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Obstetric early warning system to predict maternal morbidity of pre-eclampsia, postpartum hemorrhage and infection after birth in high-risk women: a prospective cohort study

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ABSTRACT

Objective: The purpose of early warning systems is to detect deterioration of the patient and to enable timely intervention to prevent possible severe illness. The most common causes of maternal morbidity and mortality after birth are worsening pre-eclampsia, postpartum haemorrhage and puerperal infection. Our aim was to validate the accuracy of the obstetric early warning system and different physiological triggers to predict morbidity on the postnatal ward in high-risk women.

Design: A prospective cohort study.

Setting: A tertiary referral hospital in Finland.

Participants: High-risk women (n=828) (body mass index > 35 kg/m^2, postpartum haemorrhage > 1,500 g, pre-eclampsia, chorioamnionitis during birth, type 1 diabetes or anxiety over the maternal condition based on clinical judgement) were studied on the postnatal ward in the first 24 hours after giving birth. In this study population the women without any morbidity served as a control group. The study was conducted between 1.11.2016 – 30.4. 2018 covering a period of 18 months.

Measurements and findings: The accuracy of the obstetric early warning system and its five physiological parameters—respiratory rate, oxygen saturation, blood pressure, heart rate and body temperature—and a pain score to predict worsening pre-eclampsia, complications related to postpartum haemorrhage and puerperal infection were determined. A red trigger is as a single, markedly abnormal observation, and a yellow trigger is a combination of two mildly abnormal observations. The sensitivity of obstetric early warning system at its best was 72% for pre-eclampsia, 52% for infection and 25% for postpartum haemorrhage. The red triggers were significantly associated with morbidity in each outcome studied. The red triggers of systolic blood pressure (OR 25.7, 95% CI 13.2-50.1) and diastolic blood pressure (OR 22.1, 95% CI 11.3-43.0) were independently associated with pre-eclampsia, systolic blood pressure (OR 2.7, 95% CI 1.4-5.6) and heart rate (OR 3.6, 95% CI 1.7-7.6) with postpartum haemorrhage and heart rate (OR 3.3, 1.0-10.3) with infection.

Abbreviations: BMI, body mass index; CEMACH, The Confidential Enquiry into Maternal and Child Health; CI, confidence interval; CRP, C-reactive protein; GCS, The Glasgow Coma Scale; HELLP, Hemolysis, Elevated Liver enzymes, Low Platelets; ICU, intensive care unit; MEOWS, The Modified Early Obstetrics Warning System; MET, The medical emergency team; NRS, Numeric Rating Scale; OR, odds ratio; OEWS, The Obstetric Early Warning System; PPH, postpartum haemorrhage; PS, Pain Score; T1D, type 1 diabetes.

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Keyconclusions: The sensitivity of obstetric early warning system varied depending on the type of morbidity. The highest sensitivity and positive predictive value were in pre-eclampsia. Systolic and diastolic blood pressure and heart rate were the strongest physiological parameters to predict morbidity.

Implications for practice: The systematic use of obstetric early warning system helps to improve maternal safety after birth in high-risk women. Blood pressure and pulse are the most important measurements.

Introduction

Early warning systems were first developed for non-obstetric patients to prevent serious morbidity in hospitalised patients. Deranged physiological values are present in many patients hours before they deteriorate and are admitted to intensive care (Quinn et al., 2016). The purpose of the trigger system is to detect deterioration early and thus enable timely intervention to prevent possible severe illness. Warning systems follow several simple physiological parameters, in most cases respiratory rate, oxygen saturation, blood pressure, pulse and body temperature. A trigger is defined as a single, markedly abnormal observation or a combination of mildly abnormal observations in physiological parameters (Lewis, 2007).

The use of obstetric early warning systems in hospitalised parturients is recommended by several authorities (Umar et al., 2019; Lewis, 2007; Obstetrics and Gynecology, 2014; Department of Health 2019.). Many obstetric trigger systems described in the literature are in clinical use (Umar et al. 2019; Smith et al., 2017). The majority of them are based on clinical consensus rather than statistical analyses of clinical outcome measures. However, in prospective studies, the sensitivity of trigger systems for morbidity has found to be rather good in general obstetric population, from 86% to 89%. On the other hand, the positive predictive values have been lower, from 39% to 54% (Singh, S. et al., 2012; Singh, A. et al., 2016). Only a few studies on trigger systems to predict specified outcomes based on different physiological parameter are available. The sensitivity for developing severe sepsis has ranged from 40 to100% in women with chorioamnionitis, and positive predictive values were rather low at 0.05%-15% (Lappen et al, 2010; Edwards et al., 2015). In pre-eclamptic women, high blood pressure on admission was associated with kidney injury and intensive care unit admission (Nathan et al., 2018). When on admission blood pressure and oxygen saturation measurements were combined with maternal characteristics, symptoms and several laboratory measurements, the trigger system was able to find 76% of pre-eclamptic women who developed serious complications (Van Dadelszen et al, 2011).

The most common causes for direct maternal mortality globally are worsening pre-eclampsia, postpartum haemorrhage (PPH) and sepsis (Kassebaum et al., 2014). To prevent mortality, it is reasonable to detect morbidities related to these complications. Our aim was to validate prospectively the performance of obstetric early warning system and different physiological trigger limits to predict specific morbidity among high-risk women in immediate postpartum period.

Methods

This prospective cohort study was conducted between November 1, 2016, and April 30, 2018 at a tertiary referral hospital in Finland with approximately 5,000 deliveries per annum. The hospital is part of the public health care system.

The obstetric early warning system chart used here was adapted from the seventh CEMACH report (2003–2005) (Lewis, 2007), in which the recommended trigger system was the Modified Early Obstetrics Warning System (MEOWS). The chart was reviewed by an obstetric anaesthesiologist and slightly modified to make a chart more convenient to clinical use considering for example some threshold values for red trigger. For the diastolic blood pressure, we considered 80-90 mmHg as a yellow trigger in MEOWS to be rather harmless and we chose to use only diastolic blood pressure ≥ 100 mmHg as a red trigger. Meanwhile for the oxygen saturation we were concerned whether only one limit would be enough and decided to add also yellow trigger for the lowering oxygen saturation apart from MEOWS. We used a numeric rating scale 0-10, and, in the MEOWS a pain score of 0-3 was used to describe pain intensity. The numeric rating score was chosen, because it had been used years in clinical practice in our antenatal, labor and postnatal wards. Our intention was not to compare accuracy of limits between MEOWS and the present study. We used five physiological parameters (respiratory rate, oxygen saturation, systolic and diastolic blood pressure, pulse and body temperature). Limits of the trigger thresholds for each parameter compared to MEOWS are presented in Table 1. The early warning system used in this study is referred to as the Obstetric Early Warning System (OEWS).

The trigger system was allocated to women considered to have an increased risk for morbidity after birth. The high-risk groups were defined as follows: body mass index (BMI) > 35 kg/m^2, estimated PPH > 1500 g, pre-eclampsia, anxiety over the maternal condition based on clinical judgement, chorioamnionitis during birth and type 1 diabetes (T1D). BMI before pregnancy was obtained from maternity charts, either self-reported or measured upon admission to the maternity clinic. The amount of PPH was estimated by measuring either the volume of collected blood after vaginal delivery or the sucked blood loss in caesarean section. Pre-eclampsia was diagnosed as hypertension and proteinuria occurring after 20 weeks of gestation. Hypertension was diagnosed as systolic blood pressure ≥ 140 mmHg and/or diastolic blood pressure ≥ 90 mmHg, while proteinuria was diagnosed as urinary excretion of ≥ 300 mg protein in a 24-hour specimen or a dipstick reading of 1+. The pre-eclampsia group also included HELLP (Hemolysis, Elevated Liver enzymes, Low Platelets) and superimposed pre-eclampsia, i.e., chronic hypertension with proteinuria and exacerbated hypertension or new-onset proteinuria or elevated liver enzymes or thrombocytopenia or severe symptoms of pre-eclampsia (headache, visual disturbances, epigastric pain) (Roberts et al. 2013). Intrapartum infection was diagnosed when at least two of the following criteria were met: body temperature over 38°C, tachycardia, uterine tenderness, foul odor in amniotic fluid or fetal tachycardia and intravenous antibiotics having been initiated during the birth. In most cases, antibiotics were discontinued after birth. The doctor in charge in the labor rooms, or in the operative theatre assigned women to the trigger system, when there was concern over parturient's condition. The inclusion criteria for anxiety over maternal condition was based on pre-existing chronic diseases (for example chronic hypertension, bleeding disorders, nephropathy, anemia, cardiac disease), prescribed medications (for example antihypertensive or antiarrhythmic medication) or conditions alerting follow-up during birth (for example hemorrhage < 1500 g with uncertainty over maternal wellbeing, surgically difficult or otherwise complicated cesarean section, extensive perineal tears, group B Streptococcus carrier with prolonged delivery) or any other reason for concern.

After transferring the parturient from the labor room or from the recovery room after caesarean section to the postnatal ward, the trigger system was commenced. Midwives in both the labor and postnatal wards double-checked that the inclusion criteria were met. Physiological parameters and pain scale were checked hourly during the first four hours and every four hours thereafter until 24 hours postpartum. Altogether,

Table 1
Limits of trigger thresholds for physiological parameters used in the present study's Obstetric Early Warning System (OEWS) compared to the Modified Early Obstetric Warning System (MEOWS).

	Red trigger		Yellow trigger	
	OEWS	MEOWS	OEWS	MEOWS
Respiratory rate; breaths/min	≥31 or <10	> 30 or < 10	21-30	21-30
Oxygen saturation;%	<90	<90	91-94	-
Systolic blood pressure; mmHg	≥160 or ≤90	>160 or <90	150-159 or 91-100	150-160 or 90-100
Diastolic blood pressure; mmHg	≥100	> 90	-	80-90
Heart rate, beats/minute	≥120 or ≤40	>120 or < 40	100-119 or 41-49	100-120 or 40-50
Temperature;°C	≤35 or ≥38	< 35 or > 38	35.1-35.9	35-36
Pain score	-	-	4-10 (NRS)	2-3 (PS)

NRS, Numeric Rating Scale (0-10).
PS, Pain Score (0-3).

Table 2
Diagnostic definitions of obstetric morbidity.

Obstetric morbidity	Definition
Pre-eclampsia	BP systolic≥ 160 mm/Hg or BP diastolic ≥110 mm/Hg or extra dose of antihypertensive medicine or onset of HELLP syndrome or eclampsia after delivery or transfer to high dependency/ intensive care unit or MET-alarm or cardiopulmonary dysfunction including cardiac insufficiency and pleural effusion.
Infection	temperature ≥38°C and intravenous antibiotics or bacteremia in blood culture or sepsis or infection after obstetrical intervention or pneumonia, pyelonephritis or transfer to high dependency/intensive care unit or MET-alarm.
Haemorrhage	Blood transfusion during postnatal ward stay or extra dose of medicine for the uterine contraction or abrasion or laparotomy or re-laparotomy or hysterectomy or radiological embolisation of uterine arteries co-ordinated from the inpatient ward or MET-alarm.

BP, blood pressure.
HELLP, hemolysis, elevated liver enzymes, low platelet count.
MET, medical emergency team.

there were nine measurement points. One red trigger would indicate a remarkable trigger, while two yellow triggers were needed to trigger an alarm (Table 1).

If the OEWS triggered an alarm, the following routine procedures were performed. If systolic blood pressure was ≥ 160 mmHg, an extra dose of an antihypertensive medication was given. If oxygen saturation decreased, oxygen 10 l/ minute was initiated, and the woman was placed in a half-sitting position. If systolic blood pressure dropped ≤ 90 mmHg or the pulse was over systolic blood pressure, a 1,000-ml Ringer's solution (balanced crystalloid solution, a mixture of sodium chloride, sodium lactate, potassium chloride and calcium chloride) was infused intravenously, the woman was placed in the Trendelenburg position (supine position with feet slightly elevated above the head) and peripheral blood count and C-reactive protein (CRP) were measured. Subsequently, measurement of diuresis was initiated. If the body temperature was ≥ 38°C, peripheral blood culture, blood count, CRP and urine culture were controlled, and the need for antibiotic treatment was considered. If the trigger system alarmed, the measures were repeated after 15 minutes, and the doctor in charge was informed. Medical emergency team (MET) alarm was alerted if respiratory rate was < 5/min or > 24/min, oxygen saturation was < 90 %, systolic blood pressure dropped < 90 mmHg, heart rate was < 40/min or >140/min or there was a sudden decrease in consciousness as determined by the Glasgow Coma Scale (GSC) (decreasing ≥ 2 points per hour) or repeated, prolonged convulsions.

The OEWS, rough guidelines and the rationale of the follow up system were introduced and discussed with the personnel – both midwives and doctors – in several meetings before implementation of the trigger system. Our study period started at the beginning of the OEWS implementation as a part of routine clinical practice.

Diagnostic criteria for maternal morbidity are described in Table 2. HELPP syndrome, transfer to intensive care unit, medical emergency team alarm, operative or radiological interventions for haemorrhage and sepsis were regarded as severe morbidity (ACOG and SFMF, 2016). All outcomes were defined as postpartum morbidity if they occurred during the time period from the OEWS follow-up to hospital discharge. The data from the OEWS charts were collected. Women's demographic data, prenatal characteristics and delivery statistics were collected from hospital electronic database, which provides data for national Medical Birth Register. Morbidity outcomes (Table 2) and transfers to intensive care unit (ICU) were collected from hospital records by ICD-10 (International Classification of Diseases) codes, codes of Nordic Classification of Surgical Procedures and codes for ward stays. The time point of diagnosis, surgical or radiological procedures and ICU transfers were checked from the patient's records to ensure that they took place during the stay in the postnatal ward. Other morbidity outcomes (medication, blood transfusion, MET-alarms) were collected from the patient's records. The data was collected from all women included to the study.

To describe the data, we calculated medians, ranges, and interquartile ranges for skewed continuous variables, and means and standard deviations were calculated for normally distributed variables. We used frequencies and percentages for categorical variables. The control group (women without any morbidity) and the women with morbidity were compared with Mann-Whitney *U* test for the skew-distributed continuous variables, with the independent sample *t*-test for the normally distributed continuous variables and the chi-square test or Fisher's exact test for the categorical variables, as appropriate. Binary and multivariable logistic regression analyses were also performed, with results shown as odds ratios (ORs) with 95% confidence intervals (CIs). We considered p values <0.05 statistically significant. To describe the accuracy of the trigger system's sensitivity, specificity, and positive and negative predictive values were calculated. The analyses were carried out using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY).

The study was approved by the Ethical Committee of Pirkanmaa Hospital District, Tampere, Finland (R17039).

Results

The study population (n=828) and morbidity groups (n=210 women) are presented in Fig. 1. The baseline characteristics of the study population are presented in Table 3. The women with any morbidity

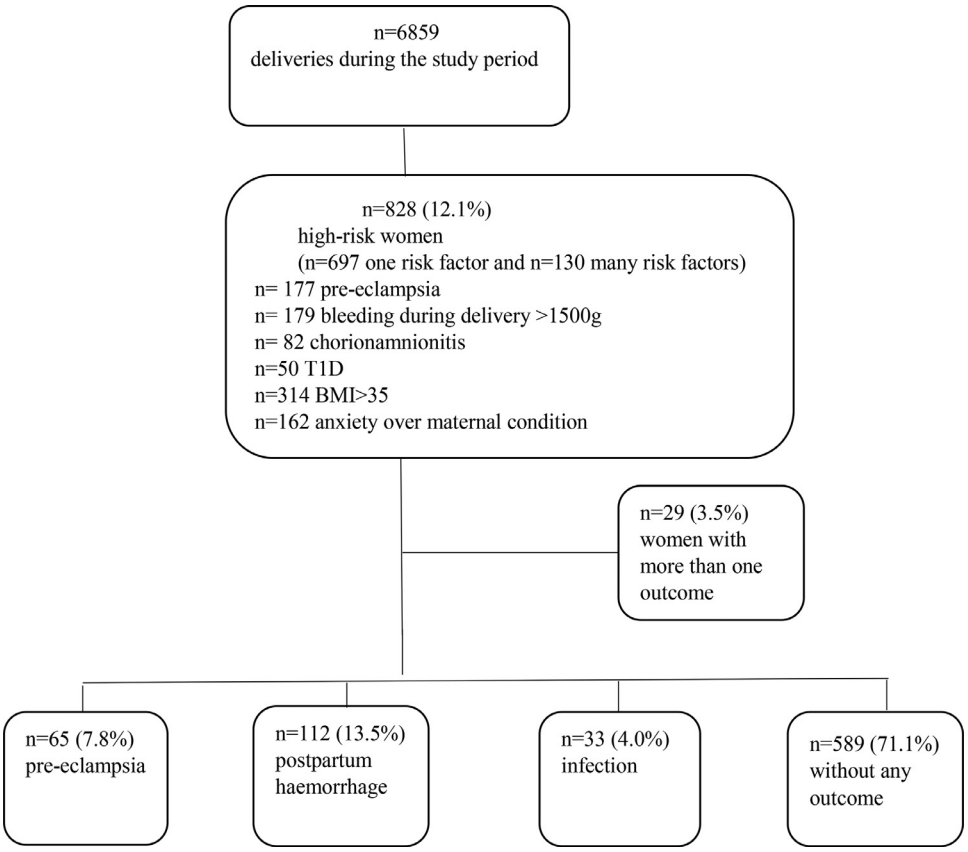

Fig. 1. Flow chart of the study population.
BMI, body mass index.
T1D, type 1 diabetes.

Table 3
Baseline characteristics of the study groups.

	Women with any outcome n=238		Women without any outcome n=589		p-value
	mean/ median/n	SD/ Q_1-Q_3/ %	mean/ median/n	SD/ Q_1-Q_3/ %	
Age, years	31	5.8	31	5.5	0.413
BMI, kg/m^2	25	22.3-30.3	32	24.1-38.7	<0.001
Weight, kg	69.0	61.0-83.0	88.0	65.0-108.0	<0.001
Smoking*	13	6	33	6	0.954
Primiparas	98	41	293	50	0.050
Hb <100g/l during pregnancy	14	6	10	2	0.003
GDM with insulin treatment	4	2	58	10	<0.001
Mode of delivery					0.372
Vaginal delivery	114	48	316	54	
Operative vaginal delivery	30	13	57	10	
Emergency and urgent CS	62	26	138	23	
Elective CS	30	13	67	11	
Days in the hospital	5	3-7	4	2-5	<0.001
Postpartum bleeding (g)	1150	500-1750	505	350-1100	<0.001
BMI > 35 kg/m^2	43	18	272	46	<0.001
Pre-eclampsia	81	34	95	16	<0.001
Postpartum haemorrhage >1500 g	89	38	90	16	<0.001
Chorioamnionitis during labor	24	10	58	10	0.918
Type 1 diabetes	10	4	40	7	0.157
Concern over maternal condition	51	21	111	19	0.397

IQR, interquartile range
Smoking*, beyond the first trimester
Hb, Hemoglobin
GDM, Gestational Diabetes Mellitus
CS, cesarean section

had significantly lower BMIs and less gestational diabetes with insulin treatment. They had more frequently low hemoglobin (< 100 g/l) during pregnancy and 53% (n = 127) of them had blood transfusion while staying in the labor or recovery rooms after birth compared to controls (4% (n = 24), p < 0.001).

There were no maternal deaths during the study period, but several cases (n = 29) of severe morbidity emerged. In the pre-eclampsia group, intensive care unit transfer was needed in one patient and five HELLP syndromes occurred. Furthermore, one woman with HELLP syndrome had cardiopulmonary dysfunction with a MET alarm. In the haemorrhage group, 16 women needed operative interventions for haemor-

Table 4.1
Sensitivity, specificity, positive predictive value and negative predictive value of any red or yellow trigger to identify morbidities in the study population (n=828).

	Pre-eclampsia		Postpartum haemorrhage		Infection	
	any red (%)	any yellow (%)	any red (%)	any yellow (%)	any red (%)	any yellow (%)
Sensitivity	72.3	13.8	25.0	28.6	51.5	12.1
Specificity	83.2	75.2	83.2	75.2	83.2	75.2
Positive predictive value	32.2	5.8	22.0	17.8	14.6	2.7
Negative predictive value	96.5	88.8	85.4	84.7	96.8	93.9

Table 4.2
The red and the yellow triggers in different morbidities compared with women without any morbidity.

	Pre-eclampsia n=65				Postpartum haemorrhage n=112				Infection n=33				Women without any morbidity n=589	
	n	%	OR	95%CI	n	%	OR	95%CI	n	%	OR	95%CI	n	%
red trigger	47	72.3	12.92	7.20-23.19	28	25.0	1.65	1.02-2.67	17	51.5	5.259	2.57-10.76	99	16.8
yellow trigger	9	13.8	0.49	0.24-1.01	32	28.6	0.82	0.53-1.29	4	12.1	0.419	0.15-1.21	146	24.8

Table 5
The means and standard deviations of physiological parameters during the 24 hour follow-up in women with and without morbidity.

	pre-eclampsia n=65		p-value	postpartum haemorrhage n=112		p-value	infection n=33		p-value	women without any morbidity n=589	
	Mean	SD		Mean	SD		Mean	SD		Mean	SD
Respiratory rate/ minute											
maximum	18.9	3.2	0.116	19.5	2.9	0.852	20.2	3.4	0.156	19.5	2.7
minimum	13.6	2.2	0.031	14.1	2.2	0.609	14.9	2.6	0.126	14.2	2.3
Oxygen saturation %											
maximum	98	0.9	0.065	99	0.8	<0.001	98	1.1	0.933	98	0.8
minimum	96	1.5	0.925	97	2.5	<0.001	96	1.3	0.629	96	1.4
Systolic blood pressure, mmHg											
maximum	161	13.2	<0.001	123	13.8	<0.001	127	14.1	0.056	132	13.1
minimum	126	12.8	<0.001	101	11.1	<0.001	105	11.6	0.139	108	11.6
Diastolic blood pressure, mmHg											
maximum	100	9.6	<0.001	81	9.9	<0.001	84	9.0	0.173	86	9.0
minimum	75	10.5	<0.001	61	9.3	0.001	64	8.4	0.897	64	8.6
Heart Rate/ minute											
maximum	85	12.1	<0.001	100	16.5	<0.001	103	16.3	0.002	95	13.3
minimum	66	7.8	<0.001	76	12.4	0.001	79	13.8	0.000	73	10.4
Temperature°C											
maximum	36.9	0.4	0.001	37.2	0.4	0.105	37.5	0.7	<0.001	37.1	0.0
minimum	35.8	0.4	0.142	35.9	0.4	0.267	35.9	0.4	0.690	35.9	0.5
NRS											
maximum	3.6	2.1	0.521	3.1	2.0	0.182	3.5	2.3	0.877	3.4	2.1
minimum	0.5	1.0	0.548	0.4	0.9	0.479	0.7	1.0	0.140	0.5	0.9

NRS numeric rating scale for pain

p-value refers to the difference between the outcome group and women without any outcome.

rhage coordinated from the inpatient ward (curette, laparotomy, re-laparotomy or radiological embolisation of uterine arteries). In the infection group there were three women with sepsis, and one woman with sepsis triggered a MET alarm due to respiratory problems.

The sensitivity (72%) and positive predictive value (32%) of the red triggers were highest for pre-eclampsia. Meanwhile, the sensitivity was lowest (25%) in the PPH group and in the infection outcome group it was 52%. In all outcome groups, specificity and negative predictive values were higher compared to sensitivities and positive predictive values (Table 4.1). Red triggers were significantly associated with morbidity in each outcome group, while yellow triggers were not significantly associated with morbidity in any specified outcome group (Table 4.2).

The means and standard deviations of physiological parameters and pain score in the different morbidity groups compared to women without any morbidity are presented in Table 5. The systolic and diastolic blood pressures were higher, and the heart rate and the maximum body temperature were significantly lower, in women with worsening pre-eclampsia compared to women without any morbidity. Only the means of maximum systolic and diastolic blood pressures exceeded the OEWS red trigger values in the pre-eclampsia group. The oxygen saturation and the heart rate were higher, the systolic and diastolic blood pressures were lower in the PPH group, but none of these mean values exceeded the red trigger values in OEWS. In the infection group, the heart rate and the maximum temperature were higher than in the control group, and none of the means exceeded the red trigger values.

Crude and adjusted morbidity risks for each abnormal physiological parameter are described in Table 6. Systolic and diastolic blood pressure in the preeclampsia group, systolic blood pressure and heart rate in the

Table 6
Crude and adjusted morbidity risk with each abnormal clinical variable using cut-offs described in the Obstetric Early Warning Score (OEWS).

				Unadjusted		Adjusted	
Morbidity	Trigger	n	%	OR	95%Cl	OR	95%Cl
Pre-eclampsia n=65							
Systolic blood pressure ≤90 or ≥160 mmHg		33	50.8	25.38	13.38-48.15	25.70	13.18-50.11
Diastolic blood pressure≥100 mmHg		30	46.2	22.09	11.56-42.21	22.07	11.34-42.97
Heart rate≤40 or ≥120 per minute		0	0	-	-	-	-
Respiratory rate 0-9 or > 31 per minute		0	0	-	-	-	-
Oxygen saturation≤ 90%		1	1.5	0.91	0.11-7.18	0.81	0.10-6.62
Temperature ≤35 or ≥38°C		1	1.5	0.45	0.06-3.37	0.37	0.05-2.84
Postpartum Haemorrhage n=112							
Systolic blood pressure ≤90 or ≥160 mmHg		15	13.4	3.81	1.92-7.55	2.67	1.35-5.64
Diastolic blood pressure≥100 mmHg		1	0.9	0.23	0.03-1.74	0.31	0.04-2.40
Heart rate≤40 or ≥120 per minute		14	12.5	3.68	1.82-7.44	3.62	1.72-7.61
Respiratory rate 0-9 or > 31 per minute		1	0.9	0.75	0.09-6.15	0.72	0.08-6.40
Oxygen saturation≤ 90%		2	1.8	1.05	0.23-4.87	1.40	0.28-6.93
Temperature ≤35 or ≥38°C		4	3.6	1.05	0.35-3.14	0.94	0.31-2.89
Infection n=33							
Systolic blood pressure ≤90 or ≥160 mmHg		3	9.1	2.46	0.70-8.66	1.84	0.51-6.68
Diastolic blood pressure≥100 mmHg		1	3.0	0.81	0.11-6.17	0.92	0.12-7.16
Heart rate≤40 or ≥120 per minute		4	12.1	3.56	1.15-10.99	3.25	1.03-10.29
Respiratory rate 0-9 or > 31per minute		1	3.0	2.60	0.31-21.76	2.67	0.30-23.46
Oxygen saturation≤ 90%		1	3.0	1.81	0.23-14.57	1.68	0.20-14.31
Temperature ≤35 or ≥38°C		3	9.1	2.85	0.80-10.11	2.38	0.65-8.69
Without any morbidity n=589							
Systolic blood pressure ≤90 or ≥160 mmHg		23	3.9	0.12	0.07-0.20	0.13	0.08-0.23
Diastolic blood pressure≥100 mmHg		22	3.7	0.22	0.13-0.38	0.19	0.10-0.34
Heart rate≤40 or ≥120 per minute		22	3.7	0.42	0.23-0.79	0.43	0.23-0.84
Respiratory rate 0-9 or > 31per minute		7	1.2	1.42	0.29-6.89	1.46	0.28-7.55
Oxygen saturation≤ 90%		10	1.7	0.67	0.24-1.86	0.64	0.22-1.89
Temperature ≤35 or ≥38°C		20	3.4	0.73	0.34-1.54	0.85	0.39-1.86

Adjusted model includes age, parity and weight

PPH group and the heart rate in the infection group were significantly associated with morbidity outcome.

There were nine measurement points in the complete OEWS protocol. The mean number of filled measurement points in the completed OEWS charts were eight measurements for all physiological parameters and numeric rating scale for pain. The percentages for over 75 % of completed measurement points were 86% (respiratory rate), 87% (oxygen saturation), 88% (systolic blood pressure), 88% (diastolic blood pressure), 88% (heart rate), 86% (temperature) and 85% (numeric rating scale for pain).

Discussion

The best sensitivity of the trigger system was in the pre-eclampsia group, it was low in the PPH group and modest in the infection group. The red triggers were associated with morbidity in all groups. Furthermore, the red triggers of systolic and diastolic blood pressure independently predicted the morbidity of worsening pre-eclampsia, systolic blood pressure and heart rate the morbidity of PPH and heart rate the morbidity of infection.

The sensitivity of the OEWS to predict worsening pre-eclampsia described mostly persistent high blood pressure and use of antihypertensive medication in our study. We found the incidence of severely elevated blood pressure to be quite high immediately after birth. Early warning system hypertension thresholds to predict adverse outcomes in pre-eclampsia before birth have been studied by Nathan et al. (Nathan et al., 2018). The highest blood pressure antenatally was associated with kidney injury, intensive care unit admissions, magnesium sulfate treatment and preterm birth (Nathan et al., 2018). Furthermore, early intervention to lower blood pressure has shown to reduce the rate of eclampsia and severe maternal morbidity (Shields et al., 2017). In our study population only two women out of 177 women with pre-eclampsia had serious complications. These findings indicate an association between high blood pressure and maternal morbidity (Nathan et al., 2018; Shields et al., 2017; Kilpatrick et al., 2016; Riaz et al., 2011) and emphasise the importance of timely management of hypertension to avoid serious complications. Systematic follow up with the OEWS increases maternal safety, especially in the women with pre-eclampsia, by addressing high blood pressure with active antihypertensive management.

The lowest sensitivity of OEWS in our study was surprisingly for predicting PPH complications. It is probable that some procedures, such as blood transfusion or extra doses of medicine to contract the uterus, were started based on other judgements than an early warning system to ensure a stable condition. This is supported by the finding that even the mean values of oxygen saturation, systolic and diastolic blood pressure and heart rate were significantly different compared to women without any morbidity, they did not exceed the alarming limits of red triggers. Despite of the low sensitivity, we cannot exclude that the OEWS follow up revealed more morbidity than would have been revealed based on only laboratory findings and other clinical judgements. It is possible that the OEWS helped to detect the most serious complications of postpartum hemorrhage in women with physiological changes.

In our study, the OEWS revealed about half of the infections. The sensitivity of the trigger system for intensive care unit admission, sepsis or maternal death was 100%, while positive predictive value was only 0.05% in a retrospective setting in women with chorioamnionitis during delivery (Lappen et al., 2010). The sensitivity varied between 40 -100% when six different trigger systems were used retrospectively to predict severe sepsis in women with chorioamnionitis during delivery, and positive predictive values were < 2-15% (Edwards et al., 2015). Compared to

previous studies, our outcomes also included milder forms of infections in addition to five women with sepsis. Our finding of modest sensitivity may be partly explained by the fact that antibiotics for infections were initiated also based on laboratory findings, and the interventions may have reduced the possibility of physiological deterioration. This is supported by the finding of physiological parameters: the mean maximum body temperature was statistically higher compared to women without any morbidity, but clinically evaluation of the difference was insignificant. The temperature as a trigger was not significantly associated with infection morbidity. In our study population only the higher heart rate was independently associated with infection morbidity. In an emergency setting in non-pregnant patients, the relative risk of heart rate to predict infection was higher than temperature (Barrett et al., 2007). In obstetric population, high heart rate along with high temperature was associated with sepsis (Parfitt and Hering, 2018; T Shields et al, 2016).

In the present study, systolic and diastolic blood pressures and heart rate were the strongest physiological triggers for morbidity. Other triggers seemed to have little predictive value. This is probably related to our study population and morbidity outcomes. It reflects that women with morbidities in our study were generally physiologically in good condition, and the number of severely ill women was low. Another reason could be that there was timely intervention to prevent deterioration. Furthermore, it seems that morbidities found in our study were less associated with respiratory problems revealed by respiratory rate and oxygen saturation.

Red triggers proved to have generally better accuracy compared to yellow triggers. They had higher sensitivity and positive predictive values in the pre-eclampsia and the infection groups, and only in the PPH group the sensitivity of yellow triggers was comparable to red triggers. The mean values of maximum heart rate in the PPH and the infection groups were within the yellow alarm range. Considering the pathophysiological changes in PPH and infection morbidities, lowering the red trigger limit of maximum heart rate might increase the sensitivity of the OEWS in these groups. Otherwise, yellow triggers had less impact on predicting morbidity, and they were not significantly associated with morbidities in any study groups. Women without any morbidity had more often alarming yellow triggers compared to alarming red triggers.

The strength of our study is a prospective setting with a large study population. We conducted the study as a screening tool in general postnatal ward in high-risk women, and were not aware of previous prospective studies with similar setting. Our study increases the evidence of the use of the OEWS to improve patient safety in everyday obstetric care. We also found the OEWS charts to be rather well completed. The limitation is low number of women with morbidity outcomes. Furthermore, there are not uniformly accepted early warning systems in obstetric population, and the physiological values as well as alarming values might differ between childbearing women and women after birth. We chose to use the MEOWS with minor practical changes, so our results are limited to trigger system similar to the MEOWS. We also limited our study to high-risk women, and the mean values of control group (women without any morbidity) included women with risk factors. Therefore, the reference values may differ from healthy women after birth. The mean differences in physiological variables between the study groups and controls may be underestimated compared to the setting if the control group had included only healthy women. We did not have a control group of high-risk women without routine obstetric early warning system follow up, and the impact of the trigger system on patient safety may be limited. Further studies are needed to explore the impact of OEWS on maternal morbidity.

Conclusion

The accuracy of the OEWS was dependent on study population and morbidity outcomes. The highest sensitivity and positive predictive values were in pre-eclamptic women, but the OEWS may increase the patient safety in all high-risk women by integrating physiological variables into other clinical follow-up methods. The red triggers were associated with morbidity in all study groups – pre-eclampsia, postpartum haemorrhage and infection. The most accurate predictors for morbidity were systolic and diastolic blood pressure and heart rate.

Declarations

(1) Conflict of interest statement- none declared

(2) Ethical Approval- Approved by the Ethical Committee of Pirkanmaa Hospital District, Tampere, Finland (R17039).

(3) Funding Sources- none declared

CRediT authorship contribution statement

Katja Hannola: Validation, Formal analysis, Investigation, Writing – original draft. **Sanna Hoppu:** Writing – review & editing. **Susanna Mennander:** Writing – review & editing. **Heini Huhtala:** Methodology, Validation, Formal analysis, Writing – review & editing. **Hannele Laivuori:** Writing – review & editing. **Kati Tihtonen:** Methodology, Validation, Formal analysis, Investigation, Data curtion, Writing – original draft, Writing – review & editing, Supervision, Project administration.

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