

ORIGINAL RESEARCH

Maternal Deaths during a Pilot Study Using Digitized Maternal Early Warning System

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Abstract

Global maternal mortality remains high, and further reduction requires innovative approaches. We developed and tested a telehealth solution that included an early warning system (EWS) and a clinical decision support (CDS) tool for the timely detection of clinical deterioration and appropriate management of women in labor. Those results were published earlier. As a follow-up to that study, we examine and analyze why preventable deaths occurred despite the telehealth EWS that alerted the providers along with treatment guidelines. Twelve maternal deaths occurred during that study, of which six occurred at the study sites and six others after transport to a tertiary institution. Nine of those were determined preventable. Telehealth identified at-risk patients in every case, provided red alerts in acute emergency (66.7%) and/or yellow alerts requiring continued observation (33.3%). Three factors that may have a positive impact on the use of a telehealth are coordinated transfers, proper referral networks, and institutional protocols and addressing the knowledge gaps of providers. EWS and CDS tools have a potential to positively impact maternal deaths by identifying developing crises of patients in a timely manner and alerting the providers. In resource-limited settings, EWS with telehealth capabilities can be particularly valuable.

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According to the United Nations, the global maternal mortality ratio (MMR) declined by 38% (342 to 211 deaths per 100,000 live births) from 2000 to 2017.¹ During the same period, India decreased its MMR at a faster rate from 370 to 154 deaths per 100,000 live births, a 58% reduction.² Further decreases, however, may require novel and innovative approaches to meet the Sustainable Developmental Goals targets.³

Thaddeus and Maine⁴ identified three delays as foundational in framing the causes of maternal mortality and morbidity: (1) seeking care, (2) accessing care, and (3) receiving care. Multiple studies have demonstrated significant associations between frequency of delay and severity of outcomes.^{5–7} These studies also emphasize that, in most of the near-miss cases, mothers were in a critical condition at the time of admission. Providing timely and appropriate care for acute obstetric emergencies is very

often the key to reducing maternal mortality and morbidity. In a detailed report on pregnancy-related mortality in California, Main et al.⁸ articulate how delayed recognition and delayed response to clinical symptoms and changing vital signs are the main factors that lead to maternal mortality. In a unique study on postpartum hemorrhage, which required multiple and timely parallel actions to prevent the adverse outcome, it was found that management guidelines were followed less than 30% of the time even when the providers were aware that they were being videotaped.⁹ The authors in that study concluded that the omission of essential steps in the chain of actions could lead to delayed recognition and treatment of postpartum hemorrhage.

A recently published pilot study based on an innovative telehealth maternal early warning system (EWS), WONDER (Women's Obstetrical, Neonatal, Death,

Evaluation, and Reduction), demonstrated a 50.1% reduction in maternal mortality.¹⁰ This digitized EWS is based on an internal algorithm that detected worsening clinical conditions using common vital signs (VS) and laboratory data of a mother in labor or in the postpartum setting. The system also includes clinical decision support (CDS) module that provides possible diagnosis and up-to-date treatment guidelines as recommended by relevant national and international organizations. These features, along with its telehealth capability, enabled early detection and the management of obstetric emergencies during the study period.¹⁰ In this article, we discuss the maternal deaths that occurred within that study and formulate the reasons for preventable deaths that occurred despite the presence of the alert system, and we outline the lessons learned and present possible solutions to prevent maternal deaths.

Materials and Methods

The medical records of all 12 maternal deaths were collected by the authors from the hospital after obtaining all necessary written consent. Six of the 12 deaths occurred at the study sites and six occurred at the tertiary hospital where the patients had been transferred. The records of all 12 patients were analyzed carefully by the authors, and the categorizations given here are those of the authors only. We have employed the three-delays model to examine if gaps in the chain of care delivery contributed to the deaths and assigned categorization for those cases appropriately.

Results

The following results section examines the preventable deaths that occurred during the project, and the role of the telehealth solution in each case. The chain of events was reconstructed in each case. The staff working to populate the WONDER EWS were instructed to record the patient's VS every 4 hours or as requested by the physician during labor and every 15 minutes after a red alert. The monitoring continued until the patients were transferred or discharged. The results were entered manually into the system. The staff physically went to the nurses' station, informed them of the alerts, handed them the order sets, and recommended treatment guidelines printed from the system. In each case, the attending medical staff had the flexibility to accept or override the recommended treatment guidelines. The criteria used to create the alerts are listed in Table 1.

Based on a detailed review of the medical records of all 12 patients who died during this study, nine (75%) deaths were categorized as preventable, which included a patient who was not registered in the WONDER telehealth EWS. The determination of whether the death was preventable or not was made for each case, and the rationale for the categorization is discussed. The records of the VS and

Table 1. Maternal health scoring criteria outlined by the Maternal Early Obstetric Warning Score System (MEOWS) modified to address local needs and requirements

Clinical parameter	Yellow alert	Red alert
Systolic blood pressure (mm Hg)	90–99 or 130–150	<90 or >150
Diastolic blood pressure (mm Hg)	50–59 or 90–99	<50 or >100
Heart rate (beats per minute)	40–50 or 100–120	<40 or >120
Respiratory rate (breaths per minute)	21–25	<10 or >26
Oxygen saturation (%)		<95%
Temperature	35–36°C 100–101°F	<35°C or >37.5°C >101°F
Urine output		<33 CC/hour
Fetal heart rate	<110	>160
Hemoglobin (grams)	8–9	<8
HIV status		Positive
Hepatitis HBsAg		Positive

HBsAg, hepatitis B surface antigen; HIV, human immunodeficiency virus.

red and yellow alerts generated for each case by the WONDER systems are displayed (Figures 1–8).

Case 1

A 25-year-old woman was admitted at 28 weeks of gestation with placenta previa and vaginal bleeding. She underwent a cesarean section (C/S), and the 1,000-g baby was transferred to the neonatal intensive care unit (NICU). The mother was discharged, but she stayed with the baby. Two weeks after discharge, the mother attended the postnatal clinic with leg swelling. After consultation with a surgeon, she was diagnosed to have superficial thrombophlebitis vs cellulitis and was admitted for follow-up. Being unaware of the seriousness, the patient took several hours to get to the floor. On admission, she was dyspneic, and the blood pressure (BP) was 110/70, temperature was 98°F, the pulse rate was 146, and the respiratory rate (RR) was 20. An internist was consulted who diagnosed her to have sinus tachycardia. In response to the persistent tachycardia, the internist ordered an echocardiogram, which was scheduled for the next day. Thereafter, the patient became acutely dyspneic with dizziness. Echocardiogram showed right atrial and right ventricular dilatation, moderate pulmonary hypertension, and left ventricular dysfunction. At this time, multiple consultations from the radiologist, anesthesiologist, cardiologist, and intensive specialist were requested. Venous doppler showed unstable deep vein thrombosis (DVT) involving the left common femoral vein and saphenous vein. At this point, the patient was transferred to the ICU, where she was intubated and started on heparin. Soon thereafter, the patient developed cardiac arrest and died (Figure 1). Although required facilities and specialists were available, the

Vital Chart										
	27.12.2017 07:00 AM	27.12.2017 06:45 AM	26.12.2017 09:00 AM	25.12.2017 11:20 PM	06.12.2017 11:59 AM	04.12.2017 11:58 AM	04.12.2017 11:17 AM	03.12.2017 11:22 AM	03.12.2017 11:21 AM	03.12.2017 11:19 AM
Temperature (F)					98.4	98.4	37			
Pulse (bpm)	160	156	120	146	86	88	80	88	80	86
Respirations (bpm)	48	50		20	16		16			16
O2 Sat (%)	85	85	99	98	99	99	99			
Sys BP (mm Hg)	90	100	110	110	110	110	110	110	110	110
Dia BP (mm Hg)	50	60	70	70	80	80	70	80	70	70
Headache										
Mental Status										
Urine Output (cc)	10									
Hb				9.1						

Fig. 1 Patient with pulmonary embolism. The blue arrow indicates the date of delivery. The red arrow indicates readmission after 21 days with tachycardia of 146, leg swelling, and pain.

Vital Chart				
	29.11.2018 10:24 AM	24.11.2018 01:30 PM	23.11.2018 10:30 AM	22.11.2018 10:30 PM
Temperature (F)	98.4	98.4	98.4	98.4
Pulse (bpm)	86	88	82	86
Respirations (bpm)	16	16	16	16
O2 Sat (%)	99	99	99	99
Sys BP (mm Hg)	120	110	110	110
Dia BP (mm Hg)	80	70	70	70
Headache				
Mental Status				
Urine Output (cc)				
Hb	10.8			9.3

Fig. 2 Case 3. Patient had repeat C/SS. Preoperative low hemoglobin generated a yellow alert.

Vital Chart				
	14.07.2018 05:00 PM	14.07.2018 04:30 PM	14.07.2018 04:00 PM	14.07.2018 04:00 PM
Temperature (F)	98.4	98.4	98.4	98.4
Pulse (bpm)	82	86	86	86
Respirations (bpm)	16	16	16	14
O2 Sat (%)	99	99	99	99
Sys BP (mm Hg)	90	90	90	90
Dia BP (mm Hg)	60	60	60	60
Headache				
Mental Status				
Urine Output (cc)				
Hb		12.5		

Fig. 3 Case 7. Patient with suspected immune thrombocytopenia. Yellow highlights indicate low systolic BP requiring continued close monitoring.

primary care providers and some of the consultants did not recognize the problem, and appropriate consultations were not obtained, which resulted in loss of 2 crucial days and most likely contributed to her death (Phase III delay). Also, if the tertiary care center had the EWS and telehealth implemented, as soon as the first set of VS was entered with red and yellow alerts, it would have created an audible alarm as well as visual alert on their dashboard. That could have initiated a call by the experts from the tertiary care to the primary providers and could have initiated appropriate care.

Case 2

A 25-year-old patient was admitted at 39 weeks of gestation, with fever and a hemoglobin (Hb) level of 8.8 g, who treated conservatively, became afebrile, and

delivered vaginally. She received one unit of packed red blood cells (PRBCs) and was discharged on day 2. The baby was admitted to the pediatric ICU for suspected choanal atresia. The mother stayed with the baby for 5 days until discharge. The day after the discharge, she admitted to the emergency room (ER) in the nearby hospital, with high fever, shortness of breath, a pulse rate of 162, and a BP of 140/100. Although the hospital had all facilities to treat her, she was diagnosed to have anemia and cardiac failure and transferred to the general hospital (GH) where she delivered. On admission to GH, she was pale, unconscious, gasping, and frothing, with a pulse rate of 168, a BP of 140/80, an oxygen saturation (SPO₂) of 58%, and a white blood count (WBC) of

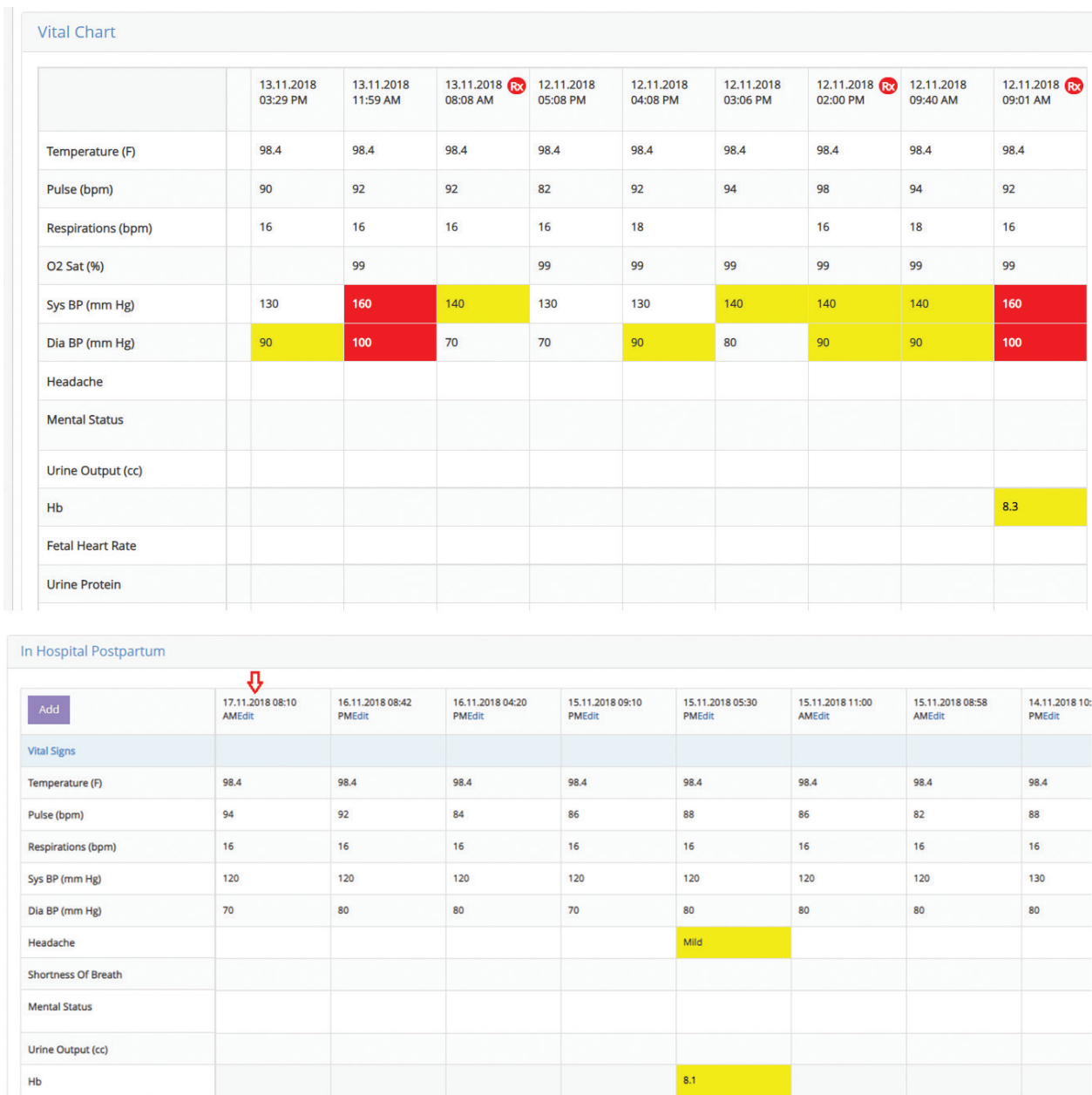


Fig. 4 Case 8. Patient with HIV and preeclampsia. The Rx symbol at the top of the graph indicates the treatment given in response to her hypertension. Hemoglobin of 8.3 grams generated a yellow alert. The red arrow indicates the 5th day post-surgery when she was found unresponsive.

69,800. She developed cardiac arrest within 5 minutes of arrival and was resuscitated and transferred to the ICU. She also developed second cardiac arrest 11 hours after admission and died. Her diagnosis was septic shock and hypoxic encephalopathy. Although the first hospital had a fully equipped ICU, the physicians still transferred an unstable patient in septic shock (Phase III delay). This case highlights several factors: (1) the lack of a monitoring system for a mother while her baby was in the NICU, which resulted in a lost opportunity to identify her sepsis earlier; (2) the physicians either lacked confidence to

care for a very sick patient or did not want the maternal death counted against their hospital, which is a common problem across the region; (3) lack of a good protocol that requires the referring physicians to communicate with the tertiary care physicians, and both must have a coordinated transport plan and could have avoided the needless transfer of an unstable patient; (4) all these had contributed to Phase III delays; (5) the primary hospital and the tertiary care hospital were not enrolled in the study and did not have access to the telehealth EWS. If the EWS was in place at both institutions, the tertiary



Fig. 5 Case 9. Patient with unexplained fever for several days after a C/S. The green arrow indicates the date of delivery. The red arrow indicates when the patient became restless. The blue arrow represents when she was transferred to a tertiary care hospital.

care center would have received alerts as soon as a set of VS was entered. The physicians from the tertiary care could have contacted the ER at the primary hospital, got the patient stabilized, and could have prevented or safely transferred her directly to tertiary care hospital without the intervening transfer to the GH.

Case 3

A 24-year-old second gravida was admitted at 32 weeks in preterm labor. She was treated conservatively and was discharged. She was readmitted after 5 days, once again in labor. Her Hb level was 9.3. She underwent repeat C/S, developed uncontrollable atonic postpartum hemorrhage, and had a subtotal hysterectomy. She received four units of PRBCs, six units of fresh frozen plasma (FFP), and four units of cryoprecipitate. She was continued on assisted ventilation. An echocardiogram showed peripartum cardiomyopathy with severe left ventricular dysfunction. Her ejection fraction (EF) was 30%. She developed sudden cardiac arrest and died (Figure 2). As discussed in the beginning, this is a non-preventable death. However, if the anemia had been identified during the prenatal period, her anemia could have been

corrected. This is one of the advantages of extending the EWS to the antenatal phase.

Case 4

A 36-year-old primigravida came to ER with a history of 2 months of amenorrhea, severe abdominal pain, 15-year of infertility, and a chronic pelvic inflammatory disease. Although the hospital had necessary facilities to care for her, the doctors transferred her to another GH of similar capacity, which took 45 minutes. The patient was restless and pale, with a pulse rate of 148, BP of 80/60, RR of 48/minute, and a SpO₂ of 96%. Abdomen was distended. Ultrasound showed free fluid in the peritoneal cavity. Her Hb rate was 4.7 grams. She underwent left salpingectomy for ruptured tubal pregnancy. She received one unit of PRBCs, two units of whole blood, and four units of FFP. At the end of the surgery, the pulse rate was 154, BP was 70/40 mm Hg with inotropic support, and SPO₂ was 90% with no urine output. During the fifth unit of transfusion, she developed cardiac arrest and died. This case highlights a common and a real problem in small and peripheral hospitals. Physicians who encounter such acute problem only occasionally lack the confidence and guidance in the

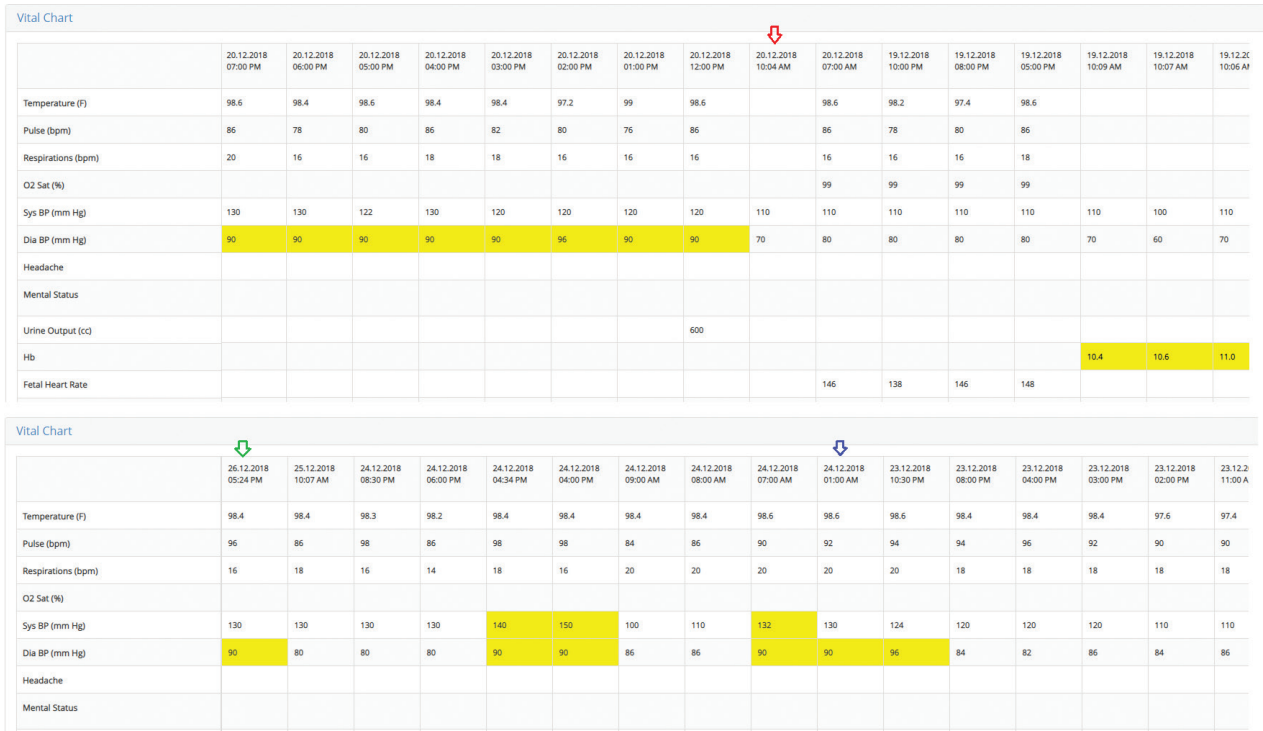


Fig. 6 Case 10. Patient with preeclampsia and HELLP syndrome. The red arrow indicates the date of delivery. The blue arrow shows the first transfer, and the green arrow shows the date of second transfer. Numerous alerts were generated during the entire stay from admission until transport to the tertiary care hospital.

moment to handle the patient despite having all the institutional capacity to do so. As a result, they transfer these patients to other hospitals, a process that results in the loss of valuable time and adverse patient outcomes (Phase III delay). The EWS described in this study includes a CDS tool that provides real-time guidelines based on the vitals entered and serves as a first line of support for physicians during emergencies. In this case, the EWS has the protocol for massive transfusion based on the severity or class of hemorrhage but was not available for physicians in the operating rooms.

Case 5

A 27-year-old third gravida came to the ER in hemorrhagic shock, with a Hb of 4.1 g, SpO₂ of 50%, and a ruptured ectopic pregnancy. She developed cardiac arrest while being prepared for surgery and died. We classified this as one of the non-preventable deaths.

Case 6

A 38-year-old second gravida was admitted at 32 weeks of gestation, with anasarca, 3+ proteinuria, a BP of 150/90, pulse rate of 96, RR of 16, Hb level of 10.5 g, serum glutamic oxaloacetic transaminase (SGOT) of 54, and a serum glutamic pyruvic transaminase (SGPT) of 45. She was treated with labetalol, nifedipine, and (magnesium sulfate) MgSO₄. Her echocardiogram result was normal.

She underwent a C/S for imminent eclampsia, oblique lie, and closed cervix. Ten hours after the C/S delivery, she was found to be dyspneic and tachypneic, with a BP of 160/100 and SpO₂ of 85% and was treated with intravenous Lasix 80 mg. On the way to the ICU, she developed sudden cardiac arrest. She was intubated and resuscitated, and an echocardiogram showed an EF of 55% and acute LV failure. A computed tomography (CT) scan showed a unilateral pneumothorax and bilateral pleural effusion. The next day she had a second cardiac arrest and died. This case resulted in a change in the hospital policy, requiring anesthesiologists to confirm that a patient is stable and safe before she is transferred from the postoperative recovery room. This patient was not registered in the EWS and, hence, did not generate any alerts.

Case 7

A 22-year-old primigravida was admitted at 41 weeks of gestation with thrombocytopenia, oligohydramnios, a BP of 100/60, Hb of 12.5, platelets count of 47,000, SGOT of 16, and SGPT of 11. The patient record shows a history of multiple sclerosis for 11/2 years. She was suspected to have immune thrombocytopenia. She transfused four units of platelets and two units of FFP and transferred to a tertiary care hospital within 3 hours. No follow-up information is available from the referral center (Figure 3). On review, the patient had a serious medical problem that

Vital Chart

	23.12.2018 11:40 AM	23.12.2018 11:40 AM
Temperature (F)	98.2	98.2
Pulse (bpm)	110	110
Respirations (bpm)	14	18
O2 Sat (%)	99	99
Sys BP (mm Hg)	100	100
Dia BP (mm Hg)	60	60

Fig. 7 Case 11. Patient with fetal demise and jaundice, and bleeding was transferred within a few hours of admission. Yellow highlight indicates tachycardia.

should have been detected during antenatal care. Again, this case presents a strong argument for extending the EWS to the antenatal period. The system would have created a red alert based on abnormal lab values, and the patient could have been referred to the specialist on time.

Case 8

A 42-year-old third gravida was admitted at term, with abdominal pain, a temperature of 98.4°F, pulse rate of 92, and a BP of 160/100. She was treated with oral labetalol of 100 mg and 5 g of intramuscular MgSO₄. Her Hb rate was 8.3 g. She was tested positive for HIV and negative for hepatitis B. The patient underwent C/S for cephalopelvic disproportion and preeclampsia. She received antiretroviral therapy in line with the World Health Organization guideline. She received three units of PRBCs. On the fifth postoperative day, she was found to be unresponsive, resuscitated, and transferred to tertiary care where she died (Figure 4). This case is considered as non-preventable.

Case 9

A 21-year-old primigravida was admitted at 34 weeks in preterm labor with a history of cough for 2 months. She delivered vaginally. On the postpartum day 4, she had a temperature of 100 and a pulse rate of 120 and was started on antibiotics. Despite adequate antibiotics, her temperature on day 6 was 103, pulse rate was 142, and the BP was 120/80, and she was restless. Her restlessness was attributed to postpartum depression, and she was started on antidepressants. Restlessness continued, and she was diagnosed to be psychotic. X-ray showed bilateral basilar pneumonia. Patient developed generalized seizure, and a neurologist was consulted. The CT brain scan showed hypodense

lesion at the thalamic and right parietal region and cerebral edema. The patient was referred to tertiary care for sepsis and suspected postpartum psychosis (Figure 5), where she died. This case highlights several issues: (1) It was not clear whether she had any antenatal care. If she had received adequate antenatal care, her persistent cough for 2 months would have been identified, and she would have been referred to the appropriate specialists (Phase I delay). (2) The cause of fever on admission (following a 2-month history of cough) was not thoroughly investigated. (3) Her persistent fever, despite being administered antibiotics, was not adequately investigated, and further consultation from a specialist was not requested until she developed seizures (Phase III delay). The EWS during this study period did not include guidelines for sepsis. Since then, the guidelines for the management of sepsis by the international surviving sepsis campaign have been incorporated.

Case 10

A 21-year-old primigravida was admitted at term and in labor to a participating primary health care (PHC). She underwent a C/S and developed postpartum hemorrhage. She received a total of five units of whole blood transfusion. During the next 3 days, her BP ranged between 110/84 and 130/90. On the 4th postoperative day, her BP was 130/90, Hb 6.2, platelet count 18,000, bilirubin 2, indirect bilirubin 1.6, creatinine 0.8, SGOT 38, and SGPT 27, and she was transferred to GH. After admission to the GH, she was given two units of PRBC and four units of platelets and was started on Labetalol and MgSO₄. Since her BP continued to be elevated with no improvement of her clinical status, she was transferred to a tertiary care hospital for Hemolysis, Elevated Liver enzymes and Low Platelets (HELLP) syndrome on the 7th day after delivery (Figure 6). She subsequently died at the tertiary care hospital, but the clinical details after the transfer were not available for review because the tertiary care hospital did not participate in the study. In this case, the severity of the patient's condition was not recognized in time, and she transferred to the GH instead of the tertiary care hospital. We believe that if the tertiary care hospital had implemented the EWS, the specialists at the tertiary care could have coordinated the care of the patient and transferred her directly to tertiary care hospital rather than to the GH, avoiding unnecessary delay (Phase III delay).

Case 11

A 27-year-old primigravida was referred from a private hospital at 36 weeks of gestation. She was jaundiced, and no fetal movements were detected. She had vaginal bleeding, with a BP of 100/60, pulse rate of 110, RR of 18, and SpO₂ of 99%. The patient transfused with four units of FFP and two units of platelets and transferred to a tertiary care hospital (Figure 7). This case again demonstrates a

Add	18.07.2017 09:57 AM Edit	17.07.2017 05:28 PM Edit	17.07.2017 09:56 AM Edit	16.07.2017 12:00 PM Edit	16.07.2017 09:56 AM Edit
Mother Vital					
Temp (F)	98.4	101			103
Pulse (bpm)	86	116	120	120	126
Resp (bpm)		18		18	
O2 Sat (%)		98		98	
Sys BP (mm Hg)	110	100	110	110	110
Dia BP (mm Hg)	80	70	70	70	70
Headache					Moderate
Shortness Of Breath					
Mental Status					
Urine Output (cc)					
Hb		10.1		11.1	
Deep Tendon Reflex					
Neuro Response					
WBC Count		10.0		10.1	
Platelet		51		89	
Bed Side Glucose					

Fig. 8 Case 12. Patient with dengue fever had multiple factors that generated alerts. The yellow highlights show high temperature, tachycardia, severe headache, low hemoglobin, and decreasing platelet count. Each risk factor created separate alert depending on severity.

lack of policy, procedure, and an integrated referral network. It is likely that an integrated referral network would have prevented a double transfer within the space of a few hours (Phase III delay).

Case 12

A 23-year-old primigravida was referred from a non-participating PHC at term, with a temperature of 103°F, pulse rate of 126, BP of 110/70, Hb of 10, WBC of 6,000, and platelet count of 1,040,000, and was tested positive

for dengue IgM. She was treated with supportive care, but her platelet counts steadily decreased to 89,000 and then to 51,000, and hence, she was transferred to a tertiary care hospital (Figure 8).

Discussion

The following discussion focuses on the eight preventable deaths that occurred among patients who were registered in the telehealth EWS. For all patients in the study, once admitted and enrolled in the WONDER EWS, the system

generated red and/or yellow alerts based on severity. These alerts were brought to the attention of the labor ward nurse or physician, in person along with the printed order sets and generated treatment guidelines by the staff managing the EWS. The system created alerts in all eight patients (100%). Five patients had red alerts, indicating that they had acute emergent clinical situations (62.5%). The other three patients had yellow alerts, indicating a clinical situation that required continued close monitoring (37.5%). At first sight, the EWS system functioned as designed to identify at-risk patients when their clinical situation started to change and, in each case, provided adequate time to the staff to intervene and initiate treatment before the clinical situation deteriorated.

Patient mortality within a hospital setting is often, the result of multiple causal factors. Our review of the cases uncovered the same, cumulative as well as cascading effect of factors in the causal chain of all eight maternal deaths. Many of these factors are well known in poor resource settings, where inadequate caregiver training, delays in initiating care, and improper care responses are common. However, our review also revealed three additional causal factors that may have a direct impact on the maternal deaths: (1) uncoordinated and/or needless transfer of patient from one institution to another and finally to a tertiary hospital, (2) gaps in implementation of EWS in all caregiving institutions, and (3) not following the appropriate treatment recommendations suggested by the system (approved recommendations from leading organizations) in real-time. These factors will be discussed in more detail here.

(1) *Transfers*: Transfers were identified as a significant causal factor in five of the eight mortalities. We identified multiple issues with the transfer process, including uncoordinated transfers, and multiple and needless transfers. Two factors that drove this breakdown include (a) lack of appropriate protocol and guidelines for transfer and (b) a lack of coordination between transferring and receiving institutions. There appeared to be no clearly defined protocols for when to initiate a transfer. In the case of a transfer, the referring and receiving institutions must be able to work together seamlessly. Skilled providers at the receiving institution should be able to coordinate care and provide guidance to stabilize the patient prior to transport. This requires practice drills and working out idiosyncrasies in each setting. In addition, the ability of the receiving institution to communicate feedbacks on the transferred patients would provide a systemic opportunity to improve care and the process flow. Telehealth EWS such as WONDER can accelerate the care-delivery process and improve outcomes. They can also expose gaps in an organization's operating procedures and protocols. Poor referral networks, protocols, and response delays are quickly brought to the surface

by a well-functioning EWS. In addition, a telehealth EWS offers the opportunity to update referral protocols and take advantage of the alert system. In addition, all the patient data entered in the EWS would be instantly visible to the receiving institution, which can help to ensure that the patient is stabilized prior to and through the transfer process.

An additional factor that precipitated the breakdown in the transfer process was that in each case, the tertiary institution did not have the EWS implemented in its workflow. This resulted in clinically unacceptable delays occurring during transfers. When a transfer was initiated to a tertiary institution that did not have WONDER EWS in place, all referrals to the receiving hospital were "blind" to the problem with no advanced warning on the patient's conditions until the patient was received and examined. If the telehealth EWS system had been functioning at the tertiary care hospital as part of the referral network, an alert created at a dispatching institution, along with the entire medical record, would have been visible to the skilled providers at the tertiary care center. We believe that in all five cases of mortality in this study, having the EWS fully implemented at the tertiary care center would have permitted the staff at the tertiary care center to intervene early and accelerate the transfer or recommend timely intervention; all of which could have resulted in a better outcome.

(2) *Gaps in implementation*: In two instances of maternal deaths reviewed here, a key factor in the causal chain was gaps in the implementation of the EWS within the GH. While the EWS was fully functional and being used in real-time by the caregivers, it was not implemented in the adjoining NICU. Mothers of children admitted to the NICU ward often stay with the child to facilitate breastfeeding because these mothers often come from remote villages, and transportation to and from the hospital is a significant burden. Unfortunately, although the babies in the NICU are monitored closely, accompanying mothers are not under the supervision of any medical personnel. This gap existed despite an understanding that women in the first week of the postpartum period are vulnerable to various complications, and Center for Disease Control reports that 20% of maternal deaths occur between day 1 and 6 after delivery.¹¹ Two patients in this study stayed in the NICU caring for their infants did not recognize their symptoms and died within a few days. If their VS and symptoms were monitored, the signs of sepsis and DVT would have been identified early and treated appropriately, and their deaths could have been prevented. Even a low or mid-level provider checking on the VS and symptoms of the mothers in NICU ward would be a reasonable solution to identify mothers who may be developing early signs of postpartum complications.

(3) *Not following system generated treatment recommendations*: In five of the eight patients, we identified suboptimal and insufficient care-response from the caregivers in the face of a crisis situation that had been flagged by the EWS (red alerts). In each case, the system generated a possible diagnosis and detailed appropriate treatment responses in real-time. Analysis of their clinical notes revealed knowledge gaps and/or lack of confidence of the caregivers, at multiple levels of the caregiving chain. In some situations, these made them uncomfortable resulting in not following the suggested recommendations.

Recommendations

Although this study is small consisting of 15,184 patients, it revealed several opportunities for improvement in the workflow between PHC-GH and tertiary care hospitals.

We outline the following lessons for future implementations: Alongside the technical aspects of instituting a telehealth EWS system, it is vital to focus on the change management issues in all parts of the care-delivery system – particularly, those that necessitate new behaviors. Staff must be trained, and process-flows recalibrated accordingly to seamlessly incorporate system-generated recommendations. Generating alerts through the implementation of an EWS is the only one step in strengthening the care delivery process. It is essential to support the staff to act on these alerts through training and regular practice drills to keep the skills fresh. It is important to ensure that caregivers do not feel threatened and, on the contrary, feel empowered by system-generated recommendations.

A larger trial using a teleconsultation system that covered all the institutions without any gaps and that included all the stakeholders with appropriate hands-on training could more effectively address the effectiveness of EWS/telehealth in reducing maternal mortality.

Limitations

The primary limitation of this analysis is the lack of extensive written medical record for the patients. However, as is the case with many hospitals in similar settings, the staff carry a very high patient load, and as such adequate and complete documentation is one of the first victims of the situation. The second limitation is that the tertiary care hospital did not participate in the pilot study, so the telehealth system did not record outcomes in the tertiary institution. Finally, not having access to detailed records of mortality in previous years prevented us from conducting simulation exercises by reviewing cases of mortality from previous years through the lens of a working EWS.

Conclusions

Early warning system and CDS tools have a potential to positively impact maternal deaths by identifying

developing crises of patients in a timely manner and alerting the providers. In resource-limited settings, EWS with telehealth capabilities and the CDS can be particularly valuable. For instance, in a similar setting, Semrau et al. report that they were able to implement the World Health Organization's checklist widely across a rural district with significantly higher adherence.¹² However, as the authors point out, for reasons unrelated to adherence, the system did not translate into improved maternal outcomes. This confirms not only an opportunity to implement behavior change guidelines at scale in a resource-constrained setting but also a caution that a checklist alone may not be sufficient to reduce maternal mortality. A warning system that generates real-time alerts along with guidance on response may be required.

As reported earlier, we did find that the use of the EWS in the labor ward worked as designed. It offered a rapid integration of a low-maintenance technology to identify critical situations and offered CDS in a timely manner. To that end, it provided a closed loop through the cycle of identify–analyze–respond to a crisis.

However, as we learned through this analysis of the maternal deaths, reducing maternal mortality and morbidity through an EWS is not only about technology but also about the people and the hospital systems that are associated with it. To be effective, the EWS should be installed throughout the entire care delivery system with adequate referral networks, institutional protocols, and improved training among the providers to respond to alerts. It is important to be always aware that the telehealth EWS is about making the entire system more effective, not just specific caregivers in the chain of care delivery.

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Dr. Narmadha Kuppaswami is the Founder and President of “Wonder Health Care.” Dr. Suresh Subramanian has no conflict of interest. Dr. Radha Rani is the clinical coordinator of the WONDER program and is a representative of Wonder Health Care Solutions. She has no conflict of interest.

Authors' contributions

Each author contributed to the conceptualization of the report, writing and revisions.

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