Published in final edited form as:

J Clin Monit Comput. 2018 August ; 32(4): 699–705. doi:10.1007/s10877-017-0065-4.

Influence of non-invasive blood pressure measurement intervals on the occurrence of intra-operative hypotension

Grant H. Kruger^{1,2}, Amy Shanks², Sachin Kheterpal², Tyler Tremper², Chi-Jung Chiang³, Robert E. Freundlich⁴, James M. Blum⁵, Albert J. Shih^{1,6}, and Kevin K. Tremper²

¹Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI, USA

²Department of Anesthesiology, University of Michigan, Ann Arbor, MI, USA

³Luren Precision Co, Hsinchu City, Taiwan

⁴Department of Anesthesiology, Vanderbilt University Medical Center, Nashville, TN, USA

⁵Critical Care Anesthesiology, Emory University School of Medicine, Atlanta, GA, USA

⁶Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI, USA

Abstract

The American Society of Anesthesiologists Standards for Basic Monitoring recommends blood pressure (BP) measurement every 5 min. Research has shown distractions or technical factors can cause prolonged measurement intervals exceeding 5 min. We investigated the relationship between prolonged non-invasive BP (NIBP) measurement interval and the incidence of hypotension, detected postinterval. Our secondary outcome was to determine independent predictors of these prolonged NIBP measurement intervals. Retrospective data were analyzed from 139,509 general anesthesia cases from our institution's Anesthesia Information Management System (AIMS).

Absolute hypotension (AH) was defined a priori as a systolic BP < 80 mmHg and relative hypotension (RH) was defined as a 40% decrease in systolic BP from the preoperative baseline. Odds ratios (OR) with 95% confidence intervals and Pearson's Chi square Test reported the association of prolonged NIBP measurement intervals on hypotension detected post-NIBP measurement interval. Logistic regression models were developed to determine independent predictors of NIBP measurement intervals. The analysis revealed that NIBP measurement intervals greater than 6 and 10 min are associated with an approximately four times higher incidence of a patient transitioning into hypotension (AH/RH > 6 min OR 4.0 / 3.6; AH/RH > 10 min OR 4.3 / 3.9; $p < 0.001$). A key finding was that the "> 10-minute AH model" indicated that age 41–80, increased co-morbidity profile, obesity and turning (repositioning) of the operative room table were significant predictors of prolonged NIBP measurement intervals ($p < 0.001$). While we do not suggest NIBP measurement intervals cause hypotension, intervals greater than 6 and 10 min

✉ Grant H. Kruger, ghkruger@umich.edu.

Conflict of interest Dr K. Tremper receives royalties from GE for software related to the Centricity AIMS. The rest of the authors declare they do not have any conflicts of interests associated with this research.

Ethical approval This research study was approved by the University of Michigan Institutional Review Board (HUM00024166). The study was retrospective in nature and required no patient involvement, and a waiver of informed consent was obtained from the institutions IRB.

are associated with a fourfold increase in the propensity of an undetected transition into both RH or AH. These data support current monitoring guidelines.

Keywords

Non-invasive blood pressure; Physiologic monitoring; Intra-operative hypertension; Measurement gaps

1 Introduction

In 1986 the American Society of Anesthesiologists (ASA) adopted standards for basic anesthetic monitoring, including recommending blood pressure (BP) be measured at least every 5 min to ensure the adequacy of the patient's circulatory function [1]. However, various technical limitations of patient monitors as well as human factors may impair a clinicians' ability to adhere to this standard [2]. Technical limitations may lead to missed measurements, such as when the BP cuff is disconnected during patient repositioning, the persistence of settings from a prior surgery (e.g. autorecycle turned off) or BPs below the detectable threshold. Human factors include the ability of physicians to deal with increased surgery complexity and distractions from other monitors and alarms requiring attention [3]. Unfortunately, the underlying cause of missed BP measurements is not recorded in electronic medical records, making it difficult to identify their source.

Although a BP measurement every 5 min is considered the standard of care, we are unaware of any scientific basis for the selection of this interval or any study confirming its importance [1]. Prolonged measurement intervals while monitoring physiologic variables or distractions blind clinicians to the patient's physiologic state. It is conceivable that prolonged BP measurement intervals may not allow a practitioner to notice a decreasing BP, which could have been treated prior to the patient becoming hypotensive. The occurrence of undetected intra-operative hypotension is especially relevant since studies have suggested that it may be associated with poor outcomes [4, 5]. For example, Kheterpal et al. found that a mean arterial pressure (MAP) < 50 mmHg, or a reduction by 40% from the patients preoperative baseline BP, was associated with an increased incidence of postoperative cardiac events [4]. A large study by Walsh et al., found additional evidence using intraoperative data from 33,330 non-cardiac surgeries, and demonstrated that even short durations of MAP < 55 mmHg were associated with renal and cardiac injury [6]. Tassoudis et al. conducted a 100-patient prospective observational study, concluding that persistent hypotension during elective major abdominal surgery is a significant risk factor for postoperative complications [7]. While the relationship between hypotension severity and outcome is still under investigation, the literature strongly supports the ASA's recommendation for regular monitoring to help maintain BP within an acceptable range.

Certain clinical situations make regular monitoring difficult to achieve. For example, after anesthesia induction, patient and/or operating room table orientation may need to be adjusted for access to the surgical site. During repositioning, noninvasive blood pressure (NIBP) monitors may be disconnected and reconnected, possibly resulting in prolonged measurement intervals. Ehrenfeld et al. found that position changes commonly resulted in

prolonged BP monitoring intervals [2]. In addition, there are other times where prolonged measurement intervals may also occur. Nair et al. found that anesthesia providers sometimes forgot to re-engage automated NIBP measurements, which led to measurement intervals > 5 min, some of which were > 15 min, with a maximum of 64 min [8].

It is unclear if prolonged measurement intervals are associated with a transition into a hypotensive state. This study seeks to better clarify what relationship, if any, exists between failure to routinely monitor BP and the occurrence of hypotensive episodes. As a secondary outcome, we also seek to clarify independent predictors of prolonged NIBP measurement intervals.

2 Methods

This study was approved by the University of Michigan Institutional Review Board (HUM00024166). Since the study was retrospective in nature a waiver of informed consent was obtained. The study consisted of 139,509 general anesthesia cases in the general adult surgical population from the University of Michigan AIMS (Centricity®, General Electric Healthcare™, Waukesha, WI) between July 1, 2004 and June 18, 2012. The NIBP was measured using the Tram-Rac 4A oscillometric module of the Marquette Solar 9500 Physiologic Monitor (General Electric Healthcare™, Milwaukee, WI), which was installed in each operating room. All the patients' monitoring systems were networked and the NIBP data was recorded to the central AIMS relational database. In preparation for the analysis, Structured Query Language (SQL) was used to extract the patients' age, ASA physical status classification, body mass index (BMI), preoperative baseline systolic NIBP, position, and bed orientation for each case. In addition, the intra-operative systolic NIBP and measurement timestamp starting from the "Patient in Room" entry were also extracted. The "Patient in Room" option must be manually selected on the AIMS system to begin capturing vital sign data. The end of the data segment was chosen to be the first non-null value from either the "Procedure end", "Patient transported", or "Anesthesia end" time documentations within the AIMS system. The following cases were excluded from the analysis: any case lasting longer than 24 h, cardiac, thoracic, vascular and electroconvulsive therapy cases, ASA 5 or 6 cases, any patients < 18 years old, and cases with no valid preoperative holding room BP. Cases with < 2 recorded NIBP measurements or invasive BP measurements were also excluded. The demographics for the study population are provided in Table 1.

For this study, two a priori definitions of intra-operative hypotension were used, based on pre-determined thresholds for clinical significance. Absolute hypotension (AH) was defined as a systolic NIBP < 80 mmHg and relative hypotension (RH) was defined as a 40% decrease in SBP from baseline. Baseline systolic NIBP was obtained from the preoperative holding room measurement recorded in the history and physical report.

Two statistical analyses were performed. First, an event level analysis was performed for > 6 and > 10 min NIBP measurement intervals to determine associations between NIBP measurement intervals and hypotension. The 6 min threshold was selected not only because it was close to the ASA recommendation, but also allowed the NIBP cuff to cycle at least once in the event of a failed measurement. The 10 min threshold was selected as it was

unlikely a measurement would not be obtained during this interval without a definite clinical cause. Unadjusted odds ratio (OR) with a 95% confidence interval and Pearson's Chi square test were used. Post-interval hypotension was only indicated if the NIBP measurement terminating a prolonged measurement interval indicated that the patient was hypotensive and the last measurement preceding the interval indicated the patient was previously normotensive. Events were not considered post-interval hypotension if the patient's NIBP measurement immediately preceding a prolonged measurement interval was hypotensive or became hypotensive after at least one normotensive measurement which terminated the measurement interval.

After the event level analysis, a case level analysis was performed to identify independent predictors of prolonged NIBP measurement intervals using binary logistic regression models. Four models were constructed: RH and AH models for measurement intervals of > 6 and > 10 min, with all models tested for co-linearity. The following covariates were entered as independent covariates into the regression models: age (31–40, 41–50, 51–60, 61–70, 71–80, 80+) all referenced to age 18–30; ASA 3 and 4 referenced to ASA 1 and 2; body mass index (< 18.5 underweight, 25.0 overweight and 30.0 obese) referenced to normal body mass index (18.5–24.99) [9]; patient position and bed orientation entries were text processed for the 6 types of positions (supine, prone, lateral, sitting, lithotomy, beach chair) and the 4 turn options (0° , 45° , 90° , 180°). In addition, we also identified if a case occurred during normal staffing hours, meaning multiple attending anesthesiologists are readily available (7 a.m.–11 p.m. Monday to Friday).

Model diagnostics were tested using both the Omnibus Tests of Model Coefficients and Hosmer and Lemeshow Test. A p-value of < 0.05 indicated statistical significance and that the associated covariate represented an independent predictor of post-NIBP measurement interval hypotension along with the adjusted odds ratio and 95% confidence interval. The receiver operating curve (ROC) area under the curve (AUC) is reported for each model. SPSS® version 19 (Armonk, New York) was used for the statistical analysis.

3 Results

Approximately 5.7 million NIBP measurements (events) associated with 139,509 general anesthesia cases were found in the database and included for analysis. Transitions from a normotensive state to a hypotensive state occurred in slightly over 3% of all these measurements or approximately 180,000 events (22,500 per year) for either AH or RH irrespective of measurement interval. Only 0.8% of measured intervals (approximately 45,600) were greater than 6 min, and only 0.2% of intervals (approximately 11,700) were greater than 10 min. Table 2 provides a summary of the associations between occurrences of AH and RH for (a) measurement intervals > 6 min and (b) measurement intervals > 10 min. On average, a measurement interval greater than 6 min preceded a transition into hypotension approximately 608 times per year. A transition into AH between successive NIBP measurements occurred in 3.1% of measurement intervals less than or equal to 6 min (ideal situation), and in 3.2% of measurement intervals less than or equal to 10 min. In addition, transitions into RH occurred in 3.5%, regardless of whether the measurement interval was less than or equal to 6 min or less than or equal to 10 min (all p-values were $<$

0.001). In comparison, the occurrence of both AH and RH transitions increased to 11.4 and 12.5% for intervals in NIBP measurement greater than 6 or 10 min, respectively.

Table 3 presents the independent predictors and corresponding adjusted OR and 95% CI for the logistic regression models. Age and BMI are ordinal variables and therefore “Age 18–30” and “BMI—Normal” are considered the reference group when comparing against the other age ranges and BMI groupings respectively. The adjusted odds ratio is presented for that specific ordinal range against the corresponding reference group. The “RH > 6 min model” demonstrated poor goodness of fit and was therefore not reported. Predictors for prolonged NIBP measurement intervals (AH > 6 and > 10 min and RH > 10 min) included age, ASA III or IV, obesity and turning of the operating room table.

The results of the Omnibus and Hosmer test are provided in Table 4. For the > 6 min post-NIBP measurement interval AH model, the AUC was found to be 0.63, with a 95% CI range of 0.62–0.64. For the > 10 min post NIBP measurement interval AH and RH model, the AUCs were found to be 0.64 and 0.68, with 95% CIs of 0.62–0.65 and 0.66–0.69 respectively.

4 Conclusions

It is not currently technically feasible to eliminate prolonged NIBP measurement intervals in the operating room. However, although prolonged NIBP measurement intervals occur infrequently, these intervals have the potential to allow for the undetected transition of a patient into a prolonged hypotensive state. It is important to stress that we do not suggest measurement gaps cause hypotension, per se. The event level analysis, as summarized in Table 2, suggests that the presence of prolonged NIBP measurement intervals results in an approximately fourfold increase in the chance of a transition into hypotension, highlighting the importance of regular measurement.

For the case-level binary logistic regression analyses age, obesity, ASA status, and whether or not the operating room table was turned were independent predictors of NIBP measurement intervals for all models listed in Table 3. For the > 10 min measurement interval RH model, we also demonstrated that, in addition to the previously mentioned predictors, multiple anesthesia provider staffing was an independent predictor. However, the AUC for all models were poor, suggesting that even though some factors were found to be independent predictors of a hypotensive event after a specific prolonged measurement interval, there are still other contributing factors that were not discovered.

Our primary contribution through this research is showing that prolonged NIBP measurement intervals > 6 min are associated with hypotensive episodes of unknown duration. It is important to note that this study does not propose a causal relationship. It does highlight the need for improved BP monitoring technologies that overcome some of the limitations of current methods, to provide more continuous patient monitoring. In future work, the effect of measurement intervals on the resulting hypotension severity and its subsequent impact on short- and long-term patient outcomes must be determined. This is especially important since prior studies suggest potential relationships between these events.

For example, Bijker et al. [10], investigated the relationship between hypotension and 1-yr mortality after non-cardiac surgery in 1705 general and vascular surgery patients. Their analysis found that the risk of mortality for elderly patients increases for extended durations of hypotension, suggesting that lower BP is tolerated for shorter durations. However, the effect of hypotension on 1 year mortality remains debatable, and no firm conclusions on the lowest acceptable intraoperative BP could be drawn from this study. Related research by Pietropaoli et al. [11] studied the short term deleterious effect of hypotension on outcomes in head injury patients. The authors studied 53 severe head injury patients who were normotensive on admission, with 17 becoming hypotensive, and found that hypotension (SBP < 80 mmHg) doubled mortality ($p < 0.001$). In the general surgery population the two large studies by Kheterpal et al. and Walsh et al. demonstrated that even short durations of hypotension can increase the incidence of postoperative cardiac and renal events [4, 6].

Since BP measurement intervals increase the likelihood of a patient transitioning into an undetected hypotensive state, it is possible to hypothesize that these intervals may similarly increase risk to the patient for other adverse events. With the proliferation of advanced automated monitoring and alerting systems in medicine, it seems that the possibility should exist to reduce or eliminate intervals in BP measurements. However, Ehrenfeld et al. also recognized this need when they found BP intervals of 10 min were common in 212,706 electronic anesthesia records. They designed and implemented near real-time automated alerts for clinicians immediately after a BP measurement interval > 10 min occurred. After the study, the incidence of intervals was reduced, but not eliminated, by near real-time feedback to providers [2]. The authors suggest that the ASA's recommendation for 5 min BP interval monitoring might not be achievable with current practices and technology [2]. In addition, this study did not investigate the added burden of the alerts on the clinicians, which is a concern discussed in numerous other articles. This fact, along with the findings from the Ehrenfeld study, suggest that simply adding additional alerts may not be sufficient to address the occurrence of prolonged BP measurement intervals [12–16].

An alternate explanation for a prolonged NIBP measurement interval could also be due to the hypotension itself. A patient may rapidly progress into hypotension and the resulting low BP could cause the patient monitor to fail to obtain a measurement. The oscillometric NIBP devices used in this study are set to cycle every 5 min and immediately recycle when a BP measurement cannot be detected, which takes < 1 min. This was a factor when deciding to study measurement intervals exceeding 6 min. However, modern NIBP devices are capable of reading values well below systolic BP of 60 mmHg, suggesting that many prolonged intervals are likely due to failure of initiating a BP measurement (possible due to the design of the equipment) rather than failure due to repeated cuff recycling. Since we found similar results with our > 10 min interval as with our > 6 min interval, we feel it is unlikely that this may have led to increased AH and RH events. However, it should be noted that not all NIBP devices will immediately recycle when a failure occurs (some may wait until the next scheduled measurement). This would lengthen the measurement interval and increase the chance of the patient transitioning into hypotension undetected.

Since the event level analysis did not consider the distribution of the episodes, we were concerned that a few unstable patients might be exhibiting numerous events and skewing the

results of our analysis. To account for this, we performed a histogram of intra-operative hypotension events per case and found that more than 95% of the patients had only one event and no more than two or three events were detected for any patient.

A limitation of this study is that our definitions of AH and RH were based on a systolic BP. Systolic BP was chosen because a comprehensive literature review demonstrated it was the most commonly used definition [5]. Although recent outcomes research has focused on MAP [6], systolic BP remains the required documentation standard in the anesthesia record for paper and electronic implementations. In addition, coronary perfusion occurs predominantly during diastole, suggesting that definitions of hypotension should not only be limited to MAP. Next, even though our results suggest that NIBP measurements with intervals of greater than 6 min were associated with an increased incidence of hypotension, our results do not confirm whether increased BP measurement frequency would reduce the incidence of hypotension, even though they would presumably facilitate earlier diagnosis and treatment. Finally, owing to technical difficulties, some of the demographic data provided in Table 1 (e.g. surgical duration) was collected on only 66% of the study population, whereas the rest were computed from the entire study population. Where truncated data was available these data represent, about 92,912 of the 136,509 subjects. From our experience we expect these data to still remain representative of the overall study population.

Using a large study population, this paper confirms published research findings indicating that NIBP values recorded in AIMS do contain measurement intervals > 5 min. In addition, we have found that these prolonged NIBP measurement intervals are associated with an increased chance of hypotension occurring (but to not cause hypotension). Given that the published ASA standards for basic monitoring indicate the measurement of BP at least every 5 min [1], these results suggest that we need to improve our management by at very least alerting for intervals in BP measurements exceeding 5 min. In addition, modern technological solutions that allow for more frequent NIBP measurements along with innovative alerting strategies should be explored to reduce the incidence of hypotension and any potential associated consequences [17].

Acknowledgments

Funding This work was supported from discretionary research funds from the Department of Anesthesiology at the University of Michigan.

References

1. American Society of Anesthesiologists. Standards for basic anesthetic monitoring. Schaumburg: American Society of Anesthesiologists; 2011.
2. Ehrenfeld JM, Epstein RH, Bader S, Kheterpal S, Sandberg WS. Automatic notifications mediated by anesthesia information management systems reduce the frequency of prolonged gaps in blood pressure documentation. *Anesth Analg*. 2011;113 (2): 356–63. doi:10.1213/ANE.0b013e31820d95e7. [PubMed: 21415437]
3. Bovill JG. Alarm systems. *Baillière's Clin Anaesthesiol*. 1990;4(1):193–200. doi:10.1016/S0950-3501(05)80182-5.
4. Kheterpal S, O'Reilly M, Englesbe MJ, Rosenberg AL, Shanks AM, Zhang L, Rothman ED, Campbell DA, Tremper KK. Preoperative and intraoperative predictors of cardiac adverse events

- after general, vascular, and urological surgery. *Anesthesiology*. 2009;110(1):58–66. doi:10.1097/ALN.0b013e318190b6dc. [PubMed: 19104171]
5. Bijker JB, van Klei WA, Kappen TH, van Wolfswinkel L, Moons KG, Kalkman CJ. Incidence of intraoperative hypotension as a function of the chosen definition: literature definitions applied to a retrospective cohort using automated data collection. *Anesthesiology*. 2007;107(2):213–20. doi: 10.1097/01.anes.0000270724.40897.8e. [PubMed: 17667564]
 6. Walsh M, Devereaux PJ, Garg AX, Kurz A, Turan A, Rodseth RN, Cywinski J, Thabane L, Sessler DI. Relationship between intraoperative mean arterial pressure and clinical outcomes after noncardiac surgery: toward an empirical definition of hypotension. *Anesthesiology*. 2013;119(3): 507–15. doi:10.1097/ALN.0b013e3182a10e26. [PubMed: 23835589]
 7. Tassoudis V, Vretzakis G, Petsiti A, Stamatiou G, Bouzia K, Melekos M, Tzovaras G. Impact of intraoperative hypotension on hospital stay in major abdominal surgery. *J Anesth*. 2011;25(4):492–9. doi:10.1007/s00540-011-1152-1. [PubMed: 21547554]
 8. Nair BG, Horibe M, Newman SF, Wu WY, Schwid HA. Near real-time notification of gaps in cuff blood pressure recordings for improved patient monitoring. *J Clin Monit Comput*. 2013;27(3):265–71. doi:10.1007/s10877-012-9425-2. [PubMed: 23283561]
 9. World Health Organization. Obesity: preventing and managing the global epidemic. WHO Technical Report Series 894; 2000.
 10. Bijker JB, van Klei WA, Vergouwe Y, Eleveld DJ, van Wolfswinkel L, Moons KG, Kalkman CJ. Intraoperative hypotension and 1-year mortality after noncardiac surgery. *Anesthesiology*. 2009;111(6):1217–26. doi:10.1097/ALN.0b013e3181c14930. [PubMed: 19934864]
 11. Pietropaoli JA, Rogers FB, Shackford SR, Wald SL, Schmoker JD, Zhuang J. The deleterious effects of intraoperative hypotension on outcome in patients with severe head injuries. *J Trauma*. 1992;33(3):403–7. [PubMed: 1404509]
 12. Blum JM, Kruger GH, Sanders KL, Gutierrez J, Rosenberg AL. Specificity improvement for network distributed physiologic alarms based on a simple deterministic reactive intelligent agent in the critical care environment. *J Clin Monit Comput*. 2009;23(1):21–30. doi:10.1007/s10877-008-9159-3. [PubMed: 19169835]
 13. Graham KC, Cvach M. Monitor alarm fatigue: standardizing use of physiological monitors and decreasing nuisance alarms. *Am J Crit Care*. 2010;19(1):28–34. doi:10.4037/ajcc2010651. [PubMed: 20045845]
 14. Schmid F, Goepfert MS, Kuhnt D, Eichhorn V, Diedrichs S, Reichensperner H, Goetz AE, Reuter DA. The wolf is crying in the operating room: patient monitor and anesthesia workstation alarming patterns during cardiac surgery. *Anesth Analg*. 2011;112(1):78–83. doi:10.1213/ANE.0b013e3181fcc504. [PubMed: 20966440]
 15. Seagull FJ, Sanderson PM. Anesthesia alarms in context: an observational study. *Hum Factors*. 2001;43(1):66–78. [PubMed: 11474765]
 16. Block FE, Jr, Schaaf C. Auditory alarms during anesthesia monitoring with an integrated monitoring system. *Int J Clin Monit Comput*. 1996;13(2):81–4. [PubMed: 8912021]
 17. Kruger GH, Chen C, Blum JM, Shih AJ, Tremper KK. Reactive Software Agent Anesthesia Decision Support System. *J Syst Cybern Inform*. 2011;9(6):30–7.

Table 1

Study population demographics

Demographic category	
Age (years) *	49 ± 17
BMI *	28 ± 7
Comorbidities [†]	
Congestive heart failure	1875 (2.0)
Arrhythmia	4067 (4.4)
Valvular heart disease	1012 (1.1)
Pulmonary circulatory disease	1238 (1.3)
Peripheral vascular disorders	2068 (2.2)
Hypertension, uncomplicated	17,844 (19)
Hypertension, complicated	3217 (3.5)
Paralysis	1458 (1.6)
Other neurological disorders	3078 (2.2)
Chronic pulmonary disease	5898 (6.4)
Diabetes, uncomplicated	7655 (8.2)
Diabetes, complicated	1331 (1.4)
Hypothyroidism	5521 (5.9)
Renal Failure	5021 (3.6)
Liver disease	2878 (3.1)
Peptic ulcer disease	442 (0.5)
AIDS/HIV	191 (0.2)
Lymphoma	2174 (2.3)
Metastatic cancer	5572 (6.0)
Solid tumor without metastasis	13,908 (15)
Rheumatoid arthritis	1996 (2.1)
Coagulopathy	1773 (1.9)
Obesity	6243 (6.7)
Weight loss	1754 (1.9)
Fluid/electrolyte disorders	5810 (6.3)
Blood loss anemia	538 (0.6)
Deficiency anemia	1390 (1.5)
Alcohol abuse	1318 (1.4)
Drug abuse	968 (1.0)
Psychoses	1203 (1.3)
Depression	10,864 (12)
Type of procedure (via primary anesthesia CPT)	
Head	22,871 (16)
Neck	13,929 (10)
Thorax—extrathoracic	11,275 (8.1)
Thorax—intrathoracic	2343 (1.7)

Demographic category	
Spine and spinal cord	3604 (2.6)
Upper abdomen	11,925 (8.6)
Lower abdomen	13,124 (9.4)
Renal	16,034 (12)
Gynecologic	7456 (5.4)
Male reproductive system	1713 (1.2)
Pelvis	898 (0.6)
Hip/leg/foot	17,433 (13)
Shoulder/arm/hand	11,802 (8.5)
Radiologic	2765 (2.0)
Other	2186 (0.9)
Emergent Operation	5649 (4.1)
General anesthesia	128,424 (92)
Surgical duration (minutes) [*] , ^T	97 ± 74

All data is presented as count N (%), except where

^{*} Denotes data is presented as mean ± standard deviation.

^T The Symbol denotes ~66% of study population data was available to compute this category, while unmarked categories were computed from >98% of study population data

Table 2

Associations between the occurrence of hypotension and measurement interval

a) 6 min NIBP measurement interval results	Interval n (%)	6 min n (%)	Interval > 6 min n (%)	p-value	Un-adjusted OR 95% CI
Absolute hypotension (AH) (systolic BP < 80 mmHg)	175,302 (3.1)		5151 (11.4)	< 0.001	4.0 (3.9–4.1)
Relative hypotension (RH) (40% decrease in systolic BP from preoperative baseline)	171,776 (3.5)		4572 (11.4)	< 0.001	3.6 (3.5–3.7)
b) 10 min NIBP measurement interval results	Interval n (%)	10 min n (%)	Interval > 10 min n (%)	p-value	Un-adjusted OR 95% CI
Absolute hypotension (AH) (systolic BP < 80 mmHg)	178,984 (3.2)		1469 (12.5)	< 0.001	4.3 (4.1–4.6)
Relative hypotension (RH) (40% decrease in systolic BP from preoperative baseline)	175,058 (3.5)		1290 (12.5)	< 0.001	3.9 (3.7–4.2)

Percentages indicate the proportion of AH or RH relative to the prolonged measurement interval as specified by the column and row headings. All p-values were significant at < 0.001

Table 3

Results of adjusted odds ratio (95% confidence interval) analysis for regression model covariates

Covariates documented in AIMS	AH > 6 min interval model (n = 4894)	AH > 10 min interval model (n = 1453)	RH > 10 min interval model (n = 1269)
Age 18–30	Reference	Reference	Reference
Age 31–40	NS	NS	NS
Age 41–50	1.3 (1.2–1.5)	1.4 (1.1–1.7)	1.7 (1.3–2.2)
Age 51–60	1.7 (1.6–1.9)	1.8 (1.5–2.3)	2.7 (2.1–3.4)
Age 61–70	1.8 (1.6–2.0)	1.8 (1.4–2.2)	2.7 (2.1–3.5)
Age 71–80	1.7 (1.5–2.0)	1.8 (1.4–2.2)	3.1 (2.3–4.1)
Age 81 plus	1.4 (1.1–1.7)	NS	2.3 (1.6–3.4)
ASA 3 or 4	1.3 (1.2–1.3)	1.5 (1.3–1.6)	1.3 (1.2–1.5)
BMI—normal	Reference	Reference	Reference
BMI—underweight	NS	NS	0.5 (0.3–0.9)
BMI—overweight	NS	NS	NS
BMI—obese	1.4 (1.3–1.5)	1.5 (1.3–1.7)	1.8 (1.5–2.1)
Any patient repositioning	NS	NS	NS
Any bed turned	2.2 (2.0–2.4)	2.0 (1.7–2.3)	2.0 (1.7–2.3)
Staffed hours (Monday to Friday 7 a.m.–11 p.m.)	NS	NS	1.5 (1.0–2.2)

Table 4

Results of Omnibus, and Hosmer and Lemeshow test of model coefficients

	AH > 6 min interval	AH > 10 min interval	RH > 10 min interval
Omnibus test			
Chi square	1010	345	475
Degrees of freedom	13	13	13
Significance	$p < 0.001$	$p < 0.001$	$p < 0.001$
Hosmer and Lemeshow Test			
Chi square	5	14	11
Degrees of freedom	8	8	8
Significance	0.7	0.1	0.2