DOI: 10.1111/1471-0528.13206
www.bjog.org

Shock index: an effective predictor of outcome in postpartum haemorrhage?

HL Nathan,[a] A El Ayadi,[b] NL Hezelgrave,[a] P Seed,[a] E Butrick,[b] S Miller,[b] A Briley,[a] S Bewley,[a] AH Shennan[a]

[a] Women's Health Academic Centre, King's College London, London, UK [b] Safe Motherhood Programs, University of California, San Francisco, CA, USA

Correspondence: Prof AH Shennan, Women's Health Academic Centre, King's College London, 10th floor, North Wing, St Thomas' Hospital, London SE1 7EH, UK. Email andrew.shennan@kcl.ac.uk

Accepted 16 October 2014.

Objectives To compare the predictive value of the shock index (SI) with conventional vital signs in postpartum haemorrhage (PPH), and to establish 'alert' thresholds for use in low-resource settings.

Design Retrospective cohort study.

Setting UK tertiary centre.

Population Women with PPH ≥1500 ml (n = 233).

Methods Systolic blood pressure (BP), diastolic BP, mean arterial pressure, pulse pressure, heart rate (HR) and SI (HR/systolic BP) were measured within the first hour following PPH. Values measured at the time of highest SI were selected for analysis. The area under the receiver operating characteristic curve (AUROC) for each parameter, used to predict admission to an intensive care unit and other adverse outcomes, was calculated. Sensitivity, specificity and negative/positive predictive values determined thresholds of the best predictor.

Main outcome measures Intensive care unit (ICU) admission, blood transfusion ≥4 iu, haemoglobin level <7 g/dl, and invasive surgical procedures.

Results Shock index has the highest AUROC to predict ICU admissions (0.75 for SI [95% CI 0.63–0.87] compared with 0.64 [95% CI 0.44–0.83] for systolic BP). SI compared favourably for other outcomes: SI ≥0.9 had 100% sensitivity (95% CI 73.5–100) and 43.4% specificity (95% CI 36.8–50.3), and SI ≥1.7 had 25.0% sensitivity (95% CI 5.5–57.2) and 97.7% specificity (CI 94.8–99.3), for predicting ICU admission.

Conclusions Shock index compared favourably with conventional vital signs in predicting ICU admission and other outcomes in PPH, even after adjusting for confounding; SI <0.9 provides reassurance, whereas SI ≥1.7 indicates a need for urgent attention. In low-resource settings this simple parameter could improve outcomes. It was not possible to adjust for resuscitative measures administered following vital sign measurement that may have influenced the outcome.

Keywords Hypovolaemic shock, postpartum haemorrhage, shock index.

Please cite this paper as: Nathan HL, El Ayadi A, Hezelgrave NL, Seed P, Butrick E, Miller S, Briley A, Bewley S, Shennan AH. Shock index: an effective predictor of outcome in postpartum haemorrhage? BJOG 2015;122:268–275.

Introduction

Globally, postpartum haemorrhage (PPH) remains the leading cause of maternal deaths,[1] 99% of which occur in low- and middle-income countries (LMICs).[2] Most deaths and severe morbidities occur because of delayed and/or substandard care in the diagnosis and management of hypovolaemic shock.[3–7] In LMICs, where women often deliver outside facilities, with unskilled or no attendants, mortality rates are higher and delays are longer because of transportation and referral difficulties. Once a woman reaches a tertiary facility, deaths occur as a result of poor recognition, and inadequate equipment and training. The keys to reducing haemorrhage-related adverse maternal outcomes are early recognition, prompt intervention, and timely referral.

A critical component of the clinical assessment of PPH, defined as blood loss ≥500 ml,[8] is an accurate estimation of blood loss. Visual estimation frequently underestimates blood loss;[9] therefore, vital signs of systolic blood pressure (SBP) and heart rate (HR) are used to determine haemodynamic stability. Thresholds of these signs are integrated into obstetric early-warning systems (EWS) (e.g. the 'Obstetric Early Warning Chart' used in the UK);[10] however, physiological compensatory mechanisms of pregnancy and postpartum may mask decompensation until late in

hypovolaemic shock, as has been reported in ruptured ectopic pregnancies.[11,12] In out-of-facility deliveries shock is commonly not identified until maternal loss of consciousness, too late for referral.

The shock index (SI), HR/SBP, has been proposed as an earlier marker of compromise than conventional vital signs in non-pregnant populations.[13] It has been studied in non-specific shock,[14–16] trauma,[17–23] and sepsis.[14,24] The normal SI range is 0.5–0.7 for healthy adults,[14,25] and an SI of >0.9 has been associated with increased mortality.[16,21,22] In an obstetric population SI has also been proposed as a reliable marker of compromise.[26] There are currently three studies assessing the value of SI in ruptured ectopic pregnancy.[27–30] In neither of two studies on PPH were predictive thresholds for clinical practice assessed.[31,32]

We have designed, validated, and are evaluating a hand-held semi-automated BP device (Microlife 3AS1-2) for use in pregnancy, specifically in LMIC settings,[33] that incorporates a traffic-light warning system for both hypertension and shock. This study aimed to determine the vital sign that best predicts adverse maternal outcomes following PPH, and to develop two threshold points: 'amber', indicating the need for referral to a higher level care facility; and 'red', to identify patients who require urgent action, regardless of the setting.

Methods

Data from a large prospective observational study of women with PPH over a 1-year period (women giving birth between 1 August 2008 and 31 July 2009) at a UK tertiary referral centre were used to identify all women with blood loss of 1500 ml or more,[34] as approved by the South East multicentre research ethics committee. All BP and HR values recorded within the first hour following recognition of PPH were included in the analysis (measured using the BP devices available on the wards). SI, mean arterial pressure (MAP), and pulse pressure (PP) were calculated from these values. For each woman, values measured at the time of the highest SI were selected for analysis.

Adverse clinical outcomes evaluated included admission to an intensive care unit (ICU), blood transfusion ≥4 iu, haemoglobin level <7 g/dl (lowest prior to discharge), and invasive surgical interventions to staunch bleeding (haemostatic uterine suturing, uterine tear repair, uterine artery embolization, internal iliac artery clamping, bilateral ligation of internal iliac arteries, aortic artery clamping, hysterectomy, and laparotomy).

Data analysis was conducted using STATA 11.2 (StataCorp, College Station, Texas, USA). For SI, HR, SBP, diastolic BP (DBP), MAP, and PP, the area under the receiver operating characteristic curve (AUROC) values and 95% confidence intervals were calculated and compared for each outcome.[35] The best vital signs parameter was selected for further analysis, according to the AUROC values achieved across the outcomes.

Four potential thresholds (two lower thresholds and two higher thresholds) of the best vital sign parameter were selected for further analysis to determine their predictive values. Owing to the nature of the data set, different methods were used to determine the lower and upper thresholds to test (as the data set comprises only high-risk women with blood loss ≥ 1500 ml, the majority had at least one adverse outcome). The two lower thresholds were selected based on recommendations of both thresholds in previous studies and the rates of false-negative results for ICU admission and other outcomes below each threshold.[14,25,31,32] The upper two thresholds were derived from the centiles of 95%, 98%, and 99% specificity of each of the four outcomes.

Sensitivities, specificities, and positive and negative predictive values were calculated for each of the four thresholds. Appropriate lower and higher thresholds were selected based on their performance in predicting ICU admission: the lower threshold selected was based on a maintained high sensitivity with a clinically practical specificity; the higher threshold selected was based on a high positive predictive value without compromising the negative predictive value. Differences were considered statistically significant at $P < 0.05$.

For each adverse outcome, logistic regression methods were used to determine which potential confounding factors were related significantly to outcome. The pre-specified potential confounding factors included age at delivery, body mass index (BMI), height, weight, parity, hypertension in pregnancy, anaemia, pyrexia in labour, mode of delivery, spinal and epidural use, and syntometrine for the management of the third stage. The effect of adjusting for these confounding factors on the relationship between SI thresholds was then assessed.

Resuscitative measures (e.g. intravenous rehydration or administration of uterotonics) were typically administered after the predictive variable (the highest SI within the first hour following recognition of PPH) had been measured, in reaction to the clinical assessment, which may have included a change in vital sigs (pulse or BP). These measures were therefore considered as an intermediate step in the causal pathway, directly influencing outcome, and therefore were not treated as confounding factors in the statistical analysis of the relationship between SI and obstetric outcome.

Clinicians were blinded to the SI value, and therefore we can be sure that patients were treated on the basis of conventional vital signs and clinical assessment only. Given that all women were treated in an obstetric tertiary unit, we have assumed that all received resuscitation; we were thus unable to analyse the prediction of outcome in the absence of resuscitative measures.

Results

A cohort of 243 women were identified with PPH ≥1500 ml, ten of whom were excluded for incomplete documentation of vital signs, resulting in a total analytic sample of 233 women (Figure 1). Patient characteristics are shown in Table 1. The median (interquartile range) time from PPH recognition to time of highest SI was 15 minutes (4–32 minutes). The median values (interquartile ranges) for each vital sign parameter are SI 0.95 (0.80–1.15), HR 102 (89–118 bpm), SBP 105 (95–120 mmHg), DBP 63 (50–75 mmHg), MAP 77 (66–90 mmHg), and PP 44 (35–50 mmHg).

Table 2 shows the performance of each vital sign parameter in predicting each of the four adverse clinical outcomes. For ICU admission, SI had the highest AUROC value at 0.75 (0.63–0.76), which was significantly higher than for SBP ($P = 0.023$), DBP ($P = 0.010$), MAP ($P = 0.022$), and PP ($P = 0.001$), yet not significantly higher than HR ($P = 0.812$). For blood transfusion ≥ 4 iu, SI had the highest AUROC of 0.67, which was significantly higher than for HR ($P = 0.032$), yet not significantly higher than SBP ($P = 0.809$), DBP ($P = 0.292$), MAP ($P = 0.402$), and PP ($P = 0.094$). For haemoglobin levels of < 7 g/dl, all predictors had similarly poor AUROC values. HR performed significantly worse than SI ($P = 0.008$), and performed worse than chance. For invasive surgical intervention, SI and HR had the highest AUROCs, but no predictor performed better than chance. SI was selected as the most consistently useful of all the predictors, as it performed well across most outcomes. Appropriate lower and higher thresholds of SI were then determined, according to predictive performance.

To establish a potential lower threshold we selected SI ≥0.7, as no woman in our data set with an SI <0.7 (e.g. 80 HR/110 SBP) was admitted to ICU and an SI of 0.7 has been identified in the literature as the upper limit of normal SI in a non-pregnant population.[14,25] As an alternative lower threshold we selected SI ≥0.9 (e.g. 101 HR/100 SBP), an SI value below which no woman in our data set was admitted to ICU, as the suggested upper limit of normal immediately postpartum.[32] Of the 233 women included in the study, there were 202 (86.7%) with SI ≥0.7 and 137 (58.8%) with SI ≥0.9. The utility of SI ≥0.7 and SI ≥0.9 as early predictors of adverse outcome are shown in Table 3.

To establish potential higher thresholds of SI, we identified values that would exclude most women without admission to ICU using the 95%, 98%, and 99% centiles to ensure high specificity (Table 4). Cut-off points of SI ≥1.5 (e.g. 112 HR/74 SBP) and SI ≥1.7 (e.g. 116 HR/78 SBP) were selected, and the performance of these as predictors of the selected outcomes is shown in Table 5. Of the 233 women included, there were 16 (6.9%) with SI ≥1.5 and eight (3.4%) with SI ≥1.7.

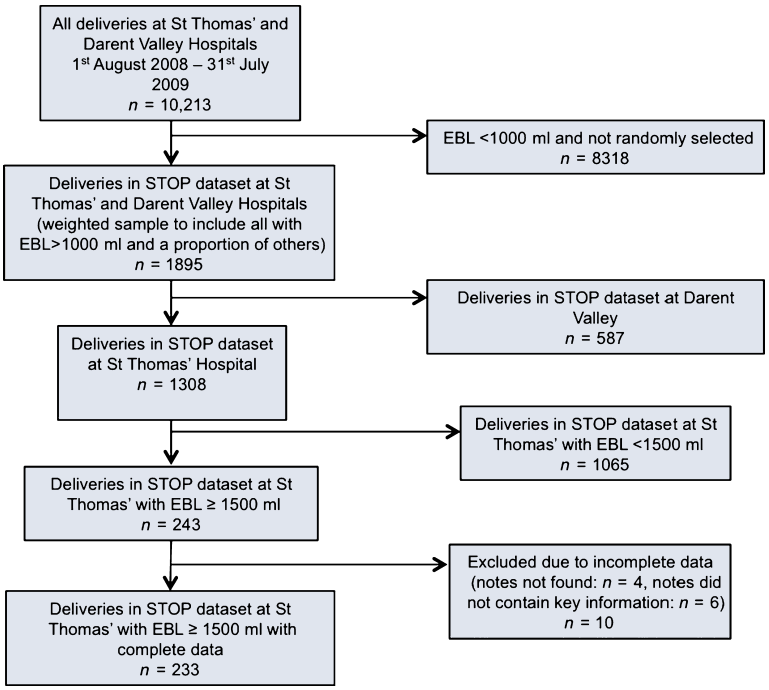

Figure 1. Flow diagram of the Surveillance and treatment of PPH data set and women included in the current analysis (EBL, estimated blood loss).

Table 1. Patient characteristics

Characteristics	Total number of patients (n = 233)
Mean age at delivery, years (SD)	32.2 (5.9)
Mean BMI (SD)	26.5 (5.8)
Parity at trial entry (n)	
P0	54.4% (n = 127)
P1	22.7% (n = 53)
P2	12% (n = 28)
P ≥ 3	10.7% (n = 25)
Mode of delivery (n)	
Vaginal delivery	58.4% (n = 136)
Caesarean delivery	41.6% (n = 97)
Mean blood loss, ml (SD)	2199 (1251)

The effect of adjusting for confounding factors on the relationship between SI thresholds and outcome was assessed, using logistic regression methods. For the relationship between ICU admission and SI ≥0.9, it was necessary to use exact logistic regression methods, as no woman admitted to an ICU had SI <0.9.[36] In general, changes were marginal, and significance tests were unaffected; however, when using SI ≥1.7 to predict major surgical intervention, after adjusting for emergency caesarean section, the odds ratio was reduced from 7.2 to 6.0, with the *P*-value moving from 0.025 to 0.064.

Discussion

Main findings

The SI identifies women at risk of adverse outcome secondary to PPH and compares favourably with conventional vital signs. For ICU admission, SI and HR were significantly better predictors than all other vital signs. For blood transfusion ≥4 iu, SI had the highest AUROC value, performing significantly better than HR. Conventional vital signs have been shown to be late markers of haemodynamic compromise in non-obstetric and obstetric populations. Monitoring postpartum women with SI may help tailor treatment decisions and reduce adverse events, through timely resuscitation and referral.

In non-pregnant populations, normal SI has been suggested as 0.5–0.7,[14,25] and SI ≥0.9 corresponds with increased mortality and morbidity.[16,21,22] The haemodynamic changes of pregnancy and postpartum may delay the recognition of hypovolaemia. Thresholds must be derived from obstetric populations and be validated for PPH. To date, only one small obstetric study has defined normal SI, as 0.7–0.9, consistent with our findings.[32]

Our study is the first to evaluate the predictive ability of SI in PPH according to multiple clinical outcomes. We tested the performance of the upper limits of SI ≥0.7 and SI ≥0.9 (Tables 4 and 5). For most outcomes (excluding haemoglobin <7 g/dl), SI ≥ 0.9 was the superior predictor and thus may be a valuable threshold in LMICs, where mortality is highest and often related to delays in complication recognition, transportation, and level of care of the facility. A threshold of SI ≥0.9 should be tested to alert community healthcare providers (HCPs) of the need for urgent transfer, e.g. as an 'amber' trigger within the BP device traffic-light EWS.

Centile specificity analysis generated two potential SI thresholds indicating a high risk of adverse events: SI ≥1.5 and SI ≥1.7. For all outcomes (excluding haemoglobin <7 g/dl), SI ≥1.7 was the superior predictor: i.e. with similar sensitivities but improved specificity. This second threshold of SI ≥1.7 could be tested as the 'red' trigger within the EWS to identify the most seriously ill patients, even in higher-level facilities, where deaths occur because of delayed shock recognition.[3] The utility of SI may have

Table 2. AUROC values (95% confidence interval) of performance of vital sign parameters to predict adverse clinical outcome among women with PPH

Vital sign	Adverse clinical outcome			
	ICU admission	Blood transfusion ≥4iu	Haemoglobin <7 g/dl	Invasive surgical intervention
SI	**0.75 (0.63–0.87)**	**0.67 (0.58–0.76)**	0.56 (0.47–0.64)	**0.62 (0.45–0.79)**
HR	**0.73 (0.64–0.83)**	0.59 (0.50–0.68)	0.46 (0.37–0.55)	**0.63 (0.46–0.80)**
SBP	0.64 (0.44–0.83)	**0.66 (0.56–0.76)**	**0.61 (0.52–0.69)**	0.55 (0.40–0.75)
DBP	0.63 (0.45–0.82)	0.63 (0.54–0.72)	0.53 (0.45–0.62)	0.57 (0.36–0.77)
MAP	0.64 (0.44–0.83)	0.64 (0.55–0.73)	0.55 (0.47–0.64)	0.56 (0.35–0.60)
PP	0.54 (0.40–0.69)	0.59 (0.50–0.68)	**0.63 (0.54–0.72)**	0.48 (0.35–0.60)

DBP, diastolic blood pressure; HR, heart rate; MAP, mean arterial pressure; PP, pulse pressure; SBP, systolic blood pressure; SI, shock index.
In bold: highest two AUROC values for each outcome.

Table 3. Performance of SI ≥0.7 and SI ≥0.9 in predicting adverse clinical outcomes among women with PPH

Outcomes	Sensitivity (95% CI)	Specificity (95% CI)	Positive predictive value (95% CI)	Negative predictive value (95% CI)	Prevalence (%)
ICU admission					
SI ≥ 0.7	100.0% (73.5–100.0)	14.5% (10.1–19.8)	6.0% (3.1–10.2)	100.0% (89.1–100.0)	5.1
SI ≥ 0.9	100.0% (73.5–100.0)	43.4% (36.8–50.3)	8.8% (4.6–14.8)	100.0% (96.2–100.0)	5.1
Blood transfusion ≥ 4 iu					
SI ≥ 0.7	92.5% (79.6–98.4)	15.2% (10.5–21.3)	18.8% (13.6–24.9)	90.6% (75.0–98.0)	17.5
SI ≥ 0.9	80.0% (64.4–90.9)	45.0% (37.7–52.4)	23.5% (16.7–31.6)	91.4% (83.8–96.2)	17.5
Haemoglobin < 7 g/dl					
SI ≥ 0.7	93.9% (83.1–98.7)	15.4% (10.5–21.5)	23.0% (17.4–29.5)	90.3% (74.2–98.0)	26.9
SI ≥ 0.9	65.3% (50.4–78.3)	42.3% (35.0–49.8)	23.4% (16.6–31.3)	81.9% (72.6–89.1)	26.9
Invasive surgical intervention					
SI ≥ 0.7	91.7% (61.5–99.8)	14.0% (9.7–19.3)	5.5% (2.8–9.6)	96.9% (83.8–99.9)	5.1
SI ≥ 0.9	83.3% (51.6–97.9)	42.5% (35.9–49.3)	7.3% (3.6–13.0)	97.9% (92.7–99.7)	5.1

Table 4. The 95%, 98%, and 99% specificities of SI according to adverse outcome among women with PPH

Outcomes	95% specificity (95% CI)	98% specificity (95% CI)	99% specificity (95% CI)	*n* (prevalence,%)
ICU admission	1.52 (1.39–1.70)	1.74 (1.57–2.00)	1.84 (1.69–2.05)	12 (5.15)
Blood transfusion ≥4 iu	1.51 (1.38–1.67)	1.69 (1.54–2.04)	1.79 (1.62–2.05)	40 (17.47)
Haemoglobin < 7 g/dl	1.59 (1.41–1.83)	1.88 (1.63–2.05)	2.01 (1.74–2.05)	49 (21.21)
Invasive surgical intervention	1.55 (1.40–1.73)	1.76 (1.59–2.01)	1.90 (1.71–20.5)	12 (5.15)

Table 5. Performance of SI ≥1.5 and SI ≥1.7 in predicting adverse clinical outcomes among women with PPH

Outcomes	Sensitivity (95% CI)	Specificity (95% CI)	Positive predictive value (95% CI)	Negative predictive value (95% CI)	Prevalence (%)
ICU admission					
SI ≥ 1.5	25.0% (5.49–57.2)	94.1% (90.2–96.8)	18.8% (4.05–45.6)	95.9% (92.3–98.1)	5.1
SI ≥ 1.7	25.0% (5.5–57.2)	97.7% (94.8–99.3)	37.5% (8.5–75.5)	96.0% (92.5–98.2)	5.1
Blood transfusion ≥4 iu					
SI ≥ 1.5	10.0% (2.8–23.7)	94.2% (89.8–97.1)	26.7% (7.8–55.1)	83.2% (77.5–87.9)	17.5
SI ≥ 1.7	10.0% (2.8–23.7)	98.4% (95.4–99.7)	57.1% (18.4–90.1)	83.8% (78.3–88.4)	17.5
Haemoglobin <7 g/dl					
SI ≥ 1.5	8.2% (2.3–19.6)	93.4% (88.8–96.5)	25.0% (7.3–52.4)	79.1% (73.0–84.3)	26.9
SI ≥ 1.7	4.1% (0.5–14.0)	96.7% (93.0–98.8)	25.0% (3.2–65.1)	78.9% (73.0–84.1)	26.9
Invasive surgical intervention					
SI ≥ 1.5	16.7% (2.1–48.4)	93.7% (89.6–96.5)	12.5% (1.6–38.3)	95.4% (91.7–97.8)	5.1
SI ≥ 1.7	16.7% (2.1–48.4)	97.3% (94.2–99.0)	25.0% (3.2–65.1)	95.6% (92.0–97.8)	5.1

greatest impact in low-resource settings; however, HCPs may not have access to technology enabling SI calculation. In these circumstances, by identifying when HR exceeds SBP, it should be understood that SI >1 indicates a need for intervention.

Strengths and limitations

This large study evaluated SI compared with conventional vital signs in PPH, according to four robust outcomes. In contrast, previous obstetric studies used blood transfusion only.[31,32] This study evaluated the predictive value of SI

and conventional vital signs using AUROC values, sensitivity, specificity and positive/negative predictive values, whereas the previous study evaluated SI according to mean values and percentages of women requiring blood transfusion.[32]

Vital signs measured at the time of highest SI were selected for analysis. These time points varied between cases, but all occurred within 1 hour of PPH recognition and allowed for contemporaneous comparison. Vital sign values are dynamic and change in response to therapeutic intervention. It is unlikely that analysing multiple measurements would alter the superiority of one predictor over the other; however, it would allow for the investigation of SI response to treatment. We recommend studies using multiple SI measurements over time for monitoring the effectiveness of resuscitation.

After adjusting for potential confounding factors and controlling for emergency caesarean section, SI is of marginally less use as a predictor of major surgical intervention. Emergency caesarean section is not independent of receiving invasive surgical intervention, which may explain this relationship. In general, however, adjusting for confounding factors did not affect our conclusions. Resuscitative measures were administered following highest SI measurement, and therefore do not independently confound the relationship between SI and outcome; rather, they lie on the causal pathway. Despite this, resuscitative measures are likely to impact on subsequent outcome, which may limit the significance of our results, particularly in settings where resuscitation is suboptimal or unavailable. We have related our prognostic variable to outcome (following the PROGRESS series recommendations). Theoretically, the optimal evaluation of SI thresholds should be in the absence of care, so that the risk difference can be assessed,[37] although this is neither feasible nor ethical.

Although acute anaemia is not indicative of bleeding, we felt that haemoglobin <7 g/dl (lowest prior to discharge) was an appropriate medium-term outcome representing morbidity. Values may be affected by resuscitation, however: for example, after blood transfusion. Thus, we also included the outcome of blood transfusion ≥4 iu. In our setting, this may explain why haemoglobin <7 g/dl was not predicted as well as the other outcomes.

The SI has the potential to guide the diagnosis and management of all types of shock in obstetrics, including antepartum haemorrhage and sepsis. This study has only evaluated SI in PPH and replication is required.[38] Research should also focus on determining whether SI cut-off points alter depending on the type of shock and the stage of pregnancy.

Interpretation

Obstetric haemorrhage remains the single most important cause of maternal deaths worldwide. A healthy woman can lose up to 30% of her blood volume before SBP decreases, leading to an assumption of haemodynamic stability and delay in care.[39] The UK Confidential Enquiries into Maternal Deaths highlighted this lack of recognition of abnormal vital signs in the majority of women who died secondary to PPH.[3]

It seems that SI is the most consistently useful outcome predictor, and could aid in the earlier recognition of haemodynamic compromise, prior to changes in HR or BP alone. We propose a threshold of SI ≥0.9 for identifying women requiring urgent high-level care. This is higher than the upper limit of normal in non-pregnant populations, reflecting the haemodynamic changes of pregnancy and the postpartum period.

In LMICs, 52% of pregnancies are complicated by anaemia, the majority of which is caused by iron deficiency, malaria, and HIV infection, compared with 20% of pregnancies in high-income countries (HICs).[40] We therefore recommend evaluating SI in LMIC settings. Firstly, the tachycardic response to anaemia will raise the upper limit of normal SI. Secondly, as smaller volumes of blood loss can result in haemodynamic compromise, estimated blood loss becomes a less reliable assessment tool and SI may be a more useful marker of compromise.

In our study, abnormal SI was derived from women treated in a well-resourced tertiary centre, where resuscitation is initiated promptly and threshold for blood transfusion and ICU admission may be lower than in other settings. Severe compromise and deteriorating vital signs are often rapidly reversed, giving lower SI values. In low-resourced departments experiencing resuscitation delays, SI may be inherently higher. Future studies should consider the impact of clinical context on outcome.[38] Thresholds of SI should be evaluated in LMICs, considering the differing baseline health of women and resources available. Our group is currently conducting a prospective observational study assessing the predictive ability of these SI thresholds in women cared for in resource-poor environments.

Conclusion

In women with PPH, SI is a consistently strong predictor of adverse clinical outcomes, even after adjusting for confounding factors. We propose thresholds of SI ≥0.9 for indicating the need for referral to a higher-level facility and SI ≥1.7 for indicating the need for urgent intervention, with the aim of promptly identifying and managing obstetric shock to reduce maternal adverse events in resource--

poor settings. It was not possible to adjust for resuscitative measures administered following vital sign measurement but influencing outcome. Research should now focus on prospective validation in LMICs, where the burden is highest and the potential for improvement greatest.

Disclosure of interests

No conflict of interest is declared. No financial relationships with any organisation that might have interest in the submitted work in the previous 3 years are declared. No other relationships or activities that could appear to have influenced the submitted work are declared. All authors had full access to all of the data in the study and can take full responsibility for the integrity of the data and the accuracy of the data analysis. King's College London is the guarantor for the study.

Contribution to authorship

Conception, HN, NH, AB, and AS; design, HN, NH, PS, AB, and AS; data acquisition, HN, AE, PS, AB, SB, and AS; analysis and interpretation, HN, AE, NH, PS, EB, SM, AB, and AS; input into drafting the article, HN, AE, NH, PS, EB, SM, and AS; revision and final approval of the article, HN, AE, NH, PS, EB, SM, AB, SB, and AS.

Details of ethics approval

The South East Multicentre Research Ethics Committee approved this large prospective observational study.

Funding

The study was funded by the Bill and Melinda Gates Foundation Grand Challenges Explorations grant.

Acknowledgements

We thank those who worked on the original study, including Jane Sandall, Rachel Tribe, Graham Tydeman, Mark Waterstone, and also the original funders (Guy's and St Thomas' Charity). ■

References

1 Say L, Chou D, Gemmill A, Tunçalp Ö, Moller A-B, Daniels J, et al. Global causes of maternal death: a WHO systematic analysis. *Lancet Glob Health* 2014;2:e323–33.
2 World Health Organisation. *The World Health Report 2005: Make Every Mother and Child Count*. Geneva: World Health Organization, 2005.
3 Cantwell R, Clutton-Brock T, Cooper G, Dawson A, Drife J, Garrod D, et al. Saving Mothers' Lives: reviewing maternal deaths to make motherhood safer: 2006–2008. The Eighth Report of the Confidential Enquiries into Maternal Deaths in the United Kingdom. *BJOG* 2011;118 (Suppl 1):1–203.
4 Berg CJ, Harper MA, Atkinson SM, Bell EA, Brown HL, Hage ML, et al. Preventability of pregnancy-related deaths: results of a state-wide review. *Obstet Gynecol* 2005;106:1228–34.
5 Lewis G. Reviewing maternal deaths to make pregnancy safer. *Best Pract Res Clin Obstet Gynaecol* 2008;22:447–63.
6 Bouvier-Colle MH, Ould El Joud D, Varnoux N, Goffinet F, Alexander S, Bayoumeu F, et al. Evaluation of the quality of care for severe obstetrical haemorrhage in three French regions. *BJOG* 2001;108:898–903.
7 Walvekar V, Virkud A, Majumder R. Management of postpartum haemorrhage in low resource settings. In: Arulkumaran S, Karoshi M, Keith L, Lalonde A, B-Lynch C, editors. *A Comprehensive Textbook of Postpartum Haemorrhage*, 2nd edn. London: Sapiens Publishing; 2012. pp. 539–44.
8 World Health Organisation. *World Health Organisation Guidelines for the Management of Postpartum Haemorrhage and Retained Placenta*. Report of a Technical Working Group, Geneva: World Health Organisation, 2009.
9 Schorn MN. Measurement of blood loss: review of the literature. *J Midwifery Womens Health* 2010;55:20–7.
10 Royal College of Obstetrics and Gynaecology. *Guidelines and Audit Committee of the Royal College of Obstetricians and Gynaecologists, Prevention and Management of Postpartum Haemorrhage: RCOG Green-top Guideline*, London: Royal College of Obstetricians and Gynaecologists. No. 52., 2011.
11 Mol BW, Hajenius PJ, Engelsbel S, Ankum WM, van der Veen F, Hemrika DJ, et al. Can noninvasive diagnostic tools predict tubal rupture or active bleeding in patients with tubal pregnancy? *Fertil Steril* 1999;71:167–73.
12 Hirata AJ, Soper DE, Bump RC, Hurt WG. Ectopic pregnancy in an urban teaching hospital: can tubal rupture be predicted? *South Med J* 1991;84:1467–9.
13 Allgower MBC. Shock index. *Dtsch Med Wochenschr* 1967;92:1947–50.
14 Rady MY, Nightingale P, Little RA, Edwards JD. Shock index: a re-evaluation in acute circulatory failure. *Resuscitation* 1992;23:227–34.
15 Liu Y-C, Liu J-H, Fang ZA, Shan G-L, Xu J, Qi Z-W, et al. Modified shock index and mortality rate of emergency patients. *World J Emerg Med* 2012;3:114–7.
16 Rady MY, Smithline HA, Blake H, Nowak R, Rivers E. A comparison of the shock index and conventional vital signs to identify acute, critical illness in the emergency department. *Ann Emerg Med* 1994;24:685–90.
17 Paladino L, Subramanian RA, Nabors S, Sinert R. The utility of shock index in differentiating major from minor injury. *Eur J Emerg Med* 2011;18:94–8.
18 Cancio LC, Wade CE, West SA, Holcomb JB. Prediction of mortality and of the need for massive transfusion in casualties arriving at combat support hospitals in Iraq. *J Trauma* 2008;64 (2 Suppl):S51–5; discussion S5–6.
19 Chen L, Reisner AT, McKenna TM, Gribok A, Reifman J. Diagnosis of hemorrhage in a prehospital trauma population using linear and nonlinear multiparameter analysis of vital signs. *Conf Proc IEEE Eng Med Biol Soc* 2007;2007:3748–51.
20 Hagiwara A, Kimura A, Kato H, Mizushima Y, Matsuoka T, Takeda M, et al. Hemodynamic reactions in patients with hemorrhagic shock from blunt trauma after initial fluid therapy. *J Trauma* 2010;69:1161–8.
21 Vandromme MJ, Griffin RL, Kerby JD, McGwin G Jr, Rue LW 3rd, Weinberg JA. Identifying risk for massive transfusion in the relatively normotensive patient: utility of the prehospital shock index. *J Trauma* 2011;70:384–8;discussion 8–90.
22 Cannon CM, Braxton CC, Kling-Smith M, Mahnken JD, Carlton E, Moncure M. Utility of the shock index in predicting mortality in traumatically injured patients. *J Trauma* 2009;67:1426–30.

23 Baron BJ, Sinert R, Zehtabchi S, Stavile KL, Scalea TM. Diagnostic utility of sublingual PCO2 for detecting hemorrhage in penetrating trauma patients. *J Trauma* 2004;57:69–74.

24 Asaari H. Value of Shock Index in prognosticating the short term outcome of death for patients presenting with severe sepsis and septic shock in the emergency department. *Med J Malaysia* 2012;67:407.

25 Rady MY, Rivers EP, Martin GB, Smithline H, Appelton T, Nowak RM. Continuous central venous oximetry and shock index in the emergency department: use in the evaluation of clinical shock. *Am J Emerg Med* 1992;10:538–41.

26 Pacagnella RC, Souza JP, Durocher J, Perel P, Blum J, Winikoff B, et al. A systematic review of the relationship between blood loss and clinical signs. *PLoS One* 2013;8:e57594.

27 Birkhahn RH, Gaeta TJ, Bei R, Bove JJ. Shock index in the first trimester of pregnancy and its relationship to ruptured ectopic pregnancy. *Acad Emerg Med* 2002;9:115–9.

28 Birkhahn RH, Gaeta TJ, Van Deusen SK, Tloczkowski J. The ability of traditional vital signs and shock index to identify ruptured ectopic pregnancy. *Am J Obstet Gynecol* 2003;189:1293–6.

29 Jaramillo S, Barnhart K, Takacs P. Use of the shock index to predict ruptured ectopic pregnancies. *Int J Gynaecol Obstet* 2011;112:68.

30 Onah H, Oguanuo T, Mgbor S. An evaluation of the shock index in predicting ruptured ectopic pregnancy. *J Obstet Gynaecol* 2006;26:445–7.

31 Sohn CH, Kim WY, Kim SR, Seo DW, Ryoo SM, Lee YS, et al. An increase in initial shock index is associated with the requirement of massive transfusion in emergency department patients with primary postpartum hemorrhage. *Shock* 2013;40:101–5.

32 Le Bas A, Chandraharan E, Addei A, Arulkumaran S. Use of the "obstetric shock index" as an adjunct in identifying significant blood loss in patients with massive postpartum hemorrhage. *Int J Gynaecol Obstet* 2013;124:253–5.

33 de Greeff A, Nathan H, Stafford N, Liu B, Shennan AH. Development of an accurate oscillometric blood pressure device for low resource settings. *Blood Press Monit* 2008;13:342–8.

34 Briley A, Seed P, Tydeman G, Ballard H, Waterstone M, Sandall J, et al. Reporting errors, incidence and risk factors for postpartum haemorrhage and progression to severe PPH: a prospective observational study. *BJOG* 2014;121:876–88.

35 DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. *Biometrics* 1988;44:837–45.

36 Hirji KF, Mehta CR, Patel NR. Computing distributions for exact logistic regression. *J Am Stat Assoc* 1987;82:1110–7.

37 Hemingway H, Croft P, Perel P, Hayden JA, Abrams K, Timmis A, et al. Prognosis research strategy (PROGRESS) 1: a framework for researching clinical outcomes. *BMJ* 2013;346:e5595.

38 Riley RD, Hayden JA, Steyerberg EW, Moons KG, Abrams K, Kyzas PA, et al. Prognosis Research Strategy (PROGRESS) 2: prognostic factor research. *PLoS Med* 2013;10:e1001380.

39 Troiano N, Harvey C, Chez B. *Massive Post Partum Hemorrhage. AWHONN High-Risk & Critical Care Obstetrics*. Mandeville: AWHONN, 2012.

40 Lee AI, Okam MM. Anemia in pregnancy. *Hematol Oncol Clin North Am* 2011;25:241–59.

