Common clinical thresholds of intraoperative hypotension and 30-day mortality following surgery: a retrospective cohort study

Philippe Dony[1], Laurence Seidel[2], Magali Pirson[3], Guy Haller[4,5]

[1]Health Services and Economics research unit: School of Public Health–Free University of Brussels, Belgium

[2]Department of Medico-economic information and Biostatistics, University Hospital of Liège, Belgium

[3]Health Services and Economics Research Unit: School of Public Health–Free University of Brussels, Belgium

[4]Department of Anesthesia, Intensive Care & Pharmacology, Geneva University Hospital, 1211 Genève 14-Switzerland

[5]Department of Epidemiology & Preventive Medicine, Monash University, The Alfred Centre, 99 Commercial Road Melbourne Vic 3004, Australia

Corresponding author

Philippe Dony

dr.dony@skynet.be

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Abstract

Background:

A wide range of thresholds define intraoperative hypotension and can be used to guide intraoperative blood pressure management. Many clinicians use the systolic blood pressure (SBP)<80 mmHg, the mean arterial pressure (MAP)<60 mmHg and the SBP percent drop from baseline (ΔSBP)>20% as alarming limits that should not be exceeded. Whether these common thresholds are valid limits that can inform clinicians on a possible increased risk of postoperative complications, particularly 30-day mortality, is currently unclear.

Methods: We performed a retrospective registry-based cohort study between January 2015 and July 2016 using departmental hospital databases and the National Death Registry. Uni- and multivariate analyses were performed to assess the association between each of these three thresholds and 30-day postoperative mortality. Six specific markers of hypotension were used.

Results: Of 11,304 patients, 86 (0.76%) died within 30 days following surgery. All intraoperative hypotension markers for SBP<80 mmHg and MAP<60 mmHg were significantly associated with 30-day mortality (P<0.005). Markers of ΔSBP>20% were not significant. After adjustment for age, gender, American Society of Anesthesiologists (ASA) score, emergency status and risk related to the type of surgery, both SBP<80 mmHg and MAP<60 mmHg (the percent area under the threshold marker) showed the strongest associations with 30-day mortality, with odds ratios (ORs) of 3.02 (95% confidence interval (CI) 1.81-5.07) and 3.77 (95%CI 2.25-6.31), respectively.

Conclusions: Commonly accepted thresholds of intraoperative hypotension, such as an SBP of 80 mmHg and an MAP of 60 mmHg, are valid alarming limits that are significantly and independently associated with 30-day mortality.

Keywords: anaesthesia, hypotension, integrated advanced information management systems, mortality, thresholds

Editorial Comment:

Prevention of intraoperative hypotension is a cornerstone in anaesthesia safety practice. Evidence for which threshold to use is sparse. This large registry-based analysis showed that several aspects of systolic blood pressure below 80 mmHg and MAP below 60 mmHg, including degree and duration of hypotension, were associated with clearly increased risk for 30-day mortality. Also, the more severe the hypotension exposure, the higher the relative risk for 30-day mortality.

Introduction

Each year, more than 312 million major surgical procedures are performed worldwide,[1] and the 30-day postoperative death rate is estimated to range between 3.5 and 6.9%.[2-5] The most common risk factors for postoperative mortality include the patient's condition and age, the type of surgery, and perioperative and early postoperative complications [6,7]. Intraoperative hypotension (IOH) has also been identified as a risk factor for major organs dysfunction,[8,9] early mortality [10,11] and other adverse postoperative outcomes[12-16]. However, many thresholds of blood pressure define IOH, including those for systolic and mean blood pressure, with absolute thresholds ranging between 100 mmHg and 50 mmHg and relative thresholds ranging between a 10% and 40% decrease from the baseline value.[17] Thresholds that have been identified as being associated with an increased risk of 30-day postoperative mortality are a mean arterial blood pressure (MAP) < 75 mmHg [18] and a decrease in the MAP from 80 mmHg to 50 mmHg [19], from 75 mmHg to 55 mmHg [14] or to 45 mmHg [20].

However, many anaesthetists still consider that critical values below which organ oxygen delivery and short-term survival may become compromised include: 1) systolic blood pressure (SBP) < 80 mmHg, 2) MAP < 60 mmHg , and 3) a 20% decrease from baseline blood pressure [17,21]. They often use one or several of these thresholds to guide blood pressure management during anaesthesia. However, whether these traditional thresholds can reliably be considered valid lower limits that should not be overstepped to minimise the risk of postoperative complications, particularly 30-day mortality, is unclear.

The purpose of this study was to assess the associations of common thresholds of IOH, including SBP < 80 mmHg, MAP < 60 mmHg and a 20% decrease from baseline blood pressure, with 30-day mortality following non-cardiac surgery and to determine which threshold had the highest level of association.

Methods

Study design and patient population

Following approval by the institutional ethics committee (University Hospital of Charleroi, Belgium committee, April 25, 2018), we performed a retrospective cohort study using data collected routinely as part of anaesthetic practice. We used the anaesthesia data warehouse, which includes information from three different sources: (1) the anaesthesia information management system (AIMS), which collects all intraoperative data; (2) the hospital management system (HMS), which records all patient-related administrative data; and (3) the hospital information system (HIS), which contains patient electronic health records.

We included all patients aged >18 years undergoing all types of surgery, except coronary artery bypass grafting (CABG) interventions, but including cardiac off-pump procedures. We excluded anaesthetic procedures with missing blood pressure recordings or containing errors (i.e., outliers or illogical values). We also discarded anaesthetic procedures that lasted less than or more than the 1st or 99th percentile, respectively, of the mean anaesthesia duration, which corresponded to durations within 16 and 477 min, respectively, and resulted in 13,069 procedures among 11,304 patients as only the last anaesthetic procedure was considered in the statistical analysis (Figure 1).

All individual surgical procedures were classified with their respective diagnostic codes (ICD 9) according to the classification framework suggested by Glance et al. The emergency status and the risk (high, intermediate and low) associated with each surgical procedure were defined[6]. For comorbidities, we used the ASA score rather than individual disease diagnostic codes since the ASA score alone has been demonstrated to have a good aptitude to reliably predict postoperative mortality[23]

For study purposes, we extracted information on patient demographic characteristics, current health status, American Society of Anesthesiologists physical status (ASA-PS) classification, the surgical procedure and in-hospital mortality. During each anaesthetic procedure, information such as pulse, blood pressure, and expired CO_2 automatically recorded by monitoring devices (IntelliVue Mx800/X2/PIICiX/IPC, Philips Healthcare, Andover) and the anaesthesia ventilator (Perseus A500™, Dräger, Lübeck, Germany) was added to the dataset. Using unique social security numbers, the dataset was linked to the National Death Registry.

Markers of intraoperative hypotension

Blood pressure was collected every 1 to 5 min noninvasively and continuously when an arterial catheter was available. When the blood pressure was measured both invasively and noninvasively, invasive measurements were used. IOH was defined as either SBP <80 mmHg, MAP < 60 mmHg or an SBP percent drop from baseline (ΔSBP) > 20%. All pressure values between the beginning and the end of anaesthesia were retained for analysis. For baseline values of (ΔSBP) > 20%, we used the last blood pressure value before admission to the operating theatre. We used simple linear interpolation between consecutive recordings to represent the blood pressure evolution over time (Figure 2).

For the analysis of IOH, we used six different customary markers to model IOH effects on adverse outcomes [22] 1) IOH1: the occurrence of ≥1 episode of hypotension below the defined threshold (1=yes/0=no); 2) IOH2: the proportion of blood pressure values recorded below the threshold (%); 3) IOH3: the area under the curve (AUC) below the defined threshold (min x mmHg); 4) IOH4: the proportion of the total AUC below the defined threshold (%); 5) IOH5: the duration of blood pressure values below the defined threshold (min); and 6) IOH6: the proportion of the total duration of anaesthesia with blood pressure values below the defined threshold (%). As an example of the calculation method used for the SBP curve displayed in Figure 2, the values of the different IOH markers are: IOH1 = 1; IOH2 = 31.3%; IOH3 = 119.6 min x mmHg; IOH4 = 6.4%; IOH5 = 21.2 min and IOH6 = 30.3%.

Study outcome

The outcome measured in this study was 30-day mortality. This outcome included postoperative deaths during the hospital stay and deaths following hospital discharge (limited to 30 days after surgery), the data of which were obtained from the Belgian National Death Registry and integrated into the AIMS.

Statistical methods

Descriptive results are summarized as the mean and standard deviation (SD) or the median and interquartile range (IQR) for quantitative variables and by frequency tables for categorical findings. Patient groups and hypotension markers according to mortality status at 30 days were compared with chi-square or Fisher exact tests for categorical findings and with Student t-tests for quantitative variables. The Wilcoxon rank sum test was used for skewed data. For each IOH marker, ROC curve analysis was performed to determine the predictive value (AUC) of 30-day mortality and identify an optimal cut-off using the Youden index. To adjust the risk of postoperative 30-day mortality for confounding factors, we used logistic regression modelling. Variables included in the model were age, sex, ASA-PS scores, emergency status and the risk related to surgery. The duration of surgery was already integrated in the definitions of hypotension markers and was not added to the multivariate analysis. The results were expressed as odds ratios (ORs) with 95% confidence intervals (95%CIs) and AUCs.

Statistical tests were considered significant at a P-value<0.05. All calculations were performed with SAS software (version 9.4) (SAS Institute, USA).

Results

Patient characteristics and differences according to 30-day mortality status

The characteristics of the 11,304 patients included in the study are described in Table 1. The mean age was 50.6 ± 18.4 years, and more female patients (60.1%) were included. Most patients (83.5%) had an ASA-PS score of 1 or 2. The average duration of procedures was 101 ± 67.5 min. The duration of anaesthesia was 20 min longer for deceased patients on average. The most frequent procedures were orthopaedic surgery (21.9%), visceral surgery (21.3%) and gynaecological surgery (20.7%). Mortality at 30 days was 0.76%, with 86 of 11,304 patients dying at 30 days. Deceased patients were older (74.5 ± 15.3 years), predominantly male (53%) and had higher ASA-PS scores (3 and ≥4). Orthopaedic (24.4%) surgery and visceral (20.9%) surgery were associated with the highest mortality at 30 days. Emergency and surgery-related risks were also notably different between the two groups.

Univariate relationships between the different intraoperative hypotension thresholds and 30-day mortality

Over the study period, 277,206 blood pressure measurements were performed among the 11,304 patients included. Blood pressure response curves were determined for each patient, and the six IOH markers were calculated according to the three different thresholds tested (SBP <80 mmHg; MAP < 60 mmHg; ΔSBP > 20%). The overall values of IOH markers and associations with mortality status are displayed in Table 2.

For SBP <80 mmHg, the occurrence of one or more SBP recordings below 80 mmHg during anaesthesia was associated with 30-day mortality (p=0.0011) and similarly with all other markers (P<0.0001). Patients in the deceased group had an average IOH duration (SBP < 80 mmHg) of 12.4 min ± 21.0. For the IOH2 marker, the proportion of SBP recordings < 80 mmHg yielded the highest AUC-ROC value of 0.625. The other markers had predictive value for 30-day mortality ranging between 0.608 and 0.616.

For MAP <60 mmHg, all IOH markers were significantly associated with 30-day mortality (P<0.01). The average duration of IOH with an MAP below 60 mmHg was 14.9 min ± 28.3. Furthermore, in these patients, on average, 16.3% of intraoperative recordings were below an MAP of 60 mmHg. The predictive values of 30-day mortality for the different markers were relatively similar, ranging between 0.600 and 0.614.

For a threshold ΔSBP > 20%, in contrast to SBP and MAP thresholds, no IOH markers were significantly associated with 30-day mortality. The AUC for the different markers ranged between 0.471 and 0.500.

Multivariate relationships between the different intraoperative hypotension thresholds and 30-day mortality

Following adjustment for other possible confounding causes of mortality, all markers of IOH for the thresholds SBP< 80 mmHg and MAP < 60 mmHg, except for IOH1 (the occurrence of ≥ 1 episode of hypotension), were significantly associated with 30-day mortality. The strongest association with 30-day postoperative mortality was found for an MAP < 60 mmHg and the marker IOH4 (% of the total AUC below the defined threshold), with an adjusted OR [95%CI] of 3.77 [2.25 – 6.31] and an AUC of 0.903. The marker IOH4 for the threshold SBP< 80 mmHg yielded a similar level of association with 30-day mortality with an adjusted OR [95%CI] of 3.02 [1.81 – 5.07] and an AUC of 0.905. As the threshold ΔSBP > 20% was not associated with an increased risk of 30-day mortality in the univariate analysis, no multivariate model was built. All data for multivariate analyses are provided in Table 3.

AUC values for the marker IOH 4 (% total area) for both thresholds are displayed in Figure 3A (SBP < 80 mmHg) and Figure 3B (MAP < 60 mmHg), with: 1) the baseline model alone with age, gender, ASA-PS score, and the risk related to surgery, 2) the IOH model alone for the SBP < 80 mmHg or MAP < 60 mmHg threshold, and 3) the full model with baseline covariates and IOH combined for the SBP < 80 mmHg or MAP < 60 mmHg threshold. The prediction of 30-day mortality with a threshold for hypotension at SBP < 80 mmHg when based solely on baseline covariates yielded a ROC-AUC of 0.891, but when IOH4 was added, the ROC-AUC increased up to 0.904 (Figure 3A). The prediction of 30-day mortality for IOH4 with a threshold for hypotension at MAP area < 60 mmHg was similar, with the ROC- AUC increasing from 0.891 to 0.903.

Discussion

In this retrospective cohort study, we assessed three common thresholds used in clinical practice to define IOH. We found that the association between IOH and 30-day mortality was statistically significant for both the MAP < 60 mmHg and SBP < 80 mmHg thresholds. The strongest association was identified for MAP < 60 mmHg when the percentage of the total AUC marker was used (IOH4), with an adjusted OR [95%CI] of 3.77 [2.25 – 6.31]. The association was weaker for SBP< 80 mmHg using the same marker IOH4, with an adjusted OR [95%CI] of 3.02 [1.81 – 5.07]. When IOH was defined as ΔSBP > 20%, no association with 30-day mortality was identified.

Our study findings are in line with those in previous work on this topic,[19] showing that an MAP below 60 mmHg for at least 10 min is significantly associated with 30-day mortality at an OR [95%CI] of 1.09 [1.07–1.11]. In our study, we found a stronger association despite adjustment with an OR [95%CI] of 3.69 [2.29 – 5.92]. This difference may be due to the longer duration of hypotension in our study (14.9 ± 28.3 min), leading to more severe long-term complications. In another study,[29] the authors identified a significant association between episodes of hypotension and 30-day mortality, but the thresholds were lower than those in our study (SBP < 70 mmHg, MAP < 49 mmHg), and the duration was shorter (5 min on average). Despite higher thresholds, we identified a significant association, again likely due to longer durations of episodes of major hypotension during surgery in our study of 12.4 ± 21 min for SBP<80 mmHg and 14.9 ± 28.3 min for MAP<60 mmHg. In another study [30] assessing risk factors for acute renal failure following liver transplantation, the authors found a significant association between 30-day mortality and episodes of hypotension with an SBP below 80 mmHg and an MAP below 60 mmHg. The association identified was important as in our study, with an OR [95%CI] of 5.92 [1.02–34.5], but hypotension occurred later in recovery or wards.

To explain the association identified between IOH and postoperative mortality, several mechanisms can be advocated. One mechanism is a decrease in the perfusion of individual organs following hypotension, particularly the brain, kidney or myocardium. Postoperative acute kidney injury, for example, is not uncommon following repeated intraoperative episodes of hypotension.[34] Renal hypoperfusion is often associated with systemic inflammation, sepsis, and coagulopathy, which can ultimately lead to death in some cases. [35] However, significant inter-individual variation exists in the lowest level that can be tolerated without end-organ injury [31]. Several end-organ autoregulation mechanisms can mitigate the consequences of hypotension up to a limit of MAP of 50 mmHg. [33] Another possible explanation for this association is that hypotension serves as a marker of other intraoperative adverse events such as drug overdose, haemorrhagic shock or anaphylactic reactions, which all cause hypotension but also other organ injuries, increasing the risk of death. IOH has therefore been suggested as an indicator of the quality of the patient management process during surgery [36,37].

An interesting finding of our study is that ΔSBP > 20% from the baseline value was not found to be significantly associated with 30-day mortality, possibly because the risks of end-organ injuries and mortality are likely higher for larger deviations of SBP such as ΔSBP > 40%, as found in other studies [11,38]. Another reason is that accurately defining “preoperative standard blood pressure” is challenging, particularly as several patients have higher blood pressure before surgery due to anxiety and stress.[39,40] As a result, a threshold of ΔSBP > 20% may apply to a number of patients who have normal intraoperative values due to a false high preoperative blood pressure.

This study has several limitations. This was a single centre study where unmeasured variables such as individual practices of the surgeon and anaesthetist may have influenced patient outcomes but could not be accounted for in the statistical analysis. However, the high ROC scores obtained (in general >0.90) suggest that this factor may have had a limited influence on the final results. Another limitation is that CABG surgeries with extracorporeal circulation were excluded from the study because arterial blood pressure management is not under the control of the anaesthetist during these procedures, and many other confounding factors may be associated with 30-day mortality. While this exclusion criterion reinforces the internal validity, it limits the generalizability of our study results.
Another limitation is that the data used in the study were extracted from our electronic anaesthesia records collected routinely as part of departmental clinical activity. As a result, not all variables that would have been necessary to build a robust predictive model could be included. Finally, the study is a retrospective cohort study aiming to assess the association between hypotension and 30-day mortality, but some variables were not initially included, which increases the risk of selection or measurement bias since particularly high or low blood pressures may have been incorrectly recorded in the system as false positive/negative signals for a number of patients.[41]

Despite these limitations, our multivariate models yielded a high ROC-AUC value of 0.90 and confirmed that hypotension at both the MAP< 60 mmHg and SBP < 80 mmHg thresholds was associated with 30-day mortality, confirming that episodes of IOH must be identified quickly as even only one episode can be associated with an increased risk of 30-day mortality, particularly in patients at a higher risk (ASA 3-4 or high-risk surgery).

While an extensive body of literature is available on the risks of end-organ injuries and mortality associated with exposure to IOH [42,43], good practice recommendations and systematic reviews do not to define a specific threshold for hypotension. They provide wide ranges of intraoperative blood pressure thresholds below which the risks of postoperative end-organ injuries and mortality increase. In addition, they are unclear regarding whether SBP or MAP is the best threshold for defining hypotension. [11] By extensively analysing the 3 most commonly used thresholds to define hypotension, our study may contribute to simplifying the discussion by validating these specific thresholds as alarming limits for blood pressure maintenance during anaesthesia.

This study also shows the value of modern AIMSs that allow the recording and storing of a major amount of information in real time, allowing early identification of an increased risk of poor outcomes. Further research should explore the implementation of alarm systems that integrate not only blood pressure thresholds but also the duration of hypotension to trigger specific alarm limits that provoke early attention from the anaesthetist.[44] Monitoring systems that provide advanced information on intraoperative blood pressure values such as AUCs for various episodes of hypotension according to specific thresholds could be developed and validated. [45] Innovative artificial intelligence with machine learning in anaesthesia could also be used to improve the accuracy of these thresholds[46,47] as predictors of postoperative mortality.[48]

Conclusion

We found that commonly accepted thresholds of hypotension within the anaesthesia community, such as an SBP of 80 mmHg and an MAP of 60 mmHg, regardless of concurrent risk factors such as comorbidities or age, are significantly associated with 30-day mortality. Within the limitations of an observational study design, these results suggest that these thresholds can be used separately or in combination during anaesthesia practice as alarming limits to guide safe blood pressure management during anaesthesia care.

Author contributions

PD wrote the first draft of the paper and was involved in the study concept and design and data acquisition; LS analysed the data; GH and MP supervised the finalization of the project; all authors read and approved the final version of the manuscript

Philippe Dony (PD), Laurence Seidel (LS), Magali Pirson (MP), Guy Haller (GH)

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Declaration of interest

Declaration of Interest: none declared

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Tables

Table 1. Patient baseline and postoperative characteristics by 30-day mortality status.

Variable	**Category**	**Overall N=11,304**	**Survival N=11,218**	**Death N=86**
Age (years)		50.6 ± 18.4	50.4 ± 18.3	74.5 ± 15.3
Gender	Female	6793 (60.1)	6753 (60.2)	40 (46.5)
	Male	4511 (39.9)	4465 (39.8)	46 (53.5)
Anaesthesia duration (min)		101 ± 67.5	101 ± 67.4	123 ± 79.5
ASA-PS	1	2935 (26.0)	2935 (26.2)	0 (0.0)
	2	6498 (57.5)	6480 (57.8)	18 (20.9)
	3	1797 (15.9)	1748 (15.6)	49 (57.0)
	≥ 4	74 (0.65)	55 (0.49)	19 (22.1)
Surgery	Orthopaedics	2470 (21.9)	2449 (21.8)	21 (24.4)
	Abdominal	2409 (21.3)	2391 (21.3)	18 (20.9)
	Gynaecology	2344 (20.7)	2342 (20.9)	2 (2.3)
	Urology	785 (6.9)	779 (6.9)	6 (7.0)
	Neurosurgery	744 (6.6)	734 (6.5)	10 (11.6)
	Maxillofacial	700 (6.2)	699 (6.2)	1 (1.2)
	Vascular	663 (5.9)	648 (5.8)	15 (17.4)
	ENT	362(3.1)	352 (3.1)	0 (0.0)
	Plastic	268 (2.4)	268 (2.4)	0 (0.0)
	Endoscopy	188 (1.7)	179 (1.6)	9 (10.5)
	Cardiac off-pump	137 (1.2)	136 (1.2)	1 (1.2)
	Ophthalmology	104 (0.92)	104 (0.93)	0 (0.0)
	Other	140 (1.2)	137 (1.2)	3 (3.5)
Emergency	**No**	**10855 (96.0)**	**10784 (96.1)**	**71 (82.6)**
	Yes	**449 (4.0)**	**434 (3.9)**	**15 (17.4)**
Surgical risk*	**Low**	**4099 (38.9)**	**4077 (39.0)**	**22 (28.6)**
	Moderate	**3854 (36.6)**	**3831 (36.7)**	**23 (29.9)**
	High	**2573 (24.4)**	**2541 (24.3)**	**32 (41.6)**

Data are presented as the mean ± SD or N (%).

All baseline characteristics differed significantly between 30-day survivors and nonsurvivors (P<0.01).

*Data missing for 778 interventions.

Table 2. Univariate associations between intraoperative hypotension defined as SBP < 80 mmHg, MAP < 60 mmHg, and ΔSBP > 20% of baseline and 30-day mortality.

Marker of IOH		**Survival** N=11,218	**Death** N=86	**P-value***	**AUC**
	SBP < 80 mmHg †				
IOH1	Occurrence ≥ 1 †	4058 (36.2%)	46 (53.5%)	0.0011	0.587
IOH2	SBP recordings † (%)	5.6 ± 11.3	15.0 ± 21.0	<0.0001	0.625
IOH3	Area of † (min x mmHg)	29.1 ± 93.2	118 ± 238	<0.0001	0.616
IOH4	Area of † (% total area)	2.3 ± 8.4	8.9 ± 17.7	<0.0001	0.612
IOH5	Duration of † (min)	4.8 ± 12.1	12.4 ± 21.0	<0.0001	0.608
IOH6	Duration of † (% total duration)	4.9 ± 11.2	13.3 ± 20.5	<0.0001	0.615
	MAP < 60 mmHg ††				
IOH1	Occurrence ≥ 1 ††	3913 (34.9)	43 (50.0)	0.0039	0.576
IOH2	MAP recordings †† (%)	6.0 ± 13.0	16.3 ± 24.1	<0.0001	0.614
IOH3	Area of †† (min x mmHg)	23.4 ± 90.8	127 ± 320	<0.0001	0.609
IOH4	Area of †† (% total area)	2.95 ± 10.7	10.4 ± 19.8	<0.0001	0.600
IOH5	Duration †† (min)	5.2 ± 15.0	14.9 ± 28.3	<0.0001	0.602
IOH6	Duration of †† (% total duration)	5.6 ± 13.4	15.0 ± 22.6	<0.0001	0.610
	ΔSBP > 20% †††				
IOH 1	Occurrence ≥ 1 ††† (yes)	7435 (66.3)	55 (64.0)	0.65	0.488
IOH2	ΔSBP recordings > ††† (%)	34.0 ± 33.8	33.8 ± 34.8	0.94	0.500
IOH3	Area of ††† (min x %)	463 ± 883	511 ± 890	0.62	0.492
IOH4	Area of ††† (% total area)	32.3 ± 37.2	34.3 ± 40.0	0.62	0.471

IOH5	Duration of ††† (min)	36.7 ± 52.6	38.4 ± 58.9	0.77	0.496
IOH6	Duration of ††† (% total duration)	34.9 ± 35.7	34.3 ± 37.0	0.88	0.500

Data are presented as the mean ± SD or N (%). P-values from the chi-square test, Fisher exact test, Student t-test, or Wilcoxon rank sum test as appropriate. AUC Area under the ROC curve (AUC).

Table 3. Multivariate relationship between intraoperative hypotension defined as SBP <80 mmHg and MAP<60 mmHg and 30-day mortality.

Marker of IOH	Cut-off according to Youden Index	Adjusted OR [95% CI]*	P-value	AUC
Baseline predictive model	NA	NA	NA	0.891
IOH1 - Occurrence ≥ 1 SBP < 80 mmHg	NA	1.42 [0.89-2.26]	0.14	0.890
IOH2 - SBP recordings < 80 mmHg (%)	11.1	2.33 [1.45-3.74]	0.0005	0.904
IOH3 - Area of SBP<80 mmHg (min x mmHg)	85.2	2.41 [1.44-4.05]	0.0009	0.903
IOH4 - Area of SBP<80 mmHg (% total area)	5.91	3.02 [1.81-5.07]	<0.0001	0.905
IOH5 - Duration of SBP<80 mmHg (min)	11.1	2.33 [1.41-3.84]	0.0010	0.902
IOH6 - Duration of SBP<80 mmHg (% total)	10.3	2.07 [1.27-3.39]	0.0038	0.902
IOH1 - Occurrence ≥ 1 MAP < 60 mmHg	NA	1.33 [0.83-2.13]	0.24	0.890
IOH2 - MAP recordings < 60 mmHg (%)	11.1	2.78 [1.71-4.50]	<0.0001	0.906
IOH3 - Area of MAP <60 mmHg (min x mmHg)	47.4	3.34 [2.02-5.52]	<0.0001	0.902
IOH4 - Area of MAP <60 mmHg (% total area)	6.04	3.77 [2.25-6.31]	<0.0001	0.903
IOH5 - Duration of MAP <60 mmHg (min)	7.22	2.26 [1.38-3.71]	0.0012	0.903
IOH6 - Duration of MAP <60 mmHg (% total)	13.1	3.05 [1.84-5.04]	<0.0001	0.905

*ORs with 95% CIs and P values for the different markers and thresholds adjusted for age, gender, ASA-PS score, emergency status and surgical risk.

ASA-PS score and type of surgery, AUC for markers tested following adjustment.

Figure legends

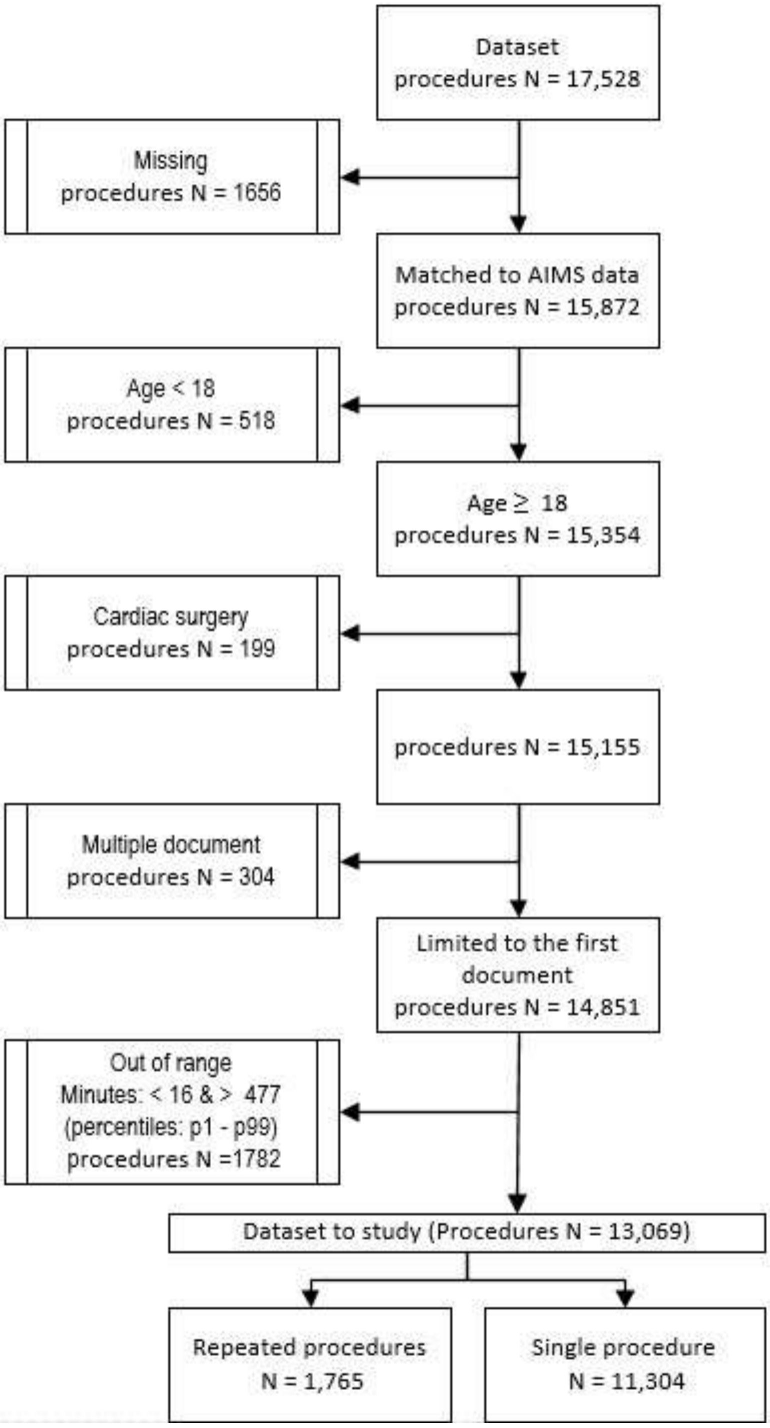
Figure 1. Flowchart of anaesthetic procedures extracted from the anaesthesia warehouse

Figure 2. Example of the SBP response curve obtained by linear interpolation between successive recordings and areas above and below the 80-mmHg threshold

Figure 3.

A. ROC curves (SP specificity, SE sensitivity) for the baseline model (AUC=0.891) for SBP area < 80 mmHg (%total area) (AUC=0.612) and baseline combined with SBP area < 80 mmHg (%total area) (AUC=0.904)

B. ROC curves (SP specificity, SE sensitivity) for the baseline model (AUC=0.891) for MAP area < 60 mmHg (%total area) (AUC=0.600) and baseline combined with MAP area < 60 mmHg (%total area) (AUC=0.903)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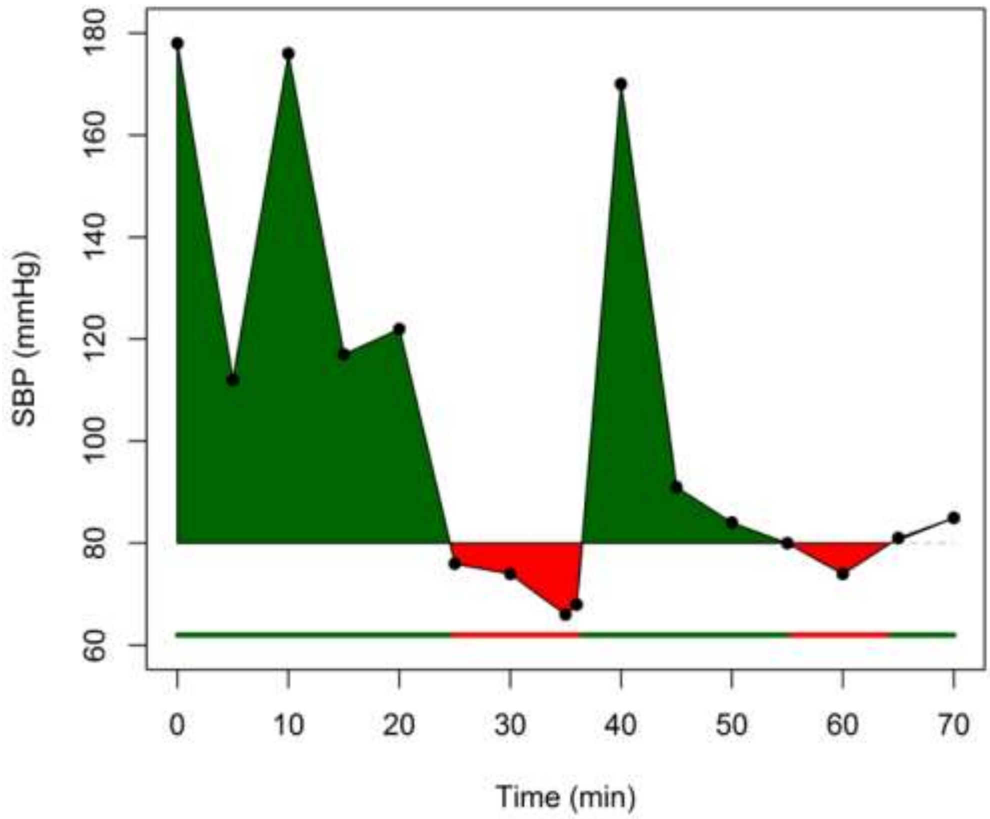
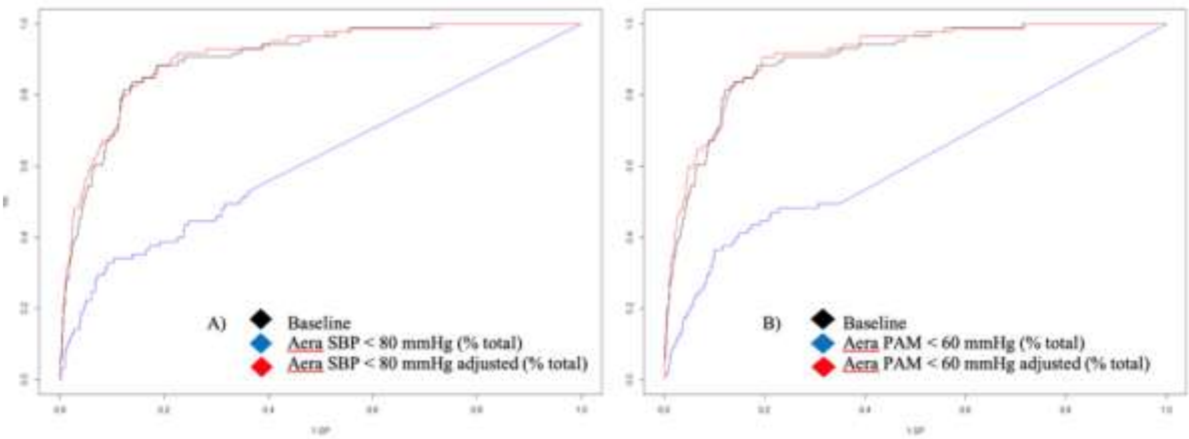
Missing
procedures N = 1656
Matched to AIMS data
procedures N = 15,872
Age < 18
procedures N = 518
Age ≥ 18
procedures N = 15,354
Cardiac surgery
procedures N = 199
procedures N = 15,155
Multiple document
procedures N = 304
Limited to the first
document
procedures N = 14,851
Out of range
Minutes: < 16 & > 477
(percentiles: p1 - p99)
procedures N =1782
Dataset to study (Procedures N = 13,069)
Repeated procedures
N = 1,765
Single procedure
N = 11,304


SBP (mmHg)
180
160
140
120
100
80
60
0
10
20
30
40
50
60
70
Time (min)


A)
Baseline
Aera SBP < 80 mmHg (% total)
Aera SBP < 80 mmHg adjusted (% total)
B)
Baseline
Aera PAM < 60 mmHg (% total)
Aera PAM < 60 mmHg adjusted (% total)