2 Identifying the Critically Ill Parturient

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Bullet Points

- Much of the increased maternal mortality in the last 25 years in the United States is likely attributable to a higher burden of maternal medical illness.
- Admission of a pregnant or postpartum patient to the intensive care unit (ICU) is estimated to occur in 1 in every 300 deliveries.
- Early identification of those at risk may accelerate care, including transfer and timely intervention, thereby reversing these trends in morbidity and mortality.
- The vital signs of normal pregnancy often overlap with abnormal vital signs, further challenging the development of a physiology-based tool with adequate sensitivity and specificity.
- The Modified Obstetric Early Warning System (MOEWS), tailored for obstetric vital signs, and obstetric-focused Sepsis in Obstetrics Score (SOS) require further assessments for improved outcomes.
- The Obstetric Comorbidity Index (OCI) is a clinical calculator using underlying comorbidities to predict need for ICU admission and the likelihood of severe maternal morbidity at delivery.
- The relatively low absolute rate of critical illness among obstetric patients remains a significant challenge for achieving validity with any scoring system.
- Early referral of women with specific comorbidities, such as abnormal placentation, severe preeclampsia, and maternal cardiac disease, is encouraged, to appropriate facilities.
- Multidisciplinary collaboration constitutes the optimal model for coordinating care and delivery planning in high-risk pregnant women.

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2.1 The Modern Parturient: A Changing Demographic

In the United States (USA), maternal mortality has increased in the last 25 years. Much of this increase is likely attributable to a higher burden of maternal medical illness [1–6]. Maternal morbidity and "near miss" events have also markedly

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increased during the same interval, by as much as 75% by some estimates [6]. Maternal critical illness, defined by end organ dysfunction, need for advanced treatment (need for ventilation, vasopressor requirement) or diagnostic criteria (see Chap. 1), is now relatively common in the obstetric population [7]. Admission of a pregnant or postpartum patient to the ICU is estimated to occur in 1 in every 300 deliveries [8], accounting for 12.1% of all ICU admissions for women aged 16–50 [9]. Obstetric patients requiring ICU-level care are also being treated outside of the formal critical care setting, with studies showing that 1–3% of parturients require ICU-level care or are at risk of developing maternal critical illness [10, 11]. Identifying obstetric patients at risk of clinical deterioration and critical illness, therefore, represents an important component of a comprehensive strategy to address the needs of increasingly ill pregnant and postpartum women. Early identification of those at risk may accelerate transfer to high-risk centers and/or allows timely intervention, thereby reversing these trends in morbidity and mortality.

2.2 Maternal Hemodynamic Screening Tools: Balancing Sensitivity and Specificity

Many public health organizations recommend routine use of validated tools to identify women at high-risk of morbidity during pregnancy [4, 12, 13]. In the United Kingdom, Confidential Enquiry into Maternal and Child Health (CEMACH) reports have led to the introduction and integration of criteria to identify derangements in physiologic parameters in pregnant women [13]. In the United States, the multidisciplinary National Partnership for Maternal Safety has also suggested that tracking several physiological parameters is a key component of identifying morbidity (Table 2.1) [4, 14].

The use of vital signs and other physiologic parameters as indicators of critical illness is well described in the general medical and surgical populations [15]. The ideal screening tool should be sufficiently sensitive to predict development of critical illness. However, it should also have a threshold of specificity that avoids overdiagnosis and recurrent false alarms (which lead to clinical fatigue) [16]. Therein lies the problem. Critical illness is less common in the obstetric population than in the general medical and surgical populations, and infrequent signals are more often missed [17]. In addition, the vital signs of normal pregnancy often overlap with abnormal vital signs. These issues challenge the development of a physiology-based tool with adequate sensitivity and specificity [18].

Table 2.1 Maternal early warning criteria from the National Partnership for Maternal Safety

Parameter	Value
Systolic blood pressure (mmHg)	<90 or >160
Diastolic blood pressure (mmHg)	>100
Heart rate (beats per minute)	<50 or >120
Respiratory rate (breaths per minute)	<10 or >30
Oxygen saturation on room air, at sea level (%)	<95
Oliguria (mL/h for ≥2 h)	<35
Maternal agitation, confusion, or unresponsiveness; Patient with preeclampsia reporting a non-remitting headache or shortness of breath	Present

Mhyre JM, D'Oria R, Hameed AB, Lappen JR, Holley SL, Hunter SK, Jones RL, King JC, D'Alton ME. The maternal early warning criteria: a proposal from the national partnership for maternal safety. Obstet Gynecol 2014;124:782–6

2.3 Predicting Adverse Outcomes in Infection

Though the etiology of severe maternal morbidity and mortality continues to evolve in the contemporary obstetric population, sepsis remains a leading cause of obstetric critical illness [19]. Early recognition and intervention during sepsis improve outcomes [20]. Therefore, the validity of many screening tools has been tested in the context of maternal infection (Table 2.2).

The systemic inflammatory response syndrome (SIRS) and modified early warning system (MEWS) are two physiology-based tools commonly used to screen for the presence of sep-

Table 2.2 Test characteristics of scoring systems for sepsis in an obstetric population

Score	Author	Population	Outcome	Components	Threshold	Characteristics
Maternal Early Warning System (MEWS)	Lappen et al., 2010	Chorioamnionitis at single-center in the United States	Severe sepsis [3] ICU admission Death	Temperature HR RR WBC count	≥5	Sensitivity 100% Specificity 90.4% NPV 100% PPV 0.05%
Modified Obstetric Early Warning Scoring Systems (MOEWS)	Edwards et al., 2015	Chorioamnionitis at single-center in the United States	Severe Sepsis [3] ICU transfer death	Temperature HR SBP DBP RR SpO_2 Mental state	≥2	Sensitivity 40–100% Specificity 3.6–96.9% PPV 1.42–15.4 NPV 99.1–100
Sequential Organ Failure Assessment (SOFA)	Jain et al., 2016	Obstetric ICU admissions in India	Death	PaO_2/FiO_2 ratio GCS score Vasopressors Creatinine/ urine output Bilirubin Platelet count	≥2 ≥8	Sensitivity 100% Specificity 3.3% Sensitivity 96.7% Specificity 78.3%
Sepsis in Obstetrics Score (SOS)	Albright et al., 2017	Pregnant or postpartum women meeting ≥2 SIRS criteria at single-center in the United States	ICU transfer	Temperature SBP HR RR SpO_2 WBC count % immature neutrophils Lactic acid	≥6	Sensitivity 64% Specificity 88% PPV 15% NPV 98.6%

HR heart rate (beats/min), *RR* respiratory rate (breaths/min), *WBC* white blood cell (10^9/L), *NPV* negative predictive value, *PPV* positive predictive value, *SBP* systolic blood pressure (mmHg), *DBP* diastolic blood pressure (mmHg), *SpO_2* peripheral oxygen saturation (%), *GCS* Glasgow Coma Scale, *MAP* mean arterial pressure (mmHg), *SIRS* systemic inflammatory response syndrome

sis. Both lack sensitivity and specificity in an obstetric population. In a retrospective study of intrapartum patients with chorioamnionitis, both SIRS and MEWS failed to accurately identify women who were admitted to the ICU, developed sepsis, or died [21]. At score thresholds deemed appropriate for clinical assessment, the MEWS criteria was found to have a positive predictive value of 0.05%, meaning only 0.05% of women meeting these criteria will have sepsis [21].

The lack of specificity of SIRS and MEWS criteria may be attributed to the physiologic differences between the obstetric population and the general medical/surgical population [21, 22]. Pregnant women have lower blood pressure compared to nonpregnant patients, a higher heart rate at the time of delivery (intermittent tachycardia often occurs during active labor), and an increase in respiratory rate related to hormonal changes [21]. However, additional confounders may also contribute to the lack of specificity. For example, fevers associated with neuraxial anesthesia or with treatment with prostaglandins (e.g., Misoprostol) may lead to overdiagnosis of sepsis. All of these factors contribute to the overall lack of specificity of standard scores in the obstetric population [23].

These challenges have inspired the creation of physiology-based surveillance scoring systems targeted specifically for use in obstetric patients. The Modified Obstetric Early Warning System (MOEWS) is routinely used for monitoring pregnant women in the UK National Health System. This score uses physiologic criteria tailored to pregnant women [24]. However, several studies have suggested that even the MOEWS has poor

sensitivity and specificity in pregnant women [24, 25], and it remains unclear whether implementation of MEOWS criteria improves clinical outcomes. Similarly, the obstetric-focused Sepsis in Obstetrics Score (SOS) offers superior validity over SIRS and MEWS for ICU admission, but still lacks specificity for predicting severe outcomes [26].

In addition to the value of an ideal scoring system for determining the need for critical care admission, it should also predict adverse outcomes such as severe maternal morbidity and mortality. Scoring systems which rely on physiologic parameters to predict mortality in ICU patients have also been shown to lack specificity in the obstetric population. The Acute Physiology and Chronic Health Evaluation II (APACHE II) scoring system analyzes 13 physiologic variables within 24 h of ICU admission [27]. A recent study analyzing the usefulness of the APACHE II scores in pregnancy showed that 7 of the 13 physiologic parameters are altered in baseline obstetric physiology, leading to overestimation of mortality risk [27].

When compared to organ-based screening tools such as the MODS (Multiple Organ Dysfunction Score) and SOFA scores, physiological-based screening tools such as SOS (Sepsis in Obstetrics) and APACHE II scores showed inferiority as predictors for sepsis-related mortality in obstetric patients [28]. These newer sepsis detection scores (SOFA/MODS) are based on organ failure rather than on the severity of inflammatory response and seem more promising for prediction of mortality in critically ill septic obstetric patients. However, the data suggesting this are still limited [29, 30].

2.4 Beyond Infection

Most of the evidence regarding the utility of screening tools in the obstetric population is limited to the realm of infection. With the evolving complexity of the modern parturient, the ideal screening tool should also have a high sensitivity and specificity for other sources of critical illness and adverse outcomes. Furthermore, these screening tools should also suggest the first step within a pathway to treat those at risk for morbidity and curb its development [14, 31]. The Maternal Early Warning Tool (MEWT) is one such tool that integrates physiologic screening for morbidity with management guidelines to address cases of clinical concern. The MEWT is comprised of a screening tool coupled with clinical pathways which address four common causes of maternal mortality: cardiovascular dysfunction, infection, hemorrhage, and hypertensive disorders of pregnancy (preeclampsia) [12]. A prospective study of this screening tool in six US hospitals has shown that implementing it led to reductions in severe maternal morbidity and composite morbidity. Furthermore, only 1 in 50 women triggered an alert when this tool was used. As noted above, the MEWT also incorporates clinical recommendations regarding treatment of prevailing causes of maternal morbidity. Inclusion of these recommendations has been shown to lead to high adherence rate to the protocols provided among treating physicians (83.1%) [12]. Drawbacks of MEWT include imperfect positive predictive values. The positive predictive value for all patients requiring ICU admission was 12% with a PPV of 7% for patients with suspected sepsis [12]. These limitations suggest that improvements in maternal screening are still required if women at risk of clinical deterioration are to be identified in a timely manner. It is also unclear whether the observed reduction in morbidity was due to use of the trigger tool or to better adherence to protocols in high-risk patients. Despite the limitation of a low positive predictive value, data from this study suggest that obstetric-specific tools such as this may potentially lower severe maternal morbidity through early recognition coupled with protocolized management.

2.5 The Identification and Management of High-Risk Pregnant and Postpartum Women

Identification of pregnant and postpartum women at risk of clinical deterioration requires use of a diverse set of strategies. Despite the inherent challenges in the available scoring systems, con-

sensus guidelines consistently underscore two key principles in identifying the high-risk parturient. First, obstetric units should implement and consistently utilize a screening system for the critically ill mother at risk of severe morbidity, however imperfect. Secondly, obstetric hospitals should have the protocols or pathways to mobilize available resources when a mother at risk for critical illness is identified [14, 31].

The importance of provider education and reinforcement in the use of screening tools cannot be overstated. Barriers to successful implementation of the MEOWS screening criteria in the UK National Health System included poor compliance with guidelines and difficulties in eliciting a response from physicians [24]. Such inconsistent use of screening tools or failure to respond can lead to delays in diagnosis that may predispose patients to severe morbidity and mortality. Studies show that up to 40% of maternal deaths are preventable; these deaths have largely been attributed to delays in diagnosis and in involvement of critical care [11, 32, 33]. Conversely, systemic implementation of screening tools alongside leadership efforts, management, and continual supervision by qualified practitioners has a demonstrated impact on the staff's perceived usefulness of screening tools when identifying high-risk parturients [24]. Therefore, maternal screening tools must be used in conjunction with other strategies to identify high-risk pregnant and peripartum women.

Once the high-risk women have been identified, clinician attention should switch quickly to management. National guidelines set forth evidence-based clinical pathways for common obstetric conditions such as postpartum hemorrhage, maternal infection, venous thromboembolism, and hypertensive disorders of pregnancies in a variety of clinical settings [1, 14, 31, 34]. The rising prevalence of chronic disease in pregnancy and a concomitant increase in patient complexity has underscored the importance of multidisciplinary management and maternal critical care in combating maternal mortality [7, 35].

Establishing maternal critical care as a formal discipline is a central strategy for preventing maternal deaths. The UK Intensive Care National Audit and Research Centre (ICNARC) recommends education in critical care scenarios pertinent to obstetric patients for staff at all levels of management (identification of sepsis for staff at all levels of training and appropriate anesthetic considerations for critically ill obstetric patients for anesthesia providers), appropriate staffing with multidisciplinary personnel trained in maternal critical care, and appropriate triaging of critically ill patients for transfer to centers with adequate resources [11]. Still, in some centers, dependent on the clinical setting, identification of an obstetric patient with critical illness may indicate transfer to an intensive care unit while in others it may not. Sometimes identification of the high-risk parturient may trigger involvement of consulting physicians to provide a multidisciplinary approach to patient management and ongoing assessment. Certain critical care skills, such as rapid assessment with transthoracic echocardiography hold promise for reproducible and rapid assessment of cardiac function and fluid status in pregnancy [36, 37]. Timely assessment of complex medical conditions will require healthcare professionals comfortable with obstetric physiology and critical care skills. Providing these critical care services, independent of location, for at risk mothers is central in reducing maternal mortality.

2.6 Accounting for Comorbidities in Screening for the High-Risk Parturient

Though rates of maternal morbidity are increasing, the relatively low absolute rate of critical illness in the obstetric patient population remains a significant challenge for achieving validity with any scoring system. The positive predictive value of any screening tool depends on the prevalence of the disease in the population of interest. A low prevalence of critical illness in an unselected patient population will preclude any attempt to increase the positive predictive value of physiology-based screening tools. Clinical covariates are important components of many disease-specific risk assessment tools. Screening tools incorporating specific comorbidities successfully

predict morbidity and mortality in non-obstetric patients [38, 39]. Incorporating such clinical comorbidities into risk assessment tools for the pregnant and critically ill population, therefore, offers exciting possibility for improving identification of those at risk of critical illness.

The Obstetric Comorbidity Index (OCI) (Table 2.3) is a clinical calculator that uses the underlying comorbidities of pregnant women to predict their need for ICU admission and the likelihood of severe maternal morbidity at delivery. The OCI considers 20 weighted maternal comorbid conditions in addition to maternal age to produce a patient-specific comorbidity index score predictive of maternal ICU admission [40]. This scoring index has been validated in independent populations and has demonstrated superiority compared to comorbidity indices derived for non-obstetric populations [41].

Table 2.3 Obstetric comorbidity index

Maternal comorbidity	Odds ratio (95% CI)	Weight
Preeclampsia with severe features or eclampsia	5.10 (4.63–5.60)	5
Chronic congestive heart failure	3.93 (1.35–11.47)	5
Congenital heart disease	3.81 (3.37–4.32)	4
Pulmonary hypertension	3.24 (2.31–4.56)	4
Chronic ischemic heart disease	2.72 (2.13–3.46)	3
Sickle cell disease	2.14 (1.63–2.81)	3
Multiple gestation	2.09 (1.86–2.35)	2
Cardiac valvular disease	1.95 (1.67–2.27)	2
Systemic lupus erythematosus	1.77 (1.24–2.52)	2
HIV	1.76 (1.37–2.27)	2
Mild or unspecified preeclampsia	1.95 (1.67–2.27)	2
Drug abuse	1.63 (1.48–1.79)	2
Placenta previa	1.61 (1.45–1.80)	2
Chronic renal disease	1.54 (1.32–1.80)	1
Previous cesarean delivery	1.45 (1.37–1.54)	1
Gestational hypertension	1.32 (1.14–1.54)	1
Alcohol abuse	1.31 (1.11–1.56)	1
Asthma	1.28 (1.19–1.39)	1
Preexisting diabetes mellitus	1.21 (1.1–1.33)	1
Maternal age (years)		
Older than 44	2.25 (1.28–3.95)	3
40–44	1.72 (1.47–2.02)	2
35–39	1.52 (1.39–1.66)	1

Bateman BT MJ, Hernandez-Diaz S, Huybrechts KF, Fischer MA, Creanga AA, Callaghan WM, Gagne JJ. Development of a comorbidity index for use in obstetric patients. *Obstet Gynecol.* 2013;122 (5):957–965

2.7 Antenatal and Early Pregnancy Screening

The role of early identification of high-risk pregnant women and appropriate referral has been underscored in the recent consensus guidelines published by the American College of Obstetricians and Gynecologists (ACOG) and the Society for Maternal-Fetal Medicine (SMFM) [35]. In response to increasingly complex patient population and rising maternal mortality, the guidelines encourage referral of women with specific comorbidities, such as those with abnormal placentation, severe preeclampsia and maternal cardiac disease, to appropriate facilities. The guidelines also offer a classification for facility level of maternal care based on the availability of potentially required resources. Among the resources outlined are nursing leadership and expertise, specialist availability, and critical care resources for the highest risk women [35]. In addition to listing the components of the hospital infrastructure recommended for these high-risk cases, the guidelines identify the availability of subspecialists and critical care unit capabilities as key features of higher-level centers.

The role of early and appropriate referral has already been recognized for certain high-risk conditions. Though all obstetric hospitals are encouraged to recognize and manage obstetric hemorrhage, facility-based criteria have been outlined for specific high-risk conditions such as abnormal placentation [42, 43]. Women with placenta accreta will benefit from antenatal referral to hospitals with adequate resources, such as a blood bank capable of massive transfusion and the availability of subspecialty services such as interventional radiology, obstetric anesthesiology, and critical care. However, older women and those with hypertension, placenta previa, and prior cesarean delivery may not be as readily

identified even though in some cases their risk of severe morbidity may be similar.

An increasingly complex obstetric population in a background, low rate of severe maternal morbidity and mortality, presents many challenges for early and reliable identification of the high-risk parturient. Screening women for high-risk conditions as a routine part of antenatal care will, therefore, likely play an increasingly important role in identifying women at risk for critical illness. Universal clinical comorbidity screening may offer an objective way to screen women for severe morbidity prior to the development of critical illness. The majority of the aforementioned screening tools and downstream pathways focus on assessment and management at the time of potential illness. However, the OCI, which has shown promise in identifying high-risk parturients, can be used in the antepartum period. This comorbidity index can identify high-risk women in the antenatal setting, allowing them to be directed to specialized centers equipped with adequate resources and personnel. Theoretically, such referral allows care coordination and provides time to plan a delivery strategy [40].

Multidisciplinary collaboration constitutes the optimal model for coordinating care and delivery planning in high-risk pregnant women [11, 35, 44, 45]. Early multidisciplinary consultation represents a valuable strategy in the care of parturients with multiple comorbidities who may benefit from coordination of care [35]. However, it remains uncertain whether maternal screening tools affect consultation practices and/or lead to timely intervention of specialists. Such scores continue to be underutilized for identifying high-risk women. In one study, only 25% of women eligible for an antepartum high-risk consultation received this resource [46]. Multidisciplinary management has been proclaimed as a vital strategy in the prevention of severe morbidity [47]; the impact that maternal screening tools may have with timely intervention of consultants represents potential areas of interest for improving clinical outcomes.

Antenatal screening for obstetric comorbidities coupled with physiology-based *intrapartum* risk assessment is a key complementary strategy for identifying mothers at risk for critical illness. Once identified, appropriate management pathways take priority. Prompt management and ongoing risk assessment according to evidence-based pathways should also follow early recognition of women with intrapartum derangements in physiology. An important potential confounding factor in studies attempting to identify high-risk women in the peripartum period may be the heterogeneity in delivery volume across hospitals. In the United States, one-third of hospitals have delivery volumes less than 500 per year and 39% of hospital births occurred in these low-volume hospitals. Given the prevalence of deliveries occurring at smaller hospitals, intrapartum access to risk-appropriate care for high-risk women cannot be assumed [48, 49]. Obstetric complications are more likely to occur in hospitals with lower delivery volumes, possibly reflecting associated experience by healthcare providers [35, 50].

2.8 Maternal Screening Tools: A Valuable Tool Looking Forward

Identification of high-risk pregnant and peripartum women represents a central strategy for an increasingly comorbid patient population. This requires a multifaceted approach which includes proper "maternal" screening tools and timely multidisciplinary management, with the goal of minimizing delays of care. Although maternal screening tools do have their limitations, implementing them has shown promise in reducing morbidity in the clinical setting. Moving forward, screening criteria should be optimized. Improving the sensitivity and specificity of the existing tools and achieving higher predictive values for identifying women at risk of clinical deterioration remain essential. Creation of maternal screening criteria which incorporate individual patient comorbidities represents an important area of potential research as this may improve the value of physiologic-based screening tools. Stratification of women based on their comorbidity indices in the antepartum setting may provide clinicians the time to assemble resources and

multidisciplinary input and enable timely transfer of women at risk to centers capabilities and resources that are adequate for their specific clinical needs.

References

1. Banayan JM, Scavone BM. National Partnership for maternal safety—maternal safety bundles. APSF Newslett. 2016;31(2). www.apsf.org/article/national-partnership-for-maternal-safety-maternal-safety-bundles/. Last Accessed 21 Oct 2018.
2. Kassebaum NJ, Bertozzi-Villa A, Coggeshall MS, et al. Global, regional, and national levels and causes of maternal mortality during 1990–2013: a systematic analysis for the global burden of disease study 2013. Lancet. 2014;384(9947):980–1004.
3. Mocumbi AO, Sliwa K, Soma-Pillay P. Medical disease as a cause of maternal mortality: the preimminence of cardiovascular pathology. Cardiovasc J Afr. 2016;27(2):84–8.
4. Mhyre JM, D'Oria R, Hameed AB, et al. The maternal early warning criteria: a proposal from the national partnership for maternal safety. J Obstet Gynecol Neonatal Nurs. 2014;43(6):771–9.
5. Singer M, Deutschman CS, Seymour CW, et al. The third international consensus definitions for sepsis and septic shock (sepsis-3). JAMA. 2016;315(8):801–10.
6. Callaghan WM, Creanga AA, Kuklina EV. Severe maternal morbidity among delivery and postpartum hospitalizations in the United States. Obstet Gynecol. 2012;120(5):1029–36.
7. Wheatly S. Maternal critical care: what's in a name? Int J Obstet Anesth. 2010;19(4):353–5.
8. Einav S, Bromiker R, Sela HY. Maternal critical illness. Curr Anesthesiol Rep. 2017;7:55–66.
9. Peña-Rosas JP, De-Regil LM, Garcia-Casal MN, Dowswell T. Daily oral iron supplementation during pregnancy. Cochrane Database Syst Rev. 2015;(7):CD004736.
10. O'Malley EG, Popivanov P, Fergus A, Tan T, Byrne B. Maternal near miss: what lies beneath? Eur J Obstet Gynecol Reprod Biol. 2016;199:116–20.
11. Knight M, Kenyon S, Brocklehurst P, Neilson J, Shakespeare J, Kurinczuk JJ, editors. on behalf of MBRRACE-UK. Saving lives, improving mothers' care—lessons learned to inform future maternity care from the UK and Ireland confidential enquiries into maternal deaths and morbidity 2009–12. Oxford: National Perinatal Epidemiology Unit, University of Oxford; 2014. www.npeu.ox.ac.uk/downloads/files/mbrrace-uk/reports/Saving%20Lives%20Improving%20Mothers%20Care%20report%202014%20Full.pdf. Last Accessed 21 Oct 2018.
12. Shields LE, Wiesner S, Klein C, Pelletreau B, Hedriana HL. Use of maternal early warning trigger tool reduces maternal morbidity. Am J Obstet Gynecol. 2016;214(4):527.e1–6.
13. Singh S, McGlennan A, England A, Simons R. A validation study of the CEMACH recommended modified early obstetric warning system (MEOWS). Anaesthesia. 2012;67(1):12–8.
14. D'Alton ME, Friedman AM, Smiley RM, et al. National partnership for maternal safety: consensus bundle on venous thromboembolism. Anesth Analg. 2016;123(4):942–9.
15. Goldhill DR, White SA, Sumner A. Physiological values and procedures in the 24 h before ICU admission from the ward. Anaesthesia. 1999;54(6):529–34.
16. Rhee C, Gohil S, Klompas M. Regulatory mandates for sepsis care--reasons for caution. N Engl J Med. 2014;370(18):1673–6.
17. Jerison HJ, Pickett RM. Vigilance: the importance of the elicited observing rate. Science. 1964;143(3609):970–1.
18. Bauer ME, Bauer ST, Rajala B, et al. Maternal physiologic parameters in relationship to systemic inflammatory response syndrome criteria: a systematic review and meta-analysis. Obstet Gynecol. 2014;124(3):535–41.
19. Bateman BT, Schmidt U, Berman MF, Bittner EA. Temporal trends in the epidemiology of severe postoperative sepsis after elective surgery: a large, nationwide sample. Anesthesiology. 2010;112(4):917–25.
20. Gauer RL. Early recognition and management of sepsis in adults: the first six hours. Am Fam Physician. 2013;88(1):44–53.
21. Lappen JR, Keene M, Lore M, Grobman WA, Gossett DR. Existing models fail to predict sepsis in an obstetric population with intrauterine infection. Am J Obstet Gynecol. 2010;203(6):573.e1–5.
22. Clark SL, Cotton DB, Lee W, et al. Central hemodynamic assessment of normal term pregnancy. Am J Obstet Gynecol. 1989;161(6 Pt 1):1439–42.
23. Segal S. Labor, epidural analgesia and maternal fever. Anesth Analg. 2010;111(6):1467–75.
24. Mackintosh N, Watson K, Rance S, Sandall J. Value of a modified early obstetric warning system (MEOWS) in managing maternal complications in the peripartum period: an ethnographic study. BMJ Qual Saf. 2014;23(1):26–34.
25. Dudley M, Wright A, Simons R, et al. Meows—time to review the trigger threshold? Arch Dis Child Fetal Neonatal Ed. 2010;95:Fa40.
26. Albright CM, Ali TN, Lopes V, Rouse DJ, Anderson BL. The sepsis in obstetrics score: a model to identify risk of morbidity from sepsis in pregnancy. Am J Obstet Gynecol. 2014;211(1):39.e31–8.
27. Ryan HM, Sharma S, Magee LA, et al. The usefulness of the APACHE II score in obstetric critical care: a structured review. J Obstet Gynaecol Can. 2016;38(10):909–18.
28. Aarvold AB, Ryan HM, Magee LA, von Dadelszen P, Fjell C, Walley KR. Multiple organ dysfunction score is superior to the obstetric-specific Sepsis in obstet-

rics score in predicting mortality in septic obstetric patients. Crit Care Med. 2017;45(1):e49–57.
29. Khan KS, Wojdyla D, Say L, Gulmezoglu AM, Van Look PF. WHO analysis of causes of maternal death: a systematic review. Lancet. 2006;367(9516):1066–74.
30. Cantwell R, Clutton-Brock T, Cooper G, 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.
31. Main EK, Goffman D, Scavone BM, et al. National partnership for maternal safety: consensus bundle on obstetric hemorrhage. Obstet Gynecol. 2015;126(1):155–62.
32. Berg CJ, Harper MA, Atkinson SM, et al. Preventability of pregnancy-related deaths: results of a state-wide review. Obstet Gynecol. 2005;106(6):1228–34.
33. Amaral E, Souza JP, Surita F, et al. A population-based surveillance study on severe acute maternal morbidity (near-miss) and adverse perinatal outcomes in Campinas, Brazil: the Vigimoma Project. BMC Pregnancy Childbirth. 2011;11:9.
34. Banayan JM, Scavone BM. National partnership for maternal safety: maternal safety bundles. Curr Anesthesiol Rep. 2017;7(1):67–75.
35. Moaveni DM, Cohn J, Zahid ZD, Ranasinghe S. Obstetric anesthesiologists as perioperative physicians: improving peripartum care and patient safety. Curr Anesthesiol Rep. 2015;5(1):65–73.
36. Dennis AT. Transthoracic echocardiography in obstetric anaesthesia and obstetric critical illness. Int J Obstet Anesth. 2011;20(2):160–8.
37. Cornette J, Laker S, Jeffery B, et al. Validation of maternal cardiac output assessed by transthoracic echocardiography against pulmonary artery catheterization in severely ill pregnant women: prospective comparative study and systematic review. Ultrasound Obstet Gynecol. 2017;49(1):25–31.
38. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis. 1987;40(5):373–83.
39. Elixhauser A, Steiner C, Harris DR, Coffey RM. Comorbidity measures for use with administrative data. Med Care. 1998;36(1):8–27.
40. Bateman BT, Mhyre JM, Hernandez-Diaz S, et al. Development of a comorbidity index for use in obstetric patients. Obstet Gynecol. 2013;122(5):957–65.
41. Metcalfe A, Lix LM, Johnson JA, et al. Validation of an obstetric comorbidity index in an external population. BJOG. 2015;122(13):1748–55.
42. Silver RM, Fox KA, Barton JR, et al. Center of excellence for placenta accreta. Am J Obstet Gynecol. 2015;212(5):561–8.
43. Awan N, Bennett MJ, Walters WA. Emergency peripartum hysterectomy: a 10-year review at the Royal Hospital for women, Sydney. Aust N Z J Obstet Gynaecol. 2011;51(3):210–5.
44. Epstein NE. Multidisciplinary in-hospital teams improve patient outcomes: a review. Surg Neurol Int. 2014;5(Suppl 7):S295–303.
45. Zwart JJ, Dupuis JR, Richters A, Ory F, van Roosmalen J. Obstetric intensive care unit admission: a 2-year nationwide population-based cohort study. Intensive Care Med. 2010;36(2):256–63.
46. Bharwani F, Macarthur A. Review of a high-risk obstetric anesthesia antepartum consult clinic. Can J Anaesth. 2014;61(3):282–3.
47. Sachs A, Aaronson J, Smiley R. The role of the anesthesiologist in the care of the parturient with cardiac disease. Semin Perinatol. 2014;38(5):252–9.
48. Bucklin BA, Hawkins JL, Anderson JR, Ullrich FA. Obstetric anesthesia workforce survey: twenty-year update. Anesthesiology. 2005;103(3):645–53.
49. American Hospital Association. AHA guide to the health care field, 2015 ed. Chicago, IL: AHA; 2014.
50. Kyser KL, Lu X, Santillan DA, et al. The association between hospital obstetrical volume and maternal postpartum complications. Am J Obstet Gynecol. 2012;207(1):42.e41–17.