The Predictive Value of Vital Sign Patterns for Morbidity in Pregnancy: A Retrospective Cohort Study

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Abstract

Objective. This study examined the predictive ability of established Maternal Early Warning systems (MEWS) for different types of maternal morbidity, in order to discern an optimal early warning system.

Design. Retrospective cohort study.

Setting. Four-hospital urban academic system.

Population. All patients admitted to the obstetric services of this hospital system in 2018.

Methods. All patient vital signs were collected and three sets of published MEWS criteria were evaluated in relation to maternal morbidity. The test characteristics of each MEWS, as well as for heart rate, blood pressure, and oxygen saturation individually and in different combinations were compared.

Main Outcome Measures. Maternal morbidity, defined as a composite of hemorrhage, infection, acute cardiac disease, and acute respiratory disease, ascertained from informatics and administrative data.

Results. Of 14,597 obstetric admissions, 2,451 patients experienced composite morbidity (16.8%). The sensitivities (15.3% - 64.8%), specificities (56.8% - 96.1%), and positive predictive values (22.3% - 44.5%) of the three MEWS criteria ranged. Of patients with any morbidity, 28% met criteria for the most liberal vital sign combination, while only 2% met criteria for the most restrictive parameters, compared to 14% and 1% of patients without morbidity, respectively. Sensitivity of all vital sign combinations was low (maximum 28.2%), while specificity ranged from 86.1 – 99.3%.

Conclusions. Though all MEWS criteria demonstrated poor sensitivity for maternal morbidity, permutations of the most abnormal vital signs have high specificity, suggesting that MEWS may be better implemented as a trigger tool to target more sensitive screening techniques for maternal morbidity.

Keywords Maternal early warning systems, vital signs, maternal morbidity, maternal physiology

Short abstract

MEWS have poor sensitivity for maternal morbidity, but can be optimized for high specificity using modified criteria.

Introduction

The persistent and pervasive crisis of severe maternal morbidity and mortality in the United States, a large portion of which is deemed preventable, offers an imperative for obstetric providers to develop strategies to screen pregnant patients for early signs of clinical compromise.[1-4] Abundant evidence from emergency, internal, and critical care medicine demonstrates that vital sign-based screening systems for evolving morbidity can successfully predict patients who will require a higher level of care, and potentially reduce morbidity and mortality.[5-8] In fact, several such systems, generally termed Maternal Early Warning Systems, or MEWS, have adapted non-pregnant adult criteria to include the altered physiology of pregnancy.[9-11] However, the ability of these MEWS to actually forecast which patients are becoming sicker is highly variable and fraught with inaccuracy.[12]

The purpose of a MEWS is to identify asymptomatic patients at high risk of imminent development of an acute disease process in order to prompt further clinician evaluation and management which can mitigate or even prevent an adverse event.[13] They are designed for universal application to patients admitted to an obstetric service, most of whom are healthy at baseline and with low absolute risk of severe morbidity, and function as a “track and trigger” device for nurses to escalate care to the provider. However, as each MEWS operationalizes different thresholds for abnormal vital signs to trigger an alert,[14] little is known about how individual components of the MEWS scores correlate with maternal morbidity or how different abnormal vital sign thresholds compare with each other. Normal vital sign ranges are different in pregnancy[15-17] and prior research has demonstrated that normal values in pregnancy may trigger alert systems devised for the general population,[18] rendering it essential to clarify the levels at which abnormal vital signs in pregnancy are actually associated with morbidity.

The purpose of this research was therefore: (i) To compare the predictive ability of different MEWS criteria for specific morbidity patterns [hemorrhage, infection, acute cardiovascular disease, and acute respiratory disease]; (ii) To assess the predictive ability of certain vital sign abnormalities at different thresholds, specifically heart rate, blood pressure, and oxygen saturation, for maternal morbidity; and (iii) To examine different combinations of these vital signs as predictors of morbidity in an attempt to optimize existing MEWS criteria.

Methods

A retrospective cross-sectional study was conducted for all patients delivering at four campuses of NewYork-Presbyterian Hospital, a large, urban integrated health system. All pregnant patients at any gestational age $\geq$ 18 years old with a delivery admission between January 1, 2018 and December 31, 2018 were included. Vital signs, diagnosis codes, and clinical informatics data were abstracted retrospectively from the health system data warehouse. All participating hospitals shared the same electronic medical record platform (Allscripts).

The primary outcome was defined as a composite of maternal morbidity including hemorrhage, infection, acute cardiovascular disease, and acute respiratory disease, which were identified based on diagnosis codes (International Classification of Diseases, 10th Revision, Clinical Modification, or ICD-10-CM) and bioinformatic electronic medical record parameters (Table 1).

Three different sets of published MEWS criteria were evaluated (Table 2):[14] the Modified Early Obstetric Warning System (MEOWS),[9] the Maternal Early Warning Criteria (MERC),[11] and the Maternal Early Warning Trigger (MEWT).[10] Four specific vital sign components of these scores – heart rate, systolic blood pressure, diastolic blood pressure, and oxygen saturation – were also assessed individually. Heart rate was evaluated at five levels (in beats per minute, bpm): > 110, > 120, > 130, > 140, > 150. Systolic blood pressure was evaluated at three thresholds (mmHg): < 90, < 80, and > 160. Diastolic blood pressure was also evaluated at three thresholds (mmHg): < 50, < 40, > 110. And oxygen saturation was evaluated at two levels (%): < 95 and < 90.

In order to assess test characteristics for MEWS, we created ten unique permutations of different vital sign thresholds (heart rate, blood pressure, oxygen saturation) and assessed their predictive ability for morbidity (Table 3). Abnormal blood pressure and oxygen saturation were divided into two categories: “restrictive” thresholds (oxygen saturation < 90%, systolic blood pressure < 80 or > 160 mmHg, and diastolic blood pressure < 40 or > 110 mmHg) and “liberal” thresholds (oxygen saturation < 95%, systolic blood pressure < 90 or > 160 mmHg, diastolic blood pressure < 50 or > 110 mmHg). Tachycardia was classified at five levels: > 110, > 120, > 130, > 140, and > 150 bpm.

The performance of each MEWS, individual vital sign, and combination of vital signs to detect maternal morbidity was evaluated by calculation of test characteristics (sensitivity, specificity, positive predictive value [PPV], negative predictive value [NPV], positive likelihood ratio [LR+], and negative likelihood ratio [LR-]). The association of different thresholds of tachycardia and the different combinations of vital signs with maternal morbidity was compared using the chi-square test. A receiver operating characteristic curve for tachycardia as a predictor of morbidity was also created. This study was approved by the Institutional Review Board at Columbia University Irving Medical Center (IRB AAAS3914).

Results

There were 14,597 obstetric patients included in this study with 5,140,107 individual vital signs measured (temperature, heart rate, respiratory rate, oxygen saturation, systolic blood pressure, diastolic blood pressure, and mean arterial pressure). A total of 2,451 patients (16.8%) experienced at least one morbidity event, including 980 cases of hemorrhage (6.7%), 1,337 cases of infection (9.2%), 362 cases of acute cardiovascular disease (2.5%), and 275 cases of acute respiratory disease (1.9%).

The performance of the MEOWS, MERC, and MEWT criteria to detect morbidity in our population, including sensitivity, specificity, PPV, NPV, LR+, and LR- is presented in Table 4. Sensitivity (15.3 – 64.8%), specificity (56.8 – 96.1%), and PPV (22.3 – 44.5%) ranged widely, while NPV had a narrow range (84.9 – 88.9%). Specifically, MEWT had the lowest sensitivity (15.3%) and highest specificity (96.1%), PPV (44.5%), and LR+ (3.9) of the three scoring systems, and this was true for each sub-type of morbidity. MERC consistently had the highest sensitivity (61.9 – 74.7%) and the lowest PPV (2.9 – 22.3%) and LR- (0.5 – 0.7).

Table 5 depicts different heart rate thresholds and the frequency of maternal morbidity. Of women who experienced any type of morbidity, 37.7% had a heart rate < 110 bpm, compared to 56.2% of women who did not experience morbidity (Figure 1). At the other extreme, 9.8% of women with any morbidity had tachycardia > 150 bpm, compared to 5.6% of women without morbidity. The difference in morbidity between women experiencing tachycardia at any point and those who did not was significant at every threshold ($p < 0.01$). The specificity was highest for heart rate > 150 bpm (94.4%) and lowest for heart rate > 110 bpm (56.2%). Tachycardia > 110 bpm had sensitivity of 62.3% for morbidity, compared to 9.8% for heart rate > 150 bpm (Table 6). Positive and negative predictive values were similar for all thresholds, ranging from 22.3 to 26.2% and 88.1 to 83.8%, respectively. The receiver operating characteristic curve for heart rate as a predictor of any morbidity demonstrated an area-under-the-curve (AUC) of 0.74 (Figure 2).

Varying cutoffs for oxygen saturation and blood pressure and the frequency of maternal morbidity are represented in Table 7. Of patients with a morbidity event, 40.9% had oxygen saturation < 95% and 12.0% had saturation < 90%, compared to 26.3 and 7.7% of patients without morbidity, respectively. Of patients who experienced any morbidity, 40.4% had systolic blood pressure < 90 mmHg, 14.6% < 80 mmHg, and 18.3% > 160 mmHg, compared to 29.3, 8.4, and 10.8% of patients without morbidity, respectively. Of patients with morbid events, 52.5% had diastolic blood pressure < 50 mmHg, 17.3% < 40 mmHg, and 14.3% > 110 mmHg, compared to 40.8, 10.3, and 8.9% in patients without morbidity. Figure 3 depicts the distribution of abnormal oxygen saturation and blood pressure levels among women with and without morbidity. Sensitivity and specificity varied widely for all parameters, while PPV and NPV were similar, ranging from 20.6 – 26.1% and 84.0 – 86.1%, respectively (Table 8). Positive and negative likelihood ratios were also similar (LR+ 1.3 – 1.7, LR- 0.8 – 1.0).

The frequency of maternal morbidity among women experiencing different levels of tachycardia coupled with restrictive and liberal blood pressure and oxygen saturation thresholds is demonstrated in Table 9. Of note, 28.2% of patients with any morbidity met the criteria for the most liberal abnormal vital sign combination, while only 2.2% met criteria for the most restrictive parameters ($p < 0.01$). Among patients who did not experience morbidity, 13.9% met the most liberal criteria, compared to 0.7% meeting restrictive criteria. Sensitivity for all combinations was low, but was highest for combinations employing the more liberal set of abnormal blood pressure and oxygen saturation thresholds in combination with the lowest definitions of tachycardia, > 110 and > 120 bpm (Table 10). Specificity for all combinations was high, ranging from 86.1 – 99.3% and with similar PPV, NPV, LR+, and LR-.

Discussion

Main Findings

These data demonstrate that test characteristics for MEWS criteria differ substantially with either low sensitivity or specificity, and suggest that further refinement of the parameters is required for optimization. Though the clinical utility of vital signs to screen obstetric patients for developing morbidity is poor, MEWS scores that utilize more stringent cut-off points may be most clinically relevant with high specificity and therefore strong ability to discriminate patients who are well.

Interpretation

This research is unique in evaluating a large volume of vital signs at a granular level in association with maternal morbidity, and using definitions corresponding to four common clinical categories of disease and characterized by both diagnosis codes and clinical elements derived from the medical record. These four categories were chosen to represent the scope of maternal morbidity in this study as they are all potential etiologies of tachycardia, hypotension, and oxygen desaturation, and embody both common and severe obstetric pathologies. Hypertensive urgency, another frequent and potentially severe form of maternal morbidity, was not included as this is already associated with specific vital sign-based definitions. Furthermore, the Safe Motherhood Initiative through the American College of Obstetricians and Gynecologists (ACOG) has already made significant headway in introducing guidelines for screening and management of hypertension.[19] The purpose of this study was to describe the less-definitional, but equally important, vital sign patterns of other major morbidities seen in obstetric patients that may require a more nuanced assessment of vital signs.

When evaluating or validating obstetric early warning scores, it is important to distinguish these from other critical illness prediction scores, such as the Sequential Organ Failure Assessment (SOFA),[20] the Acute Physiology and Chronic Health Evaluation (APACHE),[21] and the Sepsis in Obstetrics Score (SOS),[22] which were devised for patients with high clinical suspicion of severe illness, as well as risk-stratification systems based on comorbidities.[23] Rather, early warning scores are intended to function as a method of screening all patients, the majority of whom are presumed healthy and asymptomatic, in order to identify concerning vital sign patterns in patients who are at the very early stages of clinical compromise. This is predicated on the assumption that abnormal vital signs precede critical illness, which has been demonstrated in the general population.[24] A MEWS that lacks sufficient sensitivity will miss patients who may be getting sick, defeating the purpose of early identification. A high false positive rate, on the other hand, can engender a “crying wolf” phenomenon. If clinicians are regularly alerted to patients who are well, they can develop alarm fatigue, diminished responsiveness to abnormal vital signs or requests from nurses to escalate care.[25,26] The ideal MEWS, then, will optimize trigger points that collectively predict evolving pathophysiology with high fidelity, and with the lowest false positive rate possible.[27]

This study invites an even larger question of how we interpret vital signs in pregnancy in the first place. Vital signs are only meaningful if they provide a window to the patient’s actual clinical condition. For example, tachycardia may be a marker of clinical deterioration prior to critical illness, though normal pregnancy physiology may also result in an elevated heart rate. While tachycardia is a parameter included in all maternal early warning systems, it is unclear what level of tachycardia best predicts maternal morbidity. If the frequency of tachycardia is the same among sick and well patients, heart rate is rendered virtually meaningless as a vital sign. From the data in our study, we observed that most patients with tachycardia do not experience increased morbidity, and fewer than half of patients with increased morbidity experience a heart rate >120 bpm. This suggests that clinicians should not necessarily escalate care based solely on tachycardia, nor should they be falsely reassured of a patient's clinical status based on having a normal heart rate. Though poorly sensitive, a high threshold of tachycardia like > 150 bpm is very specific for morbidity. However, a heart rate above 150 bpm is abnormal to such a great extent that this should always trigger further evaluation and is not likely helpful as a screening tool in the context of maternal early warning systems.

Ultimately, it seems that no exact set of MEWS criteria can perform with both high sensitivity and high specificity, and hospitals utilizing an early warning system for obstetric care are forced to choose between the two. This may require a frameshift in clinical attitude towards MEWS. Rather than functioning to screen for morbidity, MEWS criteria can be calibrated to optimize specificity, utilizing the highest abnormal thresholds and functioning to reduce nuisance alerts. This way, automatic triggers for further evaluation in patients without other concerning features of morbidity would be reduced to those likeliest to actually require an escalation in care. While this approach foregoes the role that MEWS can potentially play in screening for morbidity, it is clear from these data and prior comparative work on MEWS that the sensitivity of MEWS is generally poor[12] and that clinical response must incorporate other criteria, such as bedside nursing assessment and subjective complaints, to avoid signal saturation from benign abnormal vital signs and to prevent delays in care for patients without abnormal vitals. Research has already demonstrated the value of harnessing patient and family input for adverse event detection and error prevention, and this should be readily assimilated into obstetric inpatient surveillance algorithms.[28,29]

Strengths and Limitations

There are several limiting features of this study design. Our analysis evaluated each patient's vital signs in aggregate and applied the MEWS criteria to a theoretical set of the most abnormal vital sign for each category. This does not replicate each patient's actual clinical course, as these abnormal vitals did not necessarily occur simultaneously, but this strategy best tests the discriminatory capacity of the early warning systems by assessing them against a theoretical amalgam of each patient's most abnormal vital signs at any point in the hospitalization. The subjective components of the MEWS scores (pain score, neurological assessment), as well as urine output and fetal status, were not evaluated in this study as they are more difficult to assess from chart review and to standardize, though these are a part of each MEWS that was evaluated. The definition of morbidity in this study is based on precedent for utilizing definitions that combine clinical and administrative data for outcomes in hospital system studies, as opposed to billing codes alone, and this can facilitate better characterization of these outcomes.[30]

Conclusion

While early warning systems outside of obstetrics abound and have faced similar challenges to clinically useful sensitivity,[31,32] effective tools to screen obstetric inpatients for evolving morbidity are arguably more critical. Unlike many other patients in the hospital, obstetric patients are generally young and healthy, and are typically admitted for routine labor and delivery without concern for a specific disease process. However, it is well known that major causes of severe maternal morbidity can and do occur even among healthy women.[33-35] In fact, women without risk factors comprise the majority of obstetric patients who experience severe maternal morbidity during delivery admissions.[36] It is therefore essential that obstetric providers be equipped with efficient, effective and objective tools to screen for evolving morbidity and to trigger the need to escalate care in our patients. While MEWS is an important first iteration and the best that we have at present, future research must investigate other strategies and technologies for prognosticating morbidity in otherwise asymptomatic patients, such as vital sign trending, machine learning, and patient-directed escalation,[37,38] so that criteria for trigger systems best reflect pathologic states.

Disclosure of interests:

The authors report no conflict of interest.

Contribution to authorship: All authors (AKG, JE, MP, MD, AF, DG) participated in the design of the study. JE extracted the data from the data warehouse and JE and AKG performed the analysis. AKG, JE, MP, MD, AF, and DG planned and composed the manuscript.

Details of ethics approval:

This study was approved by the Institutional Review Board at Columbia University Irving Medical Center (IRB AAAS3914) on June 10, 2019.

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