPM-CBPM] difference ≥ 20 mmHg. The results from the ordinal regression were expressed with correlation coefficients and *p*-value. A positive coefficient indicates that the independent variable is more likely associated with the lowest order (rank = 0), while negative coefficients are more likely associated with the highest order (rank = 3), in our study.

The Bland-Altman plot was used to graphically present any systemic difference between arterial catheter and cuff blood pressure measurements. The [ABPM-CBPM] difference was displayed on the Y-axis while the mean [(ABPM+CBPM)/2] between the two modalities was displayed on the X-axis. The Bland-Altman plot showed whether the [ABPM-CBPM] occurred more when patients were hypertensive (more dots toward the right of the X-axis). Additionally, the plot showed whether invasive arterial blood pressures were frequently higher than non-invasive blood pressures, as indicated by more dots of [ABPM-CBPM] differences upward on the Y-axis. We examined the patterns of [ABPM-CBPM] differences in four patient groups: all patients, patients with type A dissection versus all other patients, patients with type B dissection versus all other patients, and patients with symmetric BP readings versus patients with asymmetric BP readings.

We performed our statistical analyses with Minitab version 19 (Minitab Corp, State College, Pennsylvania). We considered all tests with two-tailed *p*-value <0.05 as statistically significant.

3. Results

We electronically identified 117 patients with a diagnosis of acute aortic disease who underwent arterial catheter placement at the CCRU during the study period (Fig. 1). Among the included patients, 40 (34%) had a change in clinical management and 77 (66%) did not have a change in clinical management between the invasive arterial blood pressure and non-invasive cuff blood pressure readings.

The average (standard deviation [SD]) age for the population was 65 [14] years (Table 1). We did not find any statistically significant differences in demographic factors, including patients' age or gender, between patients who had a change in management and those who did not, nor did we find any statistically significant differences in demographic factors between those with symmetric measurements versus those with asymmetric measurements (Table 3).

Among our patient population with acute aortic disease, 47% (56/117) of patients presented with type A dissection, 31% (36/117) with type B dissection and 19% (23/117) with aortic aneurysm. The average [SD] of systolic blood pressure by ABPM in those with a change in

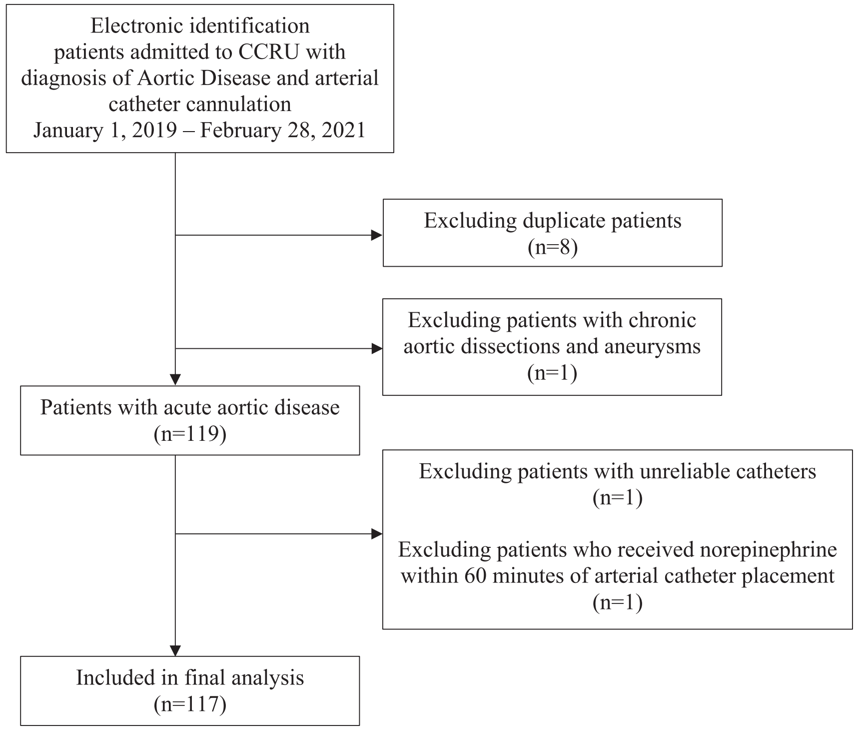


Fig. 1. Patient selection diagram.

management was 139 mmHg [22], which significantly differed from those without a change in management who had an average systolic blood pressure of 130 mmHg [24] (95% CI = -9.5 [−18.1 to −0.9]) (Table 2). Among the 36 patients with [ABPM-CBPM] difference 0–9 mmHg, 92% (33/36) did not have a change in management, compared to 8% (3/36) who did have a change in management (difference between groups 95% CI = 35 [22 to 49]). Of those with [ABPM-CBPM] difference ≥ 20 mmHg, 70% (21/30) had a change in clinical management, compared to 30% (9/30) who did not have a change in management (OR 10.4, 95% CI 4.1–26, difference between groups = −44 [−58 to −24]). This means patients who had difference between arterial catheter and cuff measurements >20 mmHg were associated with 10× increase in likelihood of having a change of clinical management (Table 2).

Increasing the anti-hypertensive infusion rate was the most common change in clinical management, occurring 68% (27/40) of the time. Adding another anti-hypertensive agent occurred in 28% (11/40) of patients with a change in management, followed by decreasing the current infusion rate, occurring 8% (3/40) of the time (Table 2).

Our multivariable logistic regression (Table 4) showed that peripheral artery disease (OR 13, 95% CI 1.18–50+, $P = 0.036$) was significantly associated with change of clinical management among patients with acute aortic diseases. No variables were removed during the regression analysis due to high VIF from collinearity. Furthermore, our multivariable ordinal regression showed that hypertension (Coef −1.26, OR 0.28, 95% CI 0.09–0.85, $P = 0.034$) was statistically associated with our highest ranking of [ABPM-CBPM] difference, where [ABPM-CBPM] ≥ 20 mmHg. On the other hand, serum lactate (Coef 0.27, OR 1.3, 95% CI 1.07, 16, $p = 0.01$) was significantly associated with the lowest ranking of [ABPM-CBPM] difference, favoring where [ABPM-CBPM] ≤ −1 mmHg (Table 4).

The Bland-Altman graph depicting [ABPM-CBPM] differences among all patients showed that most values of [ABPM-CBPM] differences were above the central axis of 0 indicating that most patients have arterial catheter blood pressure readings greater than the non-invasive cuff measurement. There is a larger percentage of patients who have [ABPM-CBPM] ≥ +10 mmHg, compared to those with [ABPM-CBPM] ≤ − 10 mmHg. This suggests that invasive arterial blood pressure values were higher than non-invasive cuff blood pressure values in a majority of patients with acute aortic disease. This plot was repeated and reproduced similar results for subset populations including type A dissection versus other types of acute aortic disease (Fig. 2B), type B dissection versus the rest of the population (Fig. 2C) and patients with asymmetric versus symmetric blood pressure readings (Fig. 2D).

Finally, one patient was documented to have an arterial catheter associated complication, leading to an overall complication rate in our patient population of 0.85% (1/117).

4. Discussion

Overall, our results suggested that up to 34% of patients with acute aortic disease had a change in management after the initiation of arterial blood pressure monitoring. Furthermore, almost half of our patients had a difference between ABPM and CBPM ≥ +10 mmHg. We also demonstrated that patients with [ABPM-CBPM] difference ≥ 20 mmHg was associated with more prevalence of change of clinical management.

Adequate blood pressure control is critical for the management of patients with acute aortic disease [14]. Previous authors have demonstrated clinically relevant differences between non-invasive and invasive blood pressure readings [8,14] in both hyper- and hypotensive patients. However, unlike our study, those were retrospective studies, which defined clinically relevant differences based on hypothetical parameters and did not demonstrate if there was an associated impact on changes in clinical management. Our study found that non-invasive cuff blood pressure monitoring usually underestimated patients' blood pressure by approximately 10 mmHg compared to invasive arterial blood pressure monitoring. When the presenting non-invasive cuff blood pressure is significantly higher or significantly lower than the recommended goal of 120 mmHg, the difference between arterial catheter and cuff measurements is less clinically relevant, as both readings would necessitate similar changes in management. However, this difference between blood pressure modalities becomes more

Table 1
Demographic characteristics of 117 patients with acute aortic disease.

	Change in clinical management		Difference between groups (95% CI)
	No ($n = 77$)	Yes ($n = 40$)	
Variables			
Age, years (mean, SD)	64 (14)	62 (15)	1.7 (−4.1 to 7.5)
Female, N (%)	25 (32)	13 (33)	−0.03 (−18 to 18)
Body Mass Index, mean (SD)	29.2 (6.7)	30.5 (8.9)	−1.3 (−4.5 to 1.9)
Diagnosis, N (%)			
Type A dissection	35 (45)	22 (55)	−10 (−29 to 9)
Type B dissection	24 (31)	12 (30)	1 (−16 to 19)
Any aneurysm	18 (23)	6 (15)	8 (−6 to 23)
Past medical history N (%)			
Diabetes	13 (17)	6 (15)	2 (−12 to 16)
Hypertension	68 (88)	33 (83)	6 (−8 to 20)
Coronary artery disease	9 (12)	3 (8)	4 (−7 to 15)
Peripheral artery disease	2 (3)	3 (8)	−5 (−14 to 4)
Any kidney disease	13 (17)	5 (13)	4 (−9 to 18)
Any liver disease	3 (4)	0 (0)	4 (−0.4 to 8)
Chronic obstructive pulmonary disease	8 (10)	5 (13)	−2 (−14 to 10)
Mechanical ventilation at arrival, N (%)	9 (12)	2 (5)	7 (−3 to 17)
Serum lactate level (mmol/L), mean (SD)	2.5 (2.3)	1.9 (1.5)	0.6 (−0.1 to 1.3)
Pain score, median [IQR]	2 [0, 5]	3 [0, 5.75]	0 (−2 to 0)
Location of arterial catheters, N (%)			
Radial	75 (97)	41 (100)	−2 (−6 to 1)
Brachial	1 (1)	0 (0)	1 (−1 to 4)
Femoral	1 (1)	0 (0)	1 (−1 to 4)
Symmetric measurements – arterial catheter and cuff, N (%)	55 (71)	26 (65)	−6 (−24 to 11)
Type of antihypertensive infusion, N (%)			
Beta-Blocker	41 (53)	22 (55)	−2 (−21 to 17)
Calcium Channel Blocker	54 (70)	30 (75)	−5 (−22 to 12)
Beta-Blocker and Calcium Channel Blocker	36 (47)	16 (40)	7 (−12 to 26)

CI, Confidence Interval; mmol/L, millimole per liter; SD, standard deviation; IQR, interquartile range.

clinically relevant when the non-invasive cuff values are closer to the recommended target of 120 mmHg because our findings suggested that arterial catheter values would be at least 10 mmHg higher than the non-invasive cuff values. This information has an important clinical implication because it indicates that using cuff blood pressure monitoring alone may lead to unrecognized or untreated relative hypertension.

Table 2
Clinical characteristics and outcomes of 117 patients with acute aortic diseases.

	Change in clinical management		Difference between groups (95% CI)
	No (n = 77)	Yes (n = 40)	
ABPM SBP (mmHg), mean (SD)	130 (24)	139 (22)	−9.5 (−18.1 to −0.9)
CBPM SBP (mmHg), mean (SD)	124 (22)	121 (15)	3.3 (−3.5 to 10.0)
Patients with ABPM-CBPM Difference ≤ −1 mmHg, N (%)*	21 (27)	5 (13)	15 (0.5 to 29)
Patients with ABPM-CBPM Difference 0–9 mmHg, N (%)	33 (43)	3 (8)	35 (22 to 49)
Patients with ABPM-CBPM Difference 10–19 mmHg, N (%)	14 (18)	11 (28)	−9 (−26 to 7)
Patients with ABPM-CBPM Difference ≥ 20 mmHg, N (%)	9 (12)	21 (53)	−41 (−58 to −24)
Type of management change, N (%)			
Increasing current infusion	NA	27 (68)	–
Adding another agent	NA	11 (28)	–
Decreasing current infusion	NA	3 (8)	–
Requiring surgery, N (%)	60 (78)	28 (70)	8 (−9 to 25)
Length of Arterial Catheter Placement, days (median, IQR)	2 [1, 4]	2.5 [1, 4.75]	0 (−1 to 1)
Hospital outcome			
Length of antihypertensive infusion, days (median, IQR)	2.0 [1.1, 4.2]	2.5 [0.8, 4.5]	0.1 (−0.8 to 0.8)
Length of stay ICU, days (median, IQR)	5 [3, 9.5]	5 [2, 7]	0 (−1,2)
Length of stay hospital, days (median, IQR)	9 [6, 14.5]	10.5 [4, 19.25]	0 (−3 to 3)
Hospital disposition, N (%)			
Home	53 (69)	20 (50)	19 (0.2 to 37)
Rehab + Nursing Home	14 (18)	15 (38)	−20 (−38 to −3)
Dead or Hospice	10 (13)	5 (13)	0.5 (−12 to 13)

CI, Confidence Interval; ABPM, arterial blood pressure monitoring; CBPM, cuff blood pressure monitoring; SBP, systolic blood pressure; ICU, intensive care unit; SD, standard deviation; IQR, interquartile range; NA, not applicable.
* There were 7 patients who had [ABPM-CBPM] ≤ −10 mmHg.

Table 3
Change in management frequency in symmetric and asymmetric readings in 117 patients with acute aortic disease.

	Arterial Catheter and Cuff symmetry		Difference between groups (95% CI)
	Asymmetric side ($n = 36$)	Symmetric side ($n = 81$)	
ABPM SBP (mmHg), mean (SD)	130 (26)	134 (22)	4 (−6 to 14)
CPPM SBP (mmHg), mean (SD)	119 (19)	125 (20)	6 (−1 to 14)
Patients with ABPM-CBPM Difference ≤ −1 mmHg, N (%)*	6 (17)	20 (25)	8 (−7 to 23)
Patients with ABPM-CBPM Difference 0–9 mmHg, N (%)	14 (39)	22 (27)	−12 (−30 to 7)
Patients with ABPM-CBPM Difference 10–19 mmHg, N (%)	6 (17)	19 (23)	7 (−8 to 22)
Patients with ABPM-CBPM Difference > 20 mmHg, N (%)	10 (28)	20 (5)	−3 (−20 to 14)
Type of management change, N (%)			
Increasing current infusion	10 (28)	17 (21)	−7 (−23 to 10)
Adding another agent	3 (8)	8 (10)	2 (−10 to 13)
Decreasing current infusion	1 (3)	2 (2)	−0.3 (−7 to 6)
Mechanical ventilation at arrival, N (%)	3 (8)	8 (10)	2 (−10 to 13)
Serum lactate level (mmol/L), mean (SD)	2.2 (2.3)	2.3 (2.0)	0.1 (−0.8 to 1.0)
Pain score, median [IQR]	2 [0, 5]	3 [0, 6]	0 (0 to 1)
Location of arterial catheters, N (%)			
Radial	35 (97)	80 (99)	2 (−4 to 7)
Brachial	0 (0)	1 (1)	1 (−1 to 4)
Femoral	1 (3)	0 (0)	- 3 (−8 to 3)
Type of antihypertensive infusion, N (%)			
Beta-Blocker	20 (56)	43 (53)	−2 (−22 to 17)
Calcium Channel Blocker	25 (69)	59 (73)	3 (−15 to 21)
Beta-Blocker and Calcium Channel Blocker	15 (42)	37 (46)	4 (−15 to 23)

CI, Confidence Interval; ABPM, arterial blood pressure monitoring; CBPM, cuff blood pressure monitoring; SBP, systolic blood pressure; ICU, intensive care unit; SD, standard deviation; IQR, interquartile range; NA, not applicable as statistical analysis was not performed.
* There were 7 patients who had [ABPM-CBPM] ≤ −10 mmHg.

Additionally, our results suggested that when the difference between modalities is greater than or equal to 20 mmHg, there appears to be the most opportunities for changes in clinical management.

Although this study took place in the intensive care unit setting, clinicians in the Emergency Department should be cognizant of these findings and consider that using arterial blood pressure monitoring in such conditions may have significant implications on medical management. The retrospective study by Drumheller indicated that arterial access can be obtained in under 8 min on average [19], speaking to the feasibility of Emergency Departments implementing policies similar to the CCRU. Further studies are needed to confirm our observation and to further investigate the association between invasive and non-invasive blood pressure modality differences with outcomes among patients with acute aortic diseases.

Despite our focus on blood pressure management, reducing heart rate and pain were also important aspects of management for patients with acute aortic diseases and may have also played a role in patients' overall management. Patients' heart rate was measured by telemetry and was the same despite blood pressure measurement modalities, so heart rate management would not be different between both blood pressure measurement modalities. Moreover, pain levels at the time of arterial cannulation, being one of the independent variables, were not associated with likelihood of change of management.

We found that peripheral artery disease (PAD) and high serum lactate are associated with higher likelihood of change of management. Peripheral artery disease increases arterial stiffness and affects the peripheral arteries, such as radial arteries where arterial catheters are commonly placed in our study [15]. On the other hand, cuffs measure the pressure at brachial arteries, which are less stiff than radial arteries and less commonly affected by PAD. Therefore, patients with PAD may be more likely to have a greater difference in blood pressure readings between their arterial catheter and cuff readings due to their own anatomical variations. Although the linkage between high serum lactate and high [ABPM-CBPM] difference is unclear, it could be due to the release of vasoactive agents during hypoperfusion state. Patients presenting with hypertensive emergencies are more likely to have end-organ hypoperfusion, and therefore increased serum lactate. The review by Rodriguez [16] proposed that during a hypertensive crisis, increased blood pressure can lead to vascular reactivity and release of vasoactive agents. This precipitates natriuresis, causing hypovolemia, and triggering the release of even more vasoconstrictive agents resulting in arteriolar fibrinoid necrosis and vasoconstriction. On the contrary, it is well documented that treating hypertensive crisis too aggressively with anti-hypertensive agents may precipitate a drop in blood pressure that results in hypoperfusion [13]. Thus, invasive arterial blood pressure monitoring in patients with acute aortic dissection and elevated serum lactate may show that patients would have unrecognized hypertension or hypoperfusion, which would need more resuscitation. Further studies are needed to confirm our observations.

Um et al [10] described that a difference > 20 mmHg between arms was a diagnostic factor for aortic dissection. Our results from both the multivariable logistic and ordinal regressions, and the Bland-Altman plot, did not show that blood pressure measurements from opposite body sides would affect the differences between blood pressure modalities nor would they affect change of management among our patients. In other words, having blood pressure monitoring on opposite body sides did not affect the decision to change patients' management. Our result could have been due to a small sample size with asymmetric

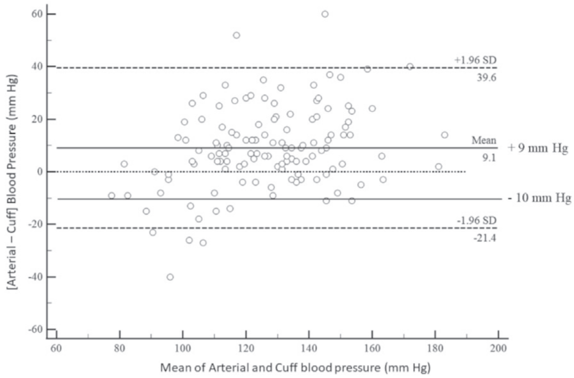
Table 4
Results from forward stepwise multivariable logistic regression measuring association between clinical factors and the likelihood of change in management between CBPM and ABPM. All predetermined factors were entered into the models.

Variables	Coef	OR	95% CI	p
Outcome: Association with Change in Clinical Management[1]				
Peripheral Artery Disease	NA	12	1.12, 50+	0.036
Secondary Outcome: Clinical Predictors of Difference in Management				
Lactate – each mmol/L	0.27	1.3	1.07, 1.6	0.01
Past medical history of Hypertension [2]	−1.26	0.28	0.09, 0.85	0.024

AUROC, area under receiver operating characteristic (AUROC) curve; *D(f)*, degree of freedom; *mmol/L*, millimoles per liter; *ABPM*, arterial blood pressure monitoring; *CBPM*, cuff blood pressure monitoring.
[1] Hosmer-Lemeshow test Chi-square 5, D(f) = 8, $P = 0.71$; AUROC: 0.66.

(A)

	[ABPM-CBPM] ≤ -10 mmHg	[ABPM-CBPM] ≥ +10 mmHg	Difference between groups (95% CI)
All patients, N (%)	7 (6)	55 (47)	- 41 (-50 to -30)



(B)

	[ABPM-CBPM] ≤ -10 mmHg	[ABPM-CBPM] ≥ +10 mmHg	Difference between groups (95% CI)
Type A dissection, N (%)	4 (7)	28 (49)	- 42 (-53 to -30)
Other, N (%)	3 (5)	27 (45)	- 40 (-50 to -29)

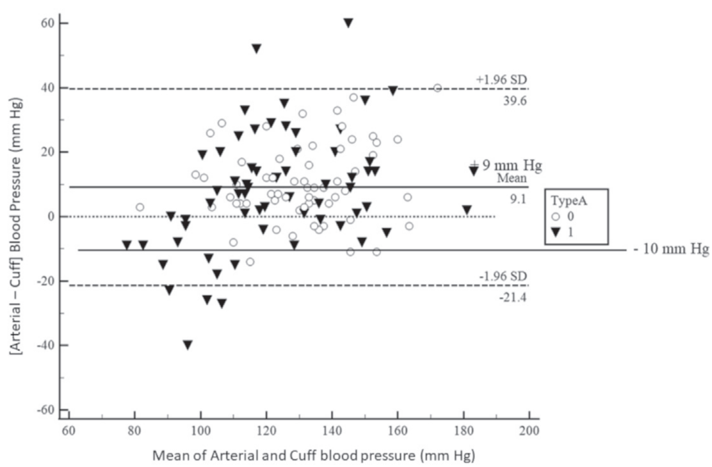


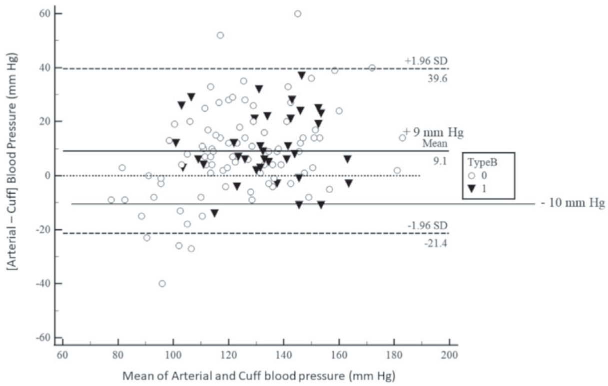
Fig. 2. A. Bland-Altman plot displaying blood pressure differences among all patients with acute aortic disease. B. Bland-Altman plot displaying blood pressure differences in patients with Type A dissection to those with Type B dissections and Aneurysms. C. Bland-Altman plot displaying blood pressure differences in patients with Type B dissection to those with Type A dissections and Aneurysms. D. Bland-Altman plot displaying blood pressure differences in patients with symmetric ABPM and CBPM measurements to those with asymmetric measurements.

measurements or due to a small difference between invasive and non-invasive blood pressure values in our patient population.

Previous authors have questioned whether the benefits of invasive monitoring would outweigh the associated risks [17]. Risks associated with arterial catheter placement include vascular complications [14] and bloodstream infections [18]. However, this risk has been documented to be <1% [12]. O'Horo et al. demonstrated a rate of arterial-catheter related bloodstream infection of 0.96/1000 catheter days [18]. Our study noted a complication rate of 1/117 (0.85%), in which one patient developed a soft hematoma after arterial catheter insertion. Thus, the decision was to remove the arterial catheter after the arterial waveform was lost on the monitor. This finding would suggest a similar complication rate to the prior studies. In contrast, a change in management occurred in 34% of patients after placement of the arterial catheter. In addition, Ruszala [7] reported that the presence of invasive arterial blood pressure monitoring prompted transporting teams to intervene more frequently, which caused more patients to achieve systolic blood pressure goals during transport between hospitals. Initiation of ABPM did not delay in patient's transport as they reported it took <10 min for arterial cannulation in patients with AoD. The potential benefit of ABPM in our patient population appears to be higher than the risks and further studies are needed to confirm our results.

(C)

	[ABPM-CBPM] ≤ -10 mmHg	[ABPM-CBPM] ≥ +10 mmHg	Difference between groups (95% CI)
Type B dissection, N (%)	3 (8)	16 (44)	- 36 (-47 to -25)
Other, N (%)	4 (5)	39 (48)	- 43 (-53 to -32)



(D)

	[ABPM-CBPM] ≤ -10 mmHg	[ABPM-CBPM] ≥ +10 mmHg	Difference between groups (95% CI)
Symmetric Measurements	5 (6)	39 (48)	- 42 (-53 to -31)
Asymmetric Measurements	2 (6)	16 (44)	- 38 (-49 to -27)

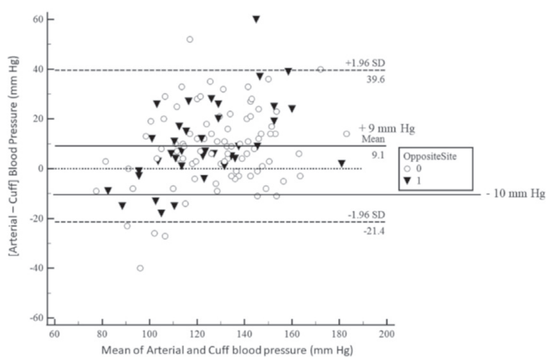


Fig. 2 (*continued*).

4.1. Limitations

Our study has several limitations. The CCRU is a unique clinical setting where patients had known acute aortic pathology on arrival. This is more often the circumstance in the intensive care unit setting rather than in the Emergency Department. However, patients who are diagnosed with acute aortic disease and are awaiting surgical consults in the Emergency Department or being transferred may still benefit from arterial monitoring. Due to our limited sample size, we may not have an accurate representation of complications associated with arterial catheter insertion. We also did not look for different clinical outcomes among patients who had a change of clinical management versus those without. This study also compared the initial non-invasive cuff blood pressure reading with the initial invasive arterial blood pressure reading. It did not look at continuous cycling of non-invasive cuff measurements, which may more closely replicate invasive blood pressure monitoring or multiple values of arterial monitoring to see blood pressure trends. Lastly, although peripheral artery disease was associated with higher likelihood of change of clinical management, the small number of peripheral artery disease caused the 95% CI to be wide, which causes the result to be less reliable.

5. Conclusions

We observed approximately 34% of patients with acute aortic dissection had a change of clinical management after arterial invasive blood pressure monitoring. Increasing the antihypertensive infusion rate was the most common change in management, further suggesting that non-invasive cuff blood pressure monitoring may have underestimated blood pressure compared to invasive arterial blood pressure monitoring. Clinicians should consider invasive arterial catheters more often in hypertensive patients with acute aortic disease as this may influence the medical management of such patients.

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Presentation

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Authors' contribution

All authors approved the submission of this manuscript.

ABPM, arterial blood pressure monitoring; CBPM, cuff blood pressure monitoring; mm Hg, millimeter of Mercury.

Credit authorship contribution statement

Jamie Palmer: Writing – review & editing, Writing – original draft, Investigation, Data curation. **Dominique Gelmann:** Writing – review & editing, Writing – original draft, Validation, Investigation, Data curation. **Emily Engelbrecht-Wiggans:** Writing – review & editing, Writing – original draft, Validation, Investigation, Data curation. **Grace Hollis:** Writing – review & editing, Writing – original draft, Investigation, Data curation. **Emily Hart:** Writing – review & editing, Writing – original draft, Validation, Data curation. **Afrah Ali:** Writing – review & editing, Writing – original draft, Validation. **Daniel J. Haase:** Methodology, Conceptualization. **Quincy Tran:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Conceptualization.

Declaration of Competing Interest

None declared.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajem.2022.06.054.

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