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ORIGINAL ARTICLE

The haemodynamic instability score

Development and internal validation of a new rating method of intra-operative haemodynamic instability

Edward Buitenwerf*, Mats F. Boekel*, Marieke I. van der Velde, Magiel F. Voogd, Michiel N. Kerstens, Götz J.K.G. Wietasch and Thomas W.L. Scheeren

BACKGROUND There is no consensus on how to define haemodynamic instability during general anaesthesia. Patients are often classified as stable or unstable based solely on blood pressure thresholds, disregarding the degree of instability. Vasoactive agents and volume therapy can directly influence classification but are usually not considered.

OBJECTIVE To develop and validate a scoring tool to quantify the overall degree of haemodynamic instability.

DESIGN Retrospective observational study.

SETTING University hospital.

PATIENTS The development cohort consisted of 50 patients undergoing high-risk surgery with a control group of 50 undergoing video-assisted thoracoscopic surgery. In the validation cohort, there were 153 high-risk surgery patients and 78 controls.

INTERVENTION None.

MAIN OUTCOME MEASURES The haemodynamic instability score (HI-score) was calculated as a weighted continuous measure ranging from 0 to 160 points, intended to reflect deviations of blood pressure and heart rate from predefined thresholds, and infusion rates of vasoactive agents and fluids. Thresholds were first determined in a development cohort and subsequently tested in a validation cohort. Results are presented as median [interquartile range].

RESULTS In the validation cohort the HI-score was 59 [37 to 96] in the high-risk surgery group compared with 44 [24 to 58] in the control group ($P < 0.001$). The score of the haemodynamic domain did not differ ($P = 0.69$) between groups: 10 [8 to 16] vs. 10 [8 to 16]. However, scores for volume therapy and vasoactive medication were significantly higher in the high-risk surgery group compared with the control group: 14 [6 to 30] vs. 6 [2 to 18], $P = 0.003$ and 35 [15 to 75] vs. 15 [5 to 35], $P < 0.001$, respectively.

CONCLUSION We developed the HI-score and demonstrated that it can appropriately quantify the degree of intra-operative haemodynamic instability. The HI-score provides a clinical tool which, after further external validation, may have future applications in both patient management and clinical research.

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Introduction

One of the key objectives of general anaesthesia is to maintain haemodynamic stability during surgery. This objective may be affected by many factors, such as pharmacodynamic effects of anaesthetic drugs on vascular tone and cardiac function, volume shifts or intra-operative hypothermia or hyperthermia. Haemodynamic stability is generally maintained with either volume therapy or vasoactive medication. The reported association of intra-operative hypotension and hypertension with postoperative morbidity and mortality suggests that haemodynamic stability is important for patient outcome.[1–5]

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In clinical reports haemodynamic instability has usually been described as a dichotomous variable, classifying a patient as either stable or unstable. There is, however, a lack of consensus on the definition of haemodynamic instability. In a meta-analysis of 46 studies there were 20 different dichotomous definitions of haemodynamic instability, predominantly based on absolute blood pressure (BP) thresholds.[6] Since haemodynamic instability reflects a variety of conditions it seems more reasonable to define haemodynamic instability as a continuous spectrum ranging from stable to extremely unstable. In addition, the interventions required to restore stability, for example the administration of vasoactive agents, can directly affect the classification of a patient as stable or unstable when using a dichotomous definition. Moreover, there is an association between the amount of vasoactive agents and fluids given and morbidity and mortality.[7,8] Therefore, both the haemodynamic variables and also the therapeutic interventions aimed at their stabilisation should be taken into account when assessing the overall degree of haemodynamic instability, particularly since the interventions might keep the variables within the normal range.

The aim of this study was to develop and validate a descriptive score to quantify the overall degree of haemodynamic instability during general anaesthesia. Such a score could be useful for clinical assessment of the degree of haemodynamic instability during a surgical procedure and identification of predictors for haemodynamic instability. Furthermore, a quantitative clinical score would also offer the possibility of a comparison between the efficacy of different interventions used to prevent and correct haemodynamic instability during general anaesthesia.

Methods

The current retrospective study had approval waived by the medical research and ethics committee of the University of Groningen, The Netherlands, according to the Dutch Medical Research Involving Human Subjects Act. It was conducted at the University Medical Center Groningen in the Netherlands between January 2014 until October 2017.

We developed and validated a scoring system describing the degree of intra-operative haemodynamic instability, called the Haemodynamic Instability-score (HI-score). Patients covering a broad haemodynamic spectrum from stable to very unstable were included to determine normalised threshold values for all the components of the HI-score and, subsequently, to validate the HI-score by testing its ability to quantify haemodynamic instability in a separate internal validation cohort. Intra-arterial continuous BP monitoring was required in all patients for accurate determination of the HI-score. We therefore chose to use patients undergoing video-assisted thoracoscopic surgery as the control group since this type of surgery was expected to reflect a low degree of haemodynamic instability while still requiring an arterial cannula. This was primarily intended for blood gas analysis, but was also used for continuous BP monitoring. To reflect a high degree of haemodynamic instability we chose patients undergoing high-risk abdominal surgery (HRS).[9] Cardiac output monitoring to facilitate haemodynamic optimisation was part of standard patient care for high-risk surgery using the FloTrac/EV1000 system (Edwards Lifesciences, Irvine, California, USA). We included patients aged at least 18 years and excluded those who had received inotropic or vasoactive medication that was not routinely used in our hospital.

Data were extracted from the hospital patient data management system (PDMS) which accurately records haemodynamic variables and the administration of medication and fluids. We retrieved the following variables during the interval between incision and the end of surgery: heart rate (HR), mean arterial pressure (MAP), systolic arterial pressure (SAP), intravenously administered vasoactive medication, volume therapy including blood transfusions, and the duration of the procedure. BP and HR recordings were collected at intervals of 15 s. The anaesthetic induction period was omitted since in many patients the arterial cannula was placed after induction preventing incorporation of this data into the score. Baseline characteristics of all patients were extracted from the electronic patient charts.

Haemodynamic instability score development

The HI-score was developed using data from 50 HRS and 50 control patients who were randomly selected from the entire cohort. The design of the HI-score was based on two main criteria. First, it should not only encompass haemodynamic variables like BP and HR, but also interventions with a direct effect on haemodynamic stability. Second, each component of the HI-score must be part of the routine measurements performed during general anaesthesia for surgical procedures with a certain risk of haemodynamic instability. Therefore, we chose the following three domains as part of the HI-score: haemodynamic variables (SAP, MAP, HR), intravenous volume therapy, and intravenous administration of vasoactive medication. Each domain was scored separately on a semiquantitative scale reflecting either the degree by which each variable deviated from the predefined threshold value or from the distribution of measurements in the development cohort as described below. Separate scores of the three domains were subsequently added up to form a total HI-score.

Threshold values for haemodynamic variables were defined as follows: SAP of 160 mmHg or less, MAP at least 60 mmHg and HR at least 50 bpm and 100 bpm or less. We chose these values as they represent clinically accepted thresholds for triggering measures to restore stability. The association between the deviation of BP from accepted norms, mortality and other adverse postoperative events encouraged us to assign points according

to the degree of deviation from these norms on an incremental basis.[1,4,10–12]

Thresholds for all other variables were determined using the entire development cohort. Either quartiles or tertiles were determined for each variable and these were subsequently applied as threshold values in the validation cohort. Incremental points were assigned to each quartile or tertile. The time of a variable being outside each of the haemodynamic targets was determined. In view of the large interindividual variation in duration of the surgical procedure this was assessed as the percentage of intra-operative time and scored incrementally. Volume therapy was assessed as mean infusion rate per kilogram of body weight ($ml\,kg^{-1}\,h^{-1}$) of the cumulative amount of intra-operatively administered fluids, to correct for procedure duration and body weight. Mean infusion rates of $84\,ml\,h^{-1}$ or less (our institutional standard baseline infusion rate) was considered normal. The mean infusion rate per kilogram of body weight of each administered vasoactive and inotropic drug was calculated to correct the cumulative dose for procedure duration and body weight. Included drugs were norepinephrine, phenylephrine and dobutamine. Since the cardiovascular potency of these drugs varies considerably, norepinephrine was assigned the most points followed by phenylephrine and dobutamine. Incremental scores per drug were assigned according to infusion rates.[7,13]

The maximum score assigned to each of the three main domains was weighted at 40-30-90 points for haemodynamic variables, volume therapy and vasoactive medication, respectively. Weights were assigned based on consensus between the investigators. In view of the importance of interventions to maintain haemodynamic stability, volume therapy and administration of vasoactive medication combined were assigned a triple weight compared with haemodynamic variables (i.e. 120 vs. 40 points). Vasoactive medication use was assigned a triple weight relative to volume therapy because of its much stronger effect in increasing BP.[14] Thus the range of the total HI-score varied from 0 to 160 points. A complete overview of all components including threshold values for corresponding scores is provided in Table 1.

Table 1 Threshold values for all haemodynamic instability score components

Domain	HI-score component	Value	Score
Haemodynamic variables	Maximum SAP (mmHg)	<160	0
		160 to 179	1
		180 to 199	3
		≥200	7
	Time SAP > 160 mmHg (%)	0	0
		0.1 to 1.0	1
		1.1 to 6.6	3
		≥6.7	7
	Minimum MAP (mmHg)	≥60	0
		50 to 59	1
		40 to 49	3
		<40	7
	Time MAP < 60 mmHg (%)	0	0
		0.1 to 1.1	1
		1.2 to 4.1	3
		≥4.2	7
	Maximum HR (bpm)	<100	0
		100 to 119	1
		≥120	3
	Time HR > 100 bpm (%)	0	0
		0.1 to 1.0	1
		>1.0	3
	Minimum HR (bpm)	≥50	0
		40 to 49	1
		<40	3
	Time HR < 50 bpm (%)	0	0
		0.1 to 1.7	1
		>1.7	3
Volume therapy	Volume therapy ($ml\,kg^{-1}\,h^{-1}$)	0 to $84\,ml\,h^{-1}$	0
		≤6.3	2
		6.4 to 9.7	6
		9.8 to 14.3	14
		>14.3	30
Cardiovascular medication	Norepinephrine ($\mu g\,kg^{-1}\,h^{-1}$)	0	0
		>0 to 1.48	5
		1.49 to 2.47	15
		2.48 to 4.14	35
		>4.14	75
	Phenylephrine ($\mu g\,kg^{-1}\,h^{-1}$)	0	0
		>0.0 to 2.06	4
		>2.06	12
	Dobutamine ($mg\,kg^{-1}\,h^{-1}$)	0	0
		>0 to 0.22	1
		>0.22	3
	Total		0 to 160

HI-score, haemodynamic instability score; HR, heart rate; MAP, mean arterial pressure; SAP, systolic arterial pressure.

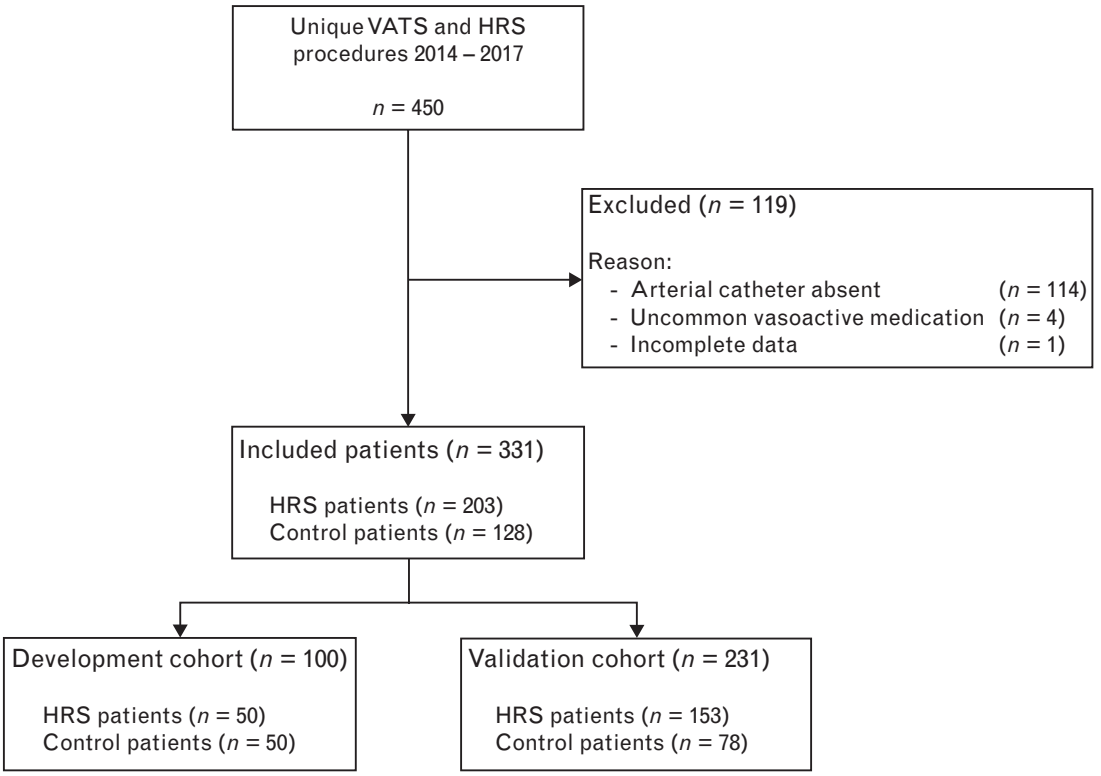
Statistical analysis

A descriptive analysis was performed for all variables. Continuous variables are reported as mean (± SD) or median [interquartile range] where appropriate and categorical data as counts and proportions. Missing data were not replaced. Means, medians and proportions were analysed using Student *t*, Mann–Whitney *U* and the χ^2 or Fisher exact tests as appropriate. Relationships between the HI-score and continuous or categorical variables were determined using Spearman correlation coefficients (r_s) or the Kruskal–Wallis test, as appropriate. Multivariable linear regression analyses were carried out to assess the relationship of the HI-score with group allocation (HRS or control) taking account of age, sex, BMI and American Society of Anesthesiologists (ASA) physical status. Two-sided *P* values less than 0.05 were considered statistically significant. Statistical Package for Social Sciences (SPSS) 23.0 for Windows (IBM SPSS Statistics, IBM Corporation, Armonk, New York, USA) was used for the statistical analysis. We adhered to the transparent reporting of a multivariable prediction model for individual prognosis or diagnosis (TRIPOD) statement.[15]

Results

In total, 450 eligible patients were identified of whom 114 were excluded due to lack of intra-arterial BP

Fig. 1



Flowchart of study subjects.

measurement, four because of the administration of uncommon vasoactive or inotropic drugs and one due to incomplete data (Fig. 1), leaving 203 HRS patients and 128 controls for analysis. The development cohort was randomly selected and consisted of 50 controls and 50 HRS patients. The validation cohort consisted of the 231 remaining patients (153 HRS patients and 78 controls).

Table 2 shows the characteristics of the development cohort and the validation cohort, and also the separate HRS and control groups of both cohorts. All patients received total intravenous anaesthesia. Patients in the validation-control group were younger compared with the validation-HRS group [62 (± 11) vs. 66 (± 12) years, $P = 0.027$]. In the validation-control group, the ASA physical status class was significantly higher and the procedure time was shorter compared with the validation-HRS group, 138 [87 to 329] vs. 287 [175 to 440] min ($P < 0.001$). Age, sex, BMI, ASA physical status and procedure duration were similar in the development and validation cohorts (data not shown). All components off the HI-score are presented in Table 3.

The total HI-score was 45 [26 to 68] in the development cohort. The haemodynamic, volume therapy and vasoactive medication components were 14 [8 to 18], 10 [3 to 26], 15 [5 to 35], respectively, in the development cohort.

The total HI-score in the validation cohort was higher in the HRS group compared with the control group, 59 [37 to 96] vs. 44 [24 to 58], ($P < 0.001$, Fig. 2). The haemodynamic component of the HI-score was not significantly different between the control and HRS group of the validation cohort, 10 [8 to 16] vs. 10 [8 to 16], ($P = 0.69$, Fig. 2). However, the HI-score components for volume therapy and vasoactive medication in the validation cohort were both higher in the HRS group compared with the control group, 14 [6 to 30] vs. 6 [2 to 18] ($P = 0.003$) and 35 [15 to 75] vs. 15 [5 to 35] ($P < 0.001$, Fig. 2).

In the total validation cohort, the HI-score was negatively associated with BMI (r_s −0.27, $P < 0.001$) but not with age or sex (r_s 0.02, $P = 0.75$ and r_s −0.05, $P = 0.49$, respectively). The HI-score was significantly higher for ASA physical status 4 at 79 [56 to 123] compared with 63 [48 to 99], 54 [35 to 91], 49 [29 to 79] and for ASA physical status 1, 2 and 3 respectively, ($P = 0.03$). Multivariable linear regression analysis was subsequently carried out to determine the independent relationship of the HI-score with group allocation (HRS or control) taking into account age, sex, BMI and ASA physical status. HI-score was independently and positively related to HRS ($\beta = 0.30$, 95% CI: 0.18 to 0.46, $P < 0.001$) and ASA

Table 2 Patient characteristics

Variables	Total, *n*=100	Development Control, *n*=50	HRS, *n*=50	Total, *n*=231	Validation Control, *n*=78	HRS, *n*=153	Control vs. HRS *P* value
Age (year)	62 (± 12)	58 (± 11)	66 (± 11)	65 (± 11)	62 (± 11)	66 (± 12)	0.027
Male sex	62 (62)	32 (64)	30 (60)	131 (57)	42 (54)	89 (58)	0.58
BMI (kg m^{-2})	26.9 (± 5.3)	27.8 (± 5.9)	26.0 (± 4.5)	26.6 (± 4.6)	27.2 (± 4.3)	26.3 (± 4.7)	0.18
ASA							0.007
Class I	4 (4)	1 (2)	3 (6)	12 (5)	2 (3)	10 (7)	
Class II	41 (41)	10 (20)	31 (62)	90 (39)	18 (23)	72 (47)	
Class III	43 (43)	27 (54)	16 (32)	108 (47)	40 (51)	68 (44)	
Class IV	3 (3)	3 (6)	0 (0)	8 (3)	5 (6)	3 (2)	
Unknown	9 (9)	9 (18)	0 (0)	13 (6)	13 (17)	0 (0)	
Procedure type							–
VATS	50 (50)	50 (100)		78 (34)	78 (100)		
HIPEC	6 (6)		6 (12)	15 (6)		15 (10)	
PPPD	3 (3)		3 (6)	22 (10)		22 (14)	
APR	18 (18)		18 (36)	30 (13)		30 (20)	
Open AAA repair	2 (2)		2 (4)	10 (4)		10 (7)	
Oesophageal resection	3 (3)		3 (6)	18 (8)		18 (12)	
Femoral popliteal repair	11 (3)		11 (22)	39 (17)		39 (25)	
Total hip arthroplasty	7 (7)		7 (14)	19 (8)		19 (12)	
Procedure duration (min)	214 [111 to 368]	124 [78 to 311]	303 [204 to 449]	239 [133 to 379]	138 [87 to 329]	287 [175 to 440]	<0.001

Data presented as mean (± SD), median [IQR] or number (percentage). AAA, abdominal aortic aneurysm; APR, abdominal perineal resection; ASA, American Society of Anesthesiologists physical status score; HIPEC, hyperthermic intraperitoneal chemotherapy; HRS, high-risk abdominal surgery; PPPD, pylorus-preserving pancreaticoduodenectomy; VATS, video-assisted thoracoscopic surgery.

physical status class 4 ($\beta = 0.17$ 95% CI: 0.01 to 0.33, $P = 0.046$), while a negative relationship was found with BMI ($\beta = -0.25$, 95% CI: −0.38 to −0.12, $P < 0.001$).

Discussion

We present the development and validation of a novel comprehensive scoring method that rates the degree of intra-operative haemodynamic instability. The HI-score was significantly higher in a high-risk surgery group compared with a low-risk. It has proved a useful descriptive tool for quantifying the degree of haemodynamic instability associated with surgical procedures of different risk categories independent from baseline differences between these two groups.

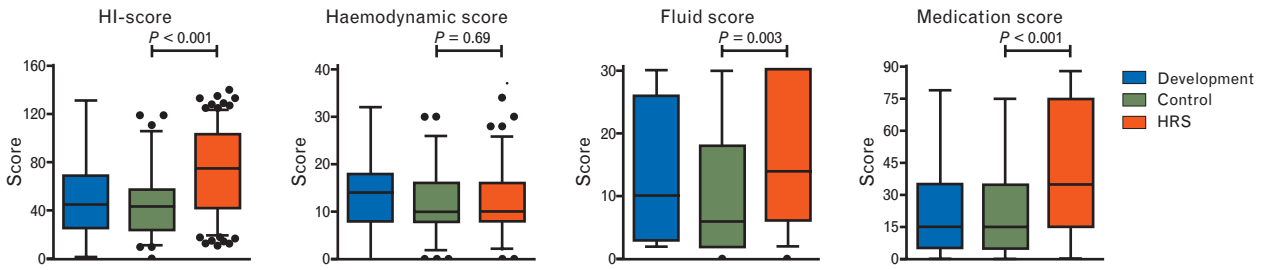
There is no consensus on how to define haemodynamic instability and the lack of a generally accepted reference standard for comparison hampers validation of any scoring system intended to quantify haemodynamic instability. Our approach was to determine normalised threshold values for all components of the HI-score in a development cohort of surgical patients that could be expected to represent a wide range of the haemodynamic instability

Table 3 Haemodynamic instability score components

Variables	Development, *n*=100	Validation Total, *n*=231	Control, *n*=78	HRS, *n*=153	Control vs. HRS *P* value
Haemodynamics					
Maximum SAP (mmHg)	162 [145 to 182]	160 [146 to 177]	151 [141 to 165]	165 [149 to 182]	<0.001
Duration SAP > 160 mmHg (%)	0.1 [0.0 to 2.1]	0.0 [0.0 to 1.0]	0.0 [0.0 to 0.1]	0.2 [0.0 to 2.1]	<0.001
Minimum MAP (mmHg)	53 [44 to 58]	53 [47 to 58]	53 [48 to 60]	53 [46 to 58]	0.47
Duration MAP < 60 mmHg (%)	1.4 [0.2 to 4.8]	1.7 [0.1 to 5.2]	2.3 [0.0 to 5.7]	1.5 [0.3 to 4.6]	0.71
Maximum HR (bpm)	103 [87 to 121]	103 [89 to 120]	114 [99 to 136]	99 [88 to 113]	<0.001
Duration HR > 100 bpm (%)	0.1 [0.0 to 1.1]	0.1 [0.0 to 2.1]	0.3 [0.0 to 9.1]	0.0 [0.0 to 1.1]	<0.001
Minimum HR (bpm)	47 [40 to 53]	49 [41 to 59]	51 [38 to 63]	48 [42 to 59]	0.88
Duration HR < 50 bpm (%)	0.2 [0.0 to 3.6]	0.0 [0.0 to 3.5]	0.0 [0.0 to 1.9]	0.2 [0.0 to 4.9]	0.10
Volume therapy					
Infusion rate (ml h^{-1})	804 [573 to 1076]	846 [631 to 1056]	676 [508 to 1003]	881 [683 to 1078]	0.001
Infusion rate (ml kg^{-1} h^{-1})	9.7 [6.25 to 14.26]	10.6 [7.8 to 14.6]	8.7 [5.9 to 14.5]	11.3 [9.1 to 14.7]	0.001
Medication					
Norepinephrine	77 (77)	199 (86)	54 (69)	145 (95)	<0.001
Norepinephrine (μg kg^{-1} h^{-1})	2.47 [1.48 to 4.14]	2.86 [1.61 to 5.18]	2.99 [1.46 to 3.99]	2.85 [1.70 to 5.72]	0.12
Phenylephrine	7 (7)	21 (9)	9 (12)	12 (8)	0.47
Phenylephrine (μg kg^{-1} h^{-1})	2.06 [0.36 to 11.70]	9.31 [3.23 to 14.99]	12.74 [4.79 to 22.13]	5.64 [2.82 to 13.06]	0.19
Dobutamine	5 (5)	9 (4)	0 (0)	9 (6)	0.030
Dobutamine (mg kg^{-1} h^{-1})	0.22 [0.17 to 0.50]	0.11 [0.04 to 0.17]	–	0.11 [0.04 to 0.17]	–

Data are presented as median [IQR] or number (percentage). HR, heart rate; HRS, high-risk abdominal surgery; MAP, mean arterial pressure; SAP, systolic arterial pressure.

Fig. 2



Boxplots demonstrating the haemodynamic instability score and its separate domains in the development cohort and the control and high-risk abdominal surgery groups of the validation cohort. Boxes represent median and IQR, whiskers represent 5th and 95th percentile and dots represent outliers.

spectrum. Previously only a few scoring systems have been developed to assess overall haemodynamic instability,[16,17] but a common flaw of these systems is that they only contain haemodynamic variables, without adjustment for stabilising therapy. Since deviation of haemodynamic variables together with the amount of administered vasoactive agents are associated with morbidity and mortality it seems logical to take these factors into account when determining the degree of haemodynamic instability.[1–5,7,8] A disregard for stabilising therapies is a potential confounding factor. Support for this can be found in the failure to see a difference in the haemodynamic component of the HI-score between the two groups despite an evident difference in corrective measures. The vasoactive medication score and volume therapy score were significantly higher in the HRS group. Of note, studies that have previously demonstrated an association between haemodynamic instability and mortality were also not corrected for stabilising measures, which further underscores the potential importance of the HI-score.[4]

The HI-score might be particularly valuable in a research setting where there is a need to determine haemodynamic instability as a continuous single variable outcome. The HI-score can be easily applied since the different components of the score are usually available. In addition to comparing different types of surgery, the HI-score can also be applied to compare different interventions during the same type of surgery, to identify predictors of haemodynamic instability or to quantify the effect of interventions that aim to prevent or correct a certain degree of haemodynamic instability. Furthermore, its application might be extended to intensive care unit (ICU) cohorts where similar methodological problems with respect to the assessment of haemodynamic instability occur. A clinical application of the HI-score might be to assist postoperative triage of patients either to the ICU or regular postoperative care unit, or to identify those patients who are at increased risk for postoperative complications. However, prospective confirmation studies are warranted for proper external validation and to determine the relationship of the HI-score with clinical endpoints such as morbidity and mortality.

Major strengths of the current study are the well defined cohorts, derivation of high-quality data from the PDMS and relatively easy application of the HI-score in future research. Because the type of vasoactive medication administered to a target group might differ from our development cohort, for future studies it might be necessary to redistribute the 90 points for vasoactive medication while taking different cardiovascular potencies into account.

The retrospective design of the study can be considered a limitation of our study. Haemodynamic targets during the procedure were not standardised and interventions by using either volume therapy or vasoactive medication were at the discretion of the anaesthesiologist and reflect common practice. The HI-score is, by design, able to adjust for differences in management as it incorporates many relevant determinants into a single score. The use of threshold values for haemodynamic variables can also be considered a weakness of the current study. In our opinion, however, the chosen threshold values reflect common clinical practice. After correction for differences in possible patient related risk factors, we found that HRS-surgery was still independently associated with a higher HI-score. Incorporation of the anaesthetic induction period into the HI-score may also be of relevance for future studies.[18]

In conclusion, we developed and internally validated a novel and comprehensive scoring system to grade intraoperative haemodynamic instability by combining haemodynamic variables and treatment measure that aim to improve haemodynamic stability. We demonstrated that the HI-score was significantly different between surgical procedures associated with low or high degrees of haemodynamic instability. The HI-score provides a clinical tool that may have applications in both patient management and clinical research.

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Conflicts of interest: none.

Presentation: none.

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